NJB, Volume 36 (1) 29-47, June, 2023

DIOSCOREOPHYLLUM CUMMINSII (STAPF) DIELS., AN AFRICAN UNDERUTILISED INDIGENOUS FRUIT

[1]Oselebe, H. O., [2]Nnamani, C. V., [1,3]Degbey, H. and [3]Achigan-Dako, G.E.
In memory of Late H. Degbey
[1]Department of Crop Production and Landscape Management, Faculty of Agriculture and Natural Resource Management, Ebonyi State University, Abakaliki, Nigeria
[2]Department of Applied Biology, Ebonyi State University, Abakaliki, Nigeria
[3]Laboratory of Genetics, Biotechnology and Seed Science, Faculty of Agronomic Sciences, University of Abomey-Calavi, 01BP526 Cotonou, Republic of Benin
Correspondence**:** drnnamanikate@gmail.com

Received 15th May, 2023; accepted 13th June, 2023

ABSTRACT
Dioscoreophyllum cumminsii commonly known as Serendipity berry is one of the African indigenous fruits that has received poor attention from scientific research and funding even though it is a reservoir of many nutritional and medicinal potentials. In Nigeria, as well as in other African countries, Serendipity berry fruit is known as a tasty sweetening protein fruit. The berries contain a water-soluble and highly sweet protein called "Monellin" or "Serendip" which is one of the sweetest known naturally-occurring substances in fruits of plants. Monellin is up to 3,000 times sweeter than sucrose, with its precursor coming from protein and not carbohydrate as in sucrose. Monellin could be used as a substitute to sugar for diabetics, dieters and for a healthier life style. It has the potential of being utilised in the formulation of food and drugs to enhance the diets of other vulnerable groups. *Dioscoreophyllum cumminsii* is threatened and could go into extinction if appropriate actions for its propagation, production and conservation are not undertaken immediately. Currently, there is dearth of information on the consumption patterns, cultivation, management, advocacy for its valorisation and sustainable conservation of its genetic resources.

Key-words: Serendipity berry; monellin; sweetener; underutilised fruit; Nigeria; Africa
https://dx.doi.org/10.4314/njbot.v36i1.3

INTRODUCTION
Fruits, generally, represent no less important part of human nutrition, for their usefulness in diet diversification but also for their roles in providing vitamins and minerals for human health promotion (Khoo *et al*., 2017). Fruits increase antioxidant concentration in blood, body tissues and potentially protect them against oxidative damage which staple food crops cannot do (Ikram *et al*., 2009; Azlan *et al.,* 2010; Abiodun *et al.,* 2014). Serendipity berry fruit is known as a taste-sweetening protein fruit (Oloyede *et al*., 2015; Ajiboye *et al*., 2016). Indeed, the berries contain a water-soluble and highly sweet protein called "Monellin" or "Serendip"(Ramstad *et al.,* 1975), which is one of the sweetest known naturally-occurring substances in the fruits of plants. It is up to 3,000 times sweeter than sucrose (Inglett and May, 1969; Furuya *et al*., 1983; Vines, 1992). Monellin could be used as a substitute for sugar for diabetics and dieters (Oselebe and Nwankiti, 2005; Wiebe *et al*., 2011) and it has the potential to be utilised in the formulation of diabetics' food and to enhance the diets of other vulnerable groups (Ayobami *et al*., 2019; Kayode *et al.,* 2020). The fruit can also serve to enrich nutritional properties and improve the nutrient content of some local foods (Ojo *et al.,* 2017). For instance, in Osun State, Nigeria, it has been used to increase the protein content of a local food called Kunun-zaki from 5.9 to 9.1% and to reduce fat from 0.9 to 0.9%. Moreover, mineral contents such as potassium, calcium and copper of Kunun-zaki with Serendipity berry have been shown to be higher than that of Kunun-zaki with sucrose (Ayobami *et al*., 2019).

In Nigeria, *D. cumminsii* leaves are among the multitude of herbal preparations used in the management and treatment of diabetes (Akharaiyi and Adegbemisipo, 2018; Świąder *et al*., 2019). It is locally called Utobilibiri, Era-ngorobi or Era-nwankita in Igbo and Omuaja or Ito-igbin or Ayun-ita in Yoruba language (Inglett and May, 1968). Apart from the monellin, this sweetener fruit also contains flavonoids, tannins, saponins, phenolic groups and steroid groups which play important roles in health maintenance and disease treatment (Furuya *et al*., 1983; Balogun and Fetuga, 1988; Ayoola *et al*., 2017; Ibitoye *et al*., 2017). The leaves are also known for their usefulness in regulating high fructose proportion in blood as hypoglycemic activity and to control hypertension, inflammation and oxidative stress (Ajiboye *et al.,* 2016; Ibitoye *et al*., 2017). It can also treat diarrhoea, dysentery and uterine hemorrhages (Ajiboye *et al*., 2016; Świąder *et al.,* 2019).

The plant is cultivated in Guinea-Bissau, Sierra Leone, Liberia, Benin and Congo (Inglett and May, 1969; Adansi, 1970; Cagan *et al.,* 1976; Hladik *et al*., 1984; Hladik and Hladik, 1990; Akoègninou *et al.,* 2000; Kimpouni, 2001; Hyde *et al.,* 2018). It is abundantly present in the rainforest zones of West Africa where its habitat is exclusively limited (Inglett, 1976; Summerfield *et al*., 1977; Hladik *et al.,* 1984; Hladik and Hladik, 1990; Malleson, 1999; Akoègninou *et al.,* 2000; Hyde *et al.,* 2018). Similarly, in Nigeria, its area of occurrence is exclusive to humid and rainforest zones in the Southwest and Southeast (Oselebe *et al.,* 2004, Obioh *et al.,* 2006; Obioh and Isichei, 2006; Obioh and Isichei, 2007; Komolafe *et al*., 2017). However, despite the multiple nutritional properties and health-promoting roles played by this fruit, it is under-exploited. This results in its negligence and underutilisation by the younger generation (Abdullahi, 2013).

Like many African indigenous fruits and vegetables, *D. cumminsii* is disappearing and its population will go into complete extinction if relevant actions for its preservation are not undertaken immediately (Obioh and Isichei, 2007). Equally, the current global population increase, associated with the irreversible urbanisation of rural areas has aggravated its extinction (Caballe, 1994; Okafor and Lamb, 1994; Obioh and Isichei, 2007; Kayode and Bamigboye, 2016). Despite the continual erosion of its genetic resources, many resource-poor populations in Africa and many rural households still rely on it for a lot of utilisations (Gbile and Adesina, 1987; Hladik and Hladik, 1990; Jimoh, 2005; Abiodun *et al*., 2014; Kayode and Bamigboye, 2016; Kayode *et al*., 2016; Akharaiyi and Adegbemisipo, 2018). Moreover, very little is known about its production and utilisation. Its production system and medicinal properties are less documented. In Ekiti State, Nigeria, local farmers are no longer willing to cultivate the crop, because of cultural stigmatisation, apparent lack of economic and ethnomedicinal values of the crop, and its poor reproductive nature. Farmers confirmed its rare utilisation in their diet habits, and its unfamiliar status with many younger farmers, even though the older farmers demonstrated remarkable knowledge of the species and were aware of its application in local medicine and in traditional diets (Kayode *et al*., 2016).

There is, therefore, the urgent need to fill these gaps of knowledge. This study was aimed to gather and synthesise information on cultivation and consumption patterns of *D. cumminsii* in its producing areas in Nigeria. The study also aimed to provide information about the traditional utilisation and various applications of the fruits by the local population. Action that need to be taken for better management and conservation of these valuable genetic resources, as well as the roadmap for the enhancement of its production, selection for greater consumption among urban and peri-urban populations in Nigeria and the whole West-African countries have been suggested.

MATERIALS AND METHODS

Dataset

To have a clear understanding on the production and utilisation of Serendipity berry, its nutritional and medicinal potentials provided by farmers, and how its genetic resources are managed for better conservation for current and upcoming generations, a systematic literature review was conducted (Akinola *et al*., 2020). This involved searching articles based on clearly formulated questions and terms, guided by intentional and explicit criteria pre-defined to select relevant documentations which fit the field of research. These were subjected to a comprehensive analysis. This approach was used to produce a rapid analysis and to release a comprehensive knowledge from a huge number of appropriate libraries and summarise insightful information from research works of many years by many scientists from many parts of the world (Ford and Pearce, 2010; Hamid, 2020;

Akinola *et al*., 2020; Tapsoba *et al.,* 2020; Yang *et al*., 2020). In this study, the first step consisted of primary documentation search from the

common research engines. This was followed by in-depth analysis to retain the most relevant of data to the field of research based on inclusion and exclusion criteria.

Primary documentation search

Primary documentation or libraries were accessed on both scholarly and grey literatures from Scopus and Google Scholar. Indeed, these two search engines were preferred because they are the most commonly used online research libraries that are more comprehensive, up-to-date and highly relevant for interdisciplinary and peer-reviewed literature. On Scopus, the following search terms were formulated**: "**Serendipity berry production, consumption, utilisation, nutritional values and medicinal applications in Africa, West Africa and Nigeria.

On Google Scholar, search topics related to Serendipity berry production, consumption, nutritional values" to local populations in Nigeria, West-Africa and Africa were formulated. "Serendipity berry and sweetening properties and sugar content", "Serendipity berry and low calorie sweeteners", "Serendipity berry and disease treatment", "consumption patterns of Serendipity berry among the local populations in Nigeria" were also used as key words for search. To keep the search as broad as possible, the years of publication were not limited and the status of the consulted sources was large to find out much documentation during this primary data collection step. These search terms were also directly typed into Google's (www.google.com) search engine to look for grey literature related to the field of research. The language was limited to English and French for the consulted libraries during the documentation search.

In-depth analysis of the primary documentation and selection of literature

After the primary documentation search on the search engines, the first sample consisted of 169 libraries including 47 found on Scopus and 122 found on Google Scholar. After removing the duplicated libraries, the datasets were screened using the inclusion and exclusion criteria. These criteria set the boundaries for the systematic review. This screening retrieved a database of 109 libraries mainly consisting of scientific publications (original research and literature reviews), book sections, conference proceedings and some grey libraries. A second screen of the dataset led to the discarding of libraries that focused on "sweetener physicochemical properties and composition" without mention of Serendipity berry. This second screening step yielded 82 libraries on which we furthered our analysis and synthesis.

Further, the final database was classified into different clusters in the function of the crop, intrinsic characteristics, crop management options, nutrition and disease treatment potentials, as well as utilisation pattern of Serendipity berry. The whole document was organised into two major parts, namely "the intrinsic characteristics of the crop" and the "crop management practices" farmers use to deal with Serendipity berry. Lexicometry to the different sections of the paper was applied by considering their respective frequencies in the database. The frequency of each study section in the dataset was summarised and the bottlenecks and the proposed techniques for sustainable production of Serendipity berry were highlighted.

RESULTS AND DISCUSSION

Systematics, classification and cytology

Dioscoreophyllum cumminsii (Stapf) Diels is a member of the Menispermaceae family. It belongs to the order of Ranunculales and genus *Dioscoreophyllum*, which contains three species namely *D. cumminsii*, *D. tenerum* and *D. volkensii* (Inglett and May, 1969; Akoègninou *et al*., 2000; Nwadinigwe, 2000; Oselebe and Nwankiti, 2005; USDA, 2016). Cytological studies undertaken by Oselebe and Nwankiti (2005) revealed that the root tip cells under mitotic division at the metaphase plates contain sixteen chromosomes (2n = 16). These chromosomes showed variations in size based on centromeric positions and are classified as metacentric and submetacentric chromosomes. Though some cells have shown more than 16 chromosomes (known as metacentric and submetacentric chromosomes), the number of 2n = 16 was adopted for the species (Oselebe and Nwankiti, 2005). Pharmacognostical studies on *Dioscoreophyllum cumminsii* and *Dioscoreophyllum volkensii* showed structural similarities between the two species. However, slight differences can also be observed between them in terms of leaf size, type and abundance of trichomes. The leaves and stems of both *D. cumminsii* and *D. volkensii* contain the quaternary alkaloids magnoflorine, jatrorrhizine and columbamine (Nwadinigwe, 2000).

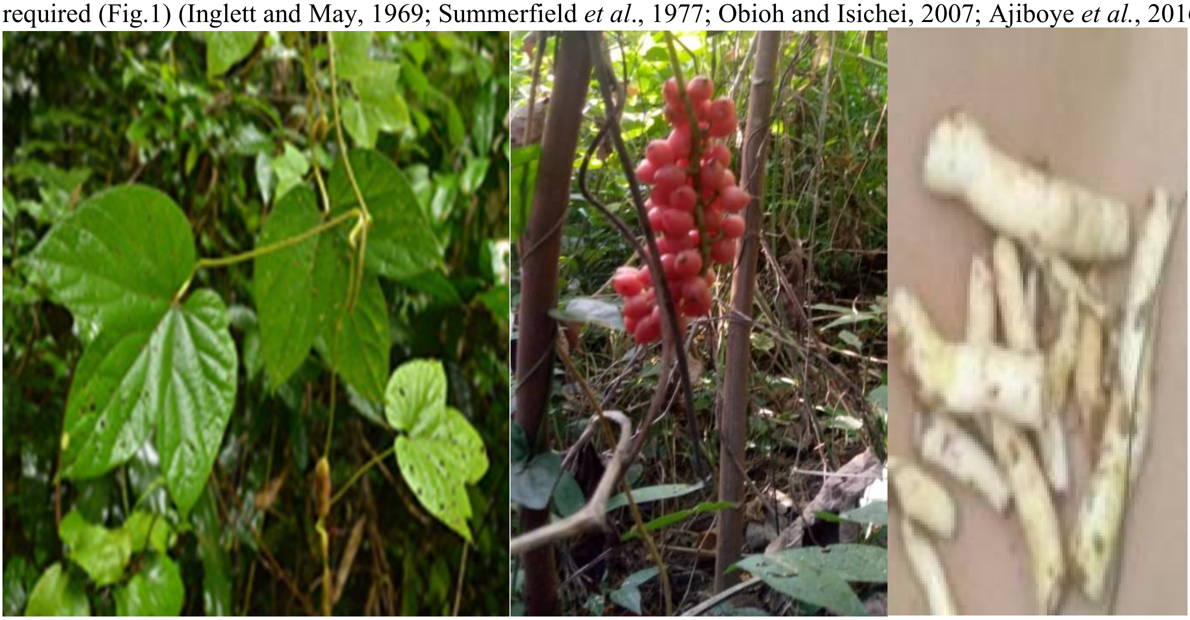
Botany of Serendipity berry and description of plant architecture

In the year 1800, the plant was called wild red berries, Guinea tomato or Serendipity berry by African natives before its discovery in 1895 by Daniel. It was later in the year 1900 that the species was assigned the scientific name *Dioscoreophyllum cumminsii* (Stapf) Diels. It is a dicotyledonous plant that grows naturally in the forest from where local populations collect it for their use (Inglett and May, 1969; Cagan, 1973; Van Der Wel *et al.*, 1974; Inglett, 1976; Ajiboye *et al.*, 2016; Kulik and Waszkiewicz-Robak, 2019).

The plant's architectural structure shows a liana, a climbing vine, sometimes 1.8 m long, vine supported by other plants. Leaves with 10-20 cm long and wide ovate- triangular in outline, are distinctly three-lobed, 7-9-veined from the broadly cordate base; petiole of 6-15 cm long. Flowers in axillary racemes are unisexual; the male racemes are up to 30 cm long, and female racemes are up to 10 cm long. The fruit is a drupelet 1 to 3.5 cm long and grows in a grape-like cluster at basal positions along the hairy vine. There are approximately 50 to 100 berries per bunch. The fruit pericarp is composed of white, semi-solid and mucilaginous pulp surrounding a friable thorny seed and enclosed by a tough outer skin. It bears slender tubers of up to 3 cm in diameter and up to 1.5 m long (Inglett and May, 1969; Van Der Wel *et al.*, 1974; Ajiboye *et al.*, 2016; Hyde *et al.*, 2018; Kulik and Waszkiewicz-Robak, 2019)**.**

Plant cycle and mechanisms of reproduction

Serendipity berry is an annual plant that grows during the rainy season within a 4-month cycle (July-October) (Inglett and May, 1968; Inglett and May, 1969). Male inflorescences first appear after 83 days and are produced on different plants over a 60-day period. Those plants which flower have near minimal values for tuber dry weight. Berries ripen from September through October, while aerial vegetation dies and stays dry between November and December (Inglett and May, 1969; Obioh and Isichei, 2007; Ajiboye *et al.*, 2016). The plant has a complex life cycle characterised by independent development of the female and male stands. It has been observed that while the males propagate asexually by subterranean tubers, the females reproduce sexually by seeds. The fruits and subterranean tubers are edible. Obioh and Isichei (2007) reported that in 1997 the tubers sprouted at the onset of the early rains in March. Male plants of Serendipity berry are more abundant in nature than the female stands. Meanwhile, for increased production for commercial purposes, both sex plants are required (Fig.1) (Inglett and May, 1969; Summerfield *et al.*, 1977; Obioh and Isichei, 2007; Ajiboye *et al.*, 2016).



a) Plant architecture b) Fruits c) Slender tubers

Fig. 1: *Dioscoreophyllum cumminsii* (Stapf) Diels

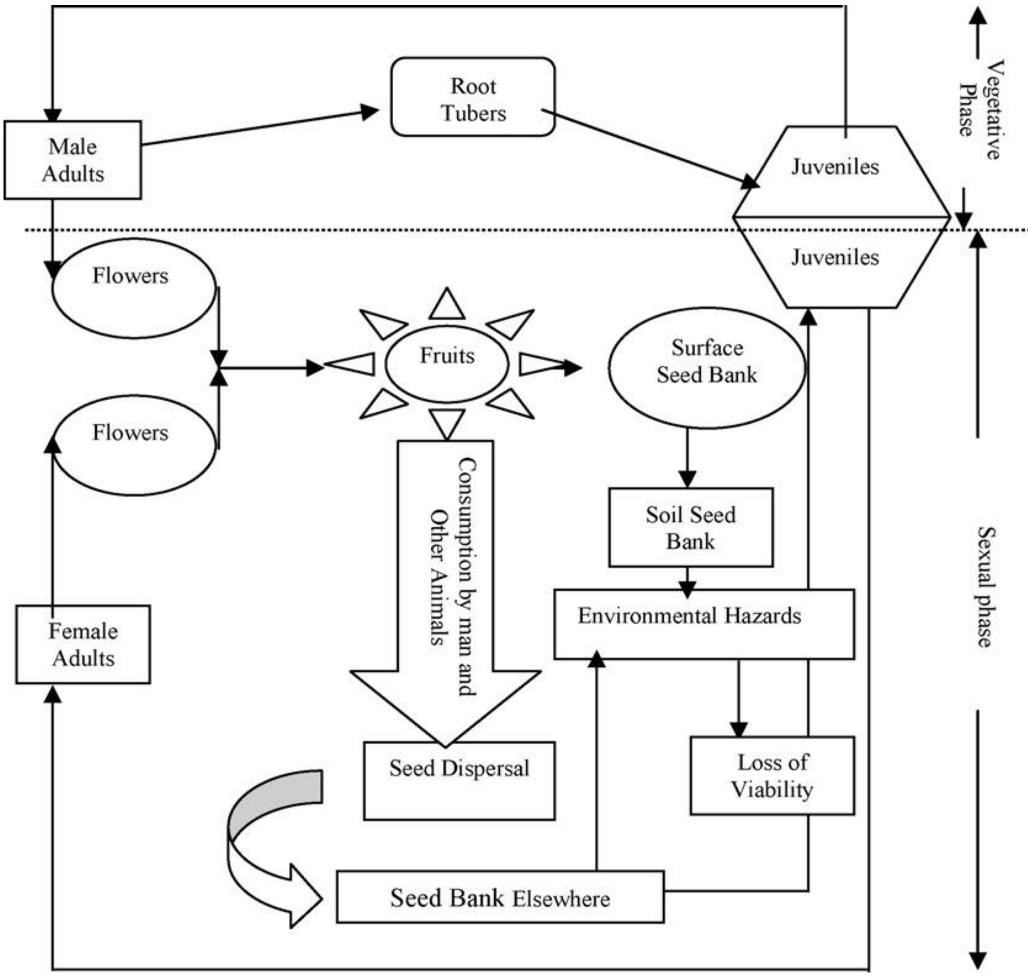


Fig. 2: The life cycle of *Dioscoreophyllum cumminsii* (Stapf) Diels
Source: Obioh and Isichei, 2007.

Level of older farmers' recognisance of Serendipity berry and cultural stigmatisation by younger farmers

Farmers' knowledge has been assessed in local areas in Ekiti State to understand more about their recognisance of the fruit (Kayode *et al*., 2016). This investigation revealed that, in general, the plant is known as a liana that climbs on other plants for support. It grows near flowing streams, ponds and rivers, but nowadays, it has become scarce (Obioh *et al*., 2006; Kayode *et al.,* 2016). In its natural habitat, it grows on its own as a wild crop, and one of its weaknesses is that its seeds do not germinate readily. The study revealed that older farmers know the crops better than younger farmers who even dislike them. About 19% and 5% of older farmers used to plant the seeds and transplant the seedlings, respectively, while no younger farmer (less than 35 years old) has been reported to grow it. The proportion of people that ate the fruits during the period of the study was higher than the number of people that harvested them, meaning that people may not have grown the crop but are willing to eat the fruits. Moreover, an ethnobotanical study undertaken on the utilisation of medicinal plants in the Omo biosphere reserve in Ogun State revealed that farmers in this region do not know much about the reproductive mechanism of the plant (Obioh *et al.,* 2006).

Field survey showed that none of the respondents was willing to cultivate the species in the study area in Ekiti state, probably because of its weaknesses such as poor and late seed germination, recalcitrant reproductive

mechanism, unavailability of planting materials, lack of commercial value of the fruits and more importantly because of their poor recognisance of the crop's potentials for both nutritional and medicinal applications. This has led to its cultural stigmatisation (Kayode *et al.,* 2016).

Habitat and geographical distribution of *Dioscoreophyllum cumminsii*

Serendipity berry is an indigenous crop to West and Central Africa. It grows in dense, humid tropical forests as a late-successional, understory species. Recognised as a woody, twinning vine exclusively distributed in tropical Africa, it grows from Guinea to Cameroons and is also found in Gabon, Congo and Sudan (Inglett and May, 1968; Okafor and Lamb, 1994; Malleson, 1999). It also grows in Zimbabwe, Mozambique, Sierra Leone, Ghana, Benin Republic and Nigeria, where its abundance occurs. In Congo, the fruit is eaten by the natives. In Zimbabwe, it is only known from the Chirinda forest, where it appears to be fairly common. In Gabon, it occurs in the Gabonese rain forest in the Northern part of the country from where populations collect the fruits (Spencer and Earle, 1972; Van Der Wel, 1972; Ichikawa, 1991; Caballe, 1994; Department of Agriculture and Forestry, 1995; Obioh and Isichei, 2007; Oselebe and Ene-Obong, 2007; Akharaiyi and Adegbemisipo, 2018; Hyde *et al*., 2018). It is cited among the food resources and represents one of the major tuber plants in African rainforest zones stretching from Cameroun, Gabon, Congo to Central Africa (Fig 2). It was used by black people many years ago. Its tubers were among the most abundant and the major food items collected from the rain forests by pygmies (Hladik *et al*., 1984; Hladik and Hladik, 1990).

In the Benin Republic, the plant was collected for the first time by Akoègninou *et al.* (2000) in the Department of Ouémé, district of Pobe Local Government Area of Pobe, and in a humid semi-deciduous and heavy forest locality. The voucher was deposited for conservation in the plant genetic resources national GenBank (Akoègninou e*t al*., 2000).

In Nigeria, serendipity berry grows in many undisturbed rainforests in the Southwest of the country (Abdullahi, 2013; Bamigboye and Kayode, 2016). Wild remnant populations are still found in the country's forest reserves. For example, the Biological Garden of Obafemi Awolowo University, Ile-Ife (7°30'- 7°32' N and 4°31'-4°33.5'E) is one of the sites where it was collected in the year 1997 (Obioh and Isichei, 2007); Olokemeji Forest Reserve which is located on latitude 7°25' N and longitude 3°33' E, and which lies about 40 km (25 miles) west of Ibadan and about 110 km (70 miles) north of the coast in southwest, is another site where the plant grows (Hopkins and Jenkin, 1962). It is also found in local forests in Ikire and Ife Local Government Areas in Oyo State. The plants fruit profusely around August, making the fruits available in large quantities in the localities (Gbile and Adesina, 1987).

The plant is found in the Orba forest in Udenu Local Government Area, Ugwuabor forest in Udi Local Government Area, in Enugu State; primary forest in Ntezi, Ngbo and Izzi in Ebonyi State; Otukpa, Akpoto forest in Benue State and in the primary forest near the International Institute of Tropical Agriculture (IITA), Ibadan (Oselebe *et al*., 2004; Oselebe and Ene-Obong, 2007). It is found in Ibodi Monkey Forest in Osun State, which is located at latitude 7° 35' N and longitude 40°40' E (Emmanuel *et al*., 2017). It also occurs in local forests in Ekiti State (Kayode and Bamigboye, 2016), in Omo Forest Reserve, also called Omo Biosphere Reserve located between latitudes 6° 35' to 7°05' N and 4° 19' to 4° 40' E in the Ijebu area of Ogun State (Isichei, 1995; Obioh and Isichei, 2006).

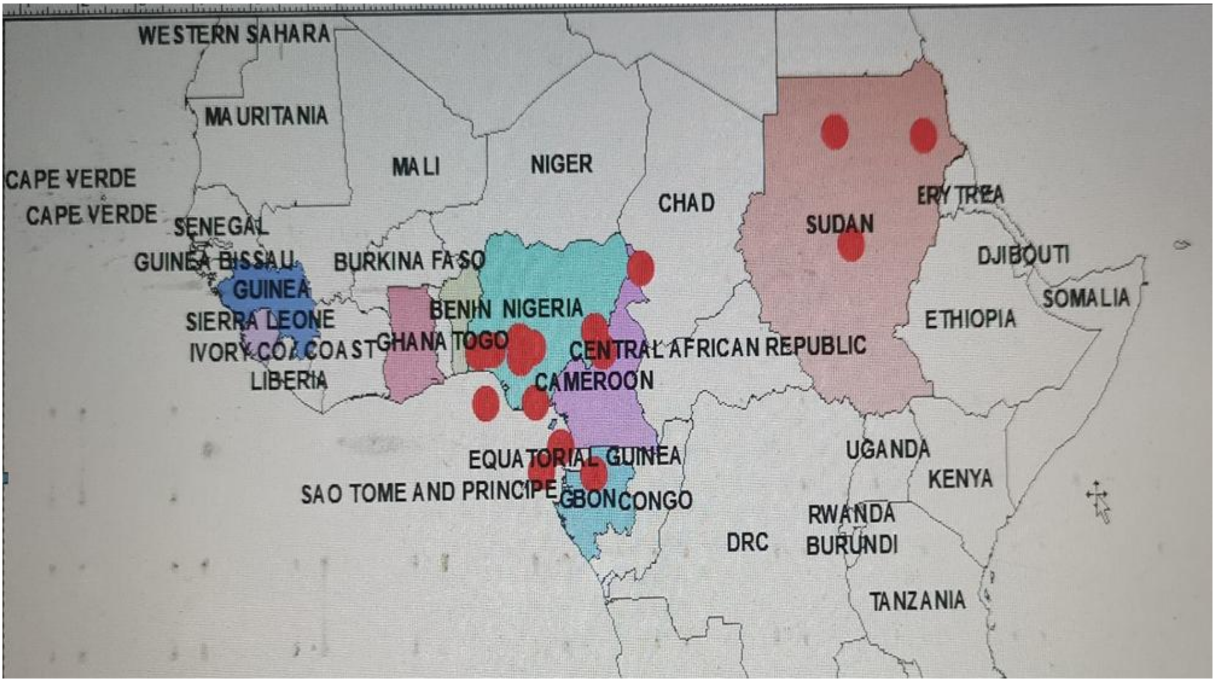


Figure 2. **Distribution Map of *D. cumminsii* in West Africa (Field work in 2019)**

Nutritional values of Serendipity berry fruits

The most important nutritional value of Serendipity berry fruits is the non-accumulation of metabolisable calories in human blood after they are consumed. The fruits have the potential to be utilised by diabetics in the formulation of their food and in enhancing the diets of other vulnerable groups. For this reason, the plant is known as an excellent beneficial sweetener source (Cagan, 1976; Gbile and Adesina, 1987; Vines, 1992; Witty, 1998; Kant, 2005; Abiodun *et al.*, 2014). The analysis of nutritional values revealed that the fruits are rich in vitamin C, 12.80 mg/100 g, which is more than the vitamin C content of watermelon (*Citrullus lanatus)* (5.2 mg/100 g) and banana (*Musa sapientum)* (10.2 mg/100 g) (Tee *et al.*, 1988; Bamigboye and Kayode, 2016).

The nutritional composition of the fruits evaluated by Abiodun and Akinoso (2014) showed dry matter content of 19.56 %, moisture content 80.44 %, soluble solids 11.20 % and vitamin C, 12.80 mg/100 g. Titratable acidity and pH were 0.21 % and 6.6, respectively (Abiodun and Akinoso, 2014). It also has an appreciable amount of total soluble solids which might serve as a source of energy. The total carotenoid value was 2.01 mg/100 g in the fruit. Oil from *Dioscoreophyllum cumminsii* (Stapf) Diels seed contains *cis-5-octadecenoic* acid as 84 % of its total fatty acids. The unsaturated acids normally found in the seed oil are present in small amounts (oleic, 1%, Iinoleic, 5.2 % and linolenic acid (0.3 %). Other unusual acids present, in minor amounts, are *cis-5-hexadecenoic* (0.6 %), l l-octadecenoic (0.9 %), and two polyenoic acids which are probably unsaturated at the 5th position (Spencer and Earle, 1972). One kg of fruit can produce 3-6 g of pure protein, monellin (Świąder *et al.*, 2019).

When tested as a partial substitute to sugar for the preparation of wheat bread, Serendipity berry extract-treated flour recorded the highest values for moisture, ash, protein, fat, fibre and carbohydrate contents of 15.22 %, 3.06 %, 14.13 %, 9.06 %, 2.50 % and 68.14 %, respectively. The sugar solution-treated flour showed the lowest values for the same constituents with 11.93%, 0.75%, 11.67%, 4.29%, 1.24% and 55.01%. Also, the proximate composition, except carbohydrate, of the bread increased while the bacterial and fungal counts decreased with an increase in the concentration of the serendipity extract (Dauda *et a*l., 2007; Kayode *et al.*, 2020).

In another experiment, Serendipity beery fruit extract was tested to reduce microbial multiplication in a high moisture content fruit juice, namely watermelon. To this end, the two juices were mixed up and conserved over a period of 12 weeks in ambient conditions. The results showed that the microbial load of the control sample, a pure watermelon juice, ranged between 1.1 x 10^5 -9.7.6 x 10^7 cfu/ml, while treated samples ranged between 0.2 x 10^5 and 1.4 x 10^5 cfu/ml, with some of the treated samples having negligible growth. Serendipity fruit extract has been used to reduce the microbial multiplication activity in the juice of watermelon and to conserve the fruit juice for over 12 weeks by maintaining its quality and colour.

The analysis of amino acid content in Serendipity berries revealed that they have lower amino acid content values than other sweet-tasting and taste-modifying protein fruits originally known in Africa. This protein contains no histidine, and only one residue each of tryptophan, cysteine and methionine were present. It contains no mono - or dimethyl derivatives of lysine or arginine (Cagan *et al.*, 1976). The complete amino acid sequence of the sweet protein monellin has been studied by Kohmura *et al.* (1990), which showed that the molecule consists of two non-covalently associated polypeptide chains, a chain of 44 amino acid residues and the B chain of 50 residues. Attempts have been made to express monellin both in microorganisms and in transgenic plants (Kohmura et al., 1990; Faus, 2000).

Sweetness property of Serendipity berry: origin, manifestation and utilisation in the human body

The sweetness of the fruits is produced by a protein molecule called monellin. Indeed, this is a carbohydrate-free basic molecule recognised as a sweetener protein molecule peculiar to Serendipity berry (Van Der Wel *et al.,* 1974; Kohmura *et al.*, 1991; Sardesai and Waldshan, 1991; Mizukoshi *et al.*, 1997). Monellin, isolated from *Dioscoreophyllum cumminsii*, is one of the most potent sweeteners known, being about 90,000 times sweeter than sucrose on a molar basis (Leone *et al.,* 2016*).* Generally, sweeteners can be classified into two main groups, namely caloric and non-caloric sweeteners. The difference is that non-caloric sweeteners reduce energy intake while caloric sweeteners don't. The advantage is that the non-caloric sweeteners will not induce an accumulation of energy in the blood and then result in lower blood sugars after consuming sweetened food. This is the main function of monellin, a chemo-stimulatory taste-active protein, which is largely sweeter than sucrose but does not induce energy accumulation in the body (Kohmura *et al.,* 1991). A study has shown that participants in the non-caloric sweetener group had a decrease in body mass index compared to an increase in body mass index in the caloric sweetener group (Wiebe *et al*., 2011). However, physico-chemical studies carried out on the fruits showed that the predominant sugars were fructose and glucose. Fructose and glucose ranged from 0.61 to 3.47 mg/100 g and 0.35 to 3.15 mg/100 g, respectively. The gel had higher sugar contents than the seed (sometimes bitter), and the peel. Soladulcine was the predominant alkaloid in the seed and peel. Total alkaloids were 1.09 mg/100 g in seed, 0.18 mg/100 g in the peel and traces of emetine in the gel (Abiodun *et al*., 2014). The bitterness of the seed prevents the use of the whole fruit for sweetening purposes (Ramstad *et al.,* 1975). The bitterness of the seed is due to the presence of a bitter substance called columbin. This molecule was first identified from colombo roots (Jateo*rhiza palmatu* Miers, Memspermaceae) and in the seeds of *Sphenocentrum jollyunum* (Memspermaceae). It was found in Serendipity berry in 1975 and later in the seed of *Melothrium aderusputuna* (Cucurbitaceae). Bitterness properties in those seeds is attributed to the diterpenoid bitter principle (Ramstad *et al.*, 1975).

A study was conducted on the structure and dynamic of monellin as an intense sweetener molecule and a non-sweet analogue molecule in which Asp^{B7} in monellin has been replaced by Abu^{B7}. The study revealed that the 3-dimensional structure of these two proteins is very similar, indicating that the lack of the P-carboxyl group in the Abu^{B7} analog is responsible for the loss of sweet potency in the non-sweet molecule (Mizukoshi *et al.*, 1997).

Medicinal applications of Serendipity beery for treatment of diseases by rural populace

D. cumminsii has a multitude of medicinal uses. The fruits, leaves and stems possess healing properties that are useful in treating diseases in Africa. The fruits, the leaves or the stem are used as poultice on sprains and bruises and as a dressing for fractures (Abiodun and Akinoso, 2014; Akharaiyi and Adegbemisipo, 2018; Świąder *et a*l., 2019). They can also be mixed with shea butter to produce an ointment for the relief of pains and stiffness. When the leaves are processed into a dark powder after being burned, they can be used to treat diarrhoea, dysentery and uterine hemorrhages (Oselebe and Nwankiti, 2005; Ibitoye *et al.*, 2017). Stem, leaves and fruits are the major parts

of the plant that are the most utilised. They contain alkaloids at a low level that cannot harm human health. Their extractions from the cultured cells of Serendipity berry are used for drug production (Abiodun *et al*., 2014).

As a non-carbohydrate sweetener, monellin has the potential to combat tooth decay, potential in low-calorie diets for diabetics and dieters, and as a sweetener in food industries (Holloway, 1977). Out of the 23 medicinal vegetables used by traditional healers of Ado in Ekiti State, Nigeria, the plant was cited among the first eight herbals used to prevent or cure frequent diseases. Apart from being used to prevent the occurrence of diabetes, the plant's leaves, stem bark, and roots serve as a remedy to type 2 diabetes mellitus, hypertension and tooth decay (Eghianruwa *et al.*, 2016; Kayode and Bamigboye, 2016; Akharaiyi and Adegbemisipo, 2018).

Ajiboye *et al.* (2016) reported that the leaves halted high-fructose-induced metabolic syndrome, by lowering the effects of hyperglycemia, insulin resistance, inflammation and oxidative stress in the rat's bodies. Similarly, increased levels of cholesterol, triglycerides, low-density lipoprotein cholesterol, very low-density lipoprotein cholesterol, atherogenic index, cardiac index and coronary artery index were significantly lowered by the aqueous leaf extract. These findings confirm the potential of hypoglycemic activity of aqueous leaf extract of *D. cumminsii* (Oloyede *et al.,* 2015; Ajiboye *et al*., 2016; Świąder *et al*., 2019). The same findings were reported earlier by Ibitoye *et al.* (2017), who investigated the anti-dyslipidemic, anti-inflammatory and antioxidant activities of the aqueous leaf extract of Serendipity berry in high, fat diet-fed rats. It was observed that the aqueous leaf extract of Serendipity berry reduced the level of insulin, leptin, protein carbonyl, fragmented DNA, tumour necrosis factor-α and interleukin- (IL-) 6 and IL- 8; it could increase the adiponectin level (Ibitoye *et al.,*2017).

Health maintenance properties of Serendipity berry

Presently, there are six recognised natural sweet proteins and one taste-modifying protein known to be less hazardous to humans.These include Thaumatin, Curculin, Miraculin, Brazzein, Pentadin, Monellin and Mabinlin. These are found in plants such as *Thaumatococcus daniellii* (Marantaceae), *Curculigo latifolia* (Hypoxidaceae), *Synsepalum dulcificum* (Sapotaceae), *Pentadiplandra brazzeana* (Pentadiplandraceae), *Dioscoreophyllum cumminsii* (Menispermaceae) and *Capparis masaikai* (Capparaceae), respectively (Inglett and May, 1968; Inglett and May, 1969; Van Der Wel *et al*., 1974; Summerfield *et al.,* 1977; Kant, 2005; Agboola *et al.*, 2014; Swiader *et al.*, 2019.

Due to their harmless nature, these substances represent the potential replacement of the current artificial sweeteners (aspartame, saccharin and acesulfame-K) whose effect on human health in the long term has not been established yet (Faus, 2000*;* Rotimi *et al.,* 2014*;* Świąder *et al.,* 2019). In industries, the sweetener protein of Serendipity berry can be processed to make a final sweet product with low-calorie content (Kohmura *et al.,* 1990). Cultured cells of *D. cumminsii* showed a higher alkaloid content than that of the living plant, which is surprising because in plant tissue culture, a lower or negligible proportion of alkaloid than that in the original plant had been observed. Indeed, alkaloids are well-known nitrogen-containing natural bioactive compounds. They possess valuable therapeutic properties and are useful in health maintenance. They contribute to multiple biological activities and can transform into active metabolites. The high proportion of alkaloids in cultured cells of Serendipity berry shows the medicinal and health maintenance benefits of the plant to consumers (Furuya *et al.,* 1983; Debnath *et al.*, 2018).

The molecular weight of Serendipity berry protein molecule is estimated at 10,000-10,700 g/mol, lower than the range established for protein weight (12,000-26,000 g/mol), while the value of the medium-heavy protein is estimated at 64,000 g/mol; the highest value can reach 1,000,000 g/mol (Cagan, 1973; Cagan *et al.*, 1976; Kohmura *et al*., 1990). The importance of this property is that the monellin protein of this plant could be freely filtered by glomerulus and reabsorbed by the intact proximal tubule (Vincent *et al.,* 2012). This increases urinary excretion and leads to the easy excretion of the protein from urine. Also, the presence of the protein in urine is associated with diabetes in the body. The easy excretion of monellin from urine is a key driving factor in the prevention of diabetes (Lapolla *et al.,* 2009; Vincent *et al*., 2012).

Besides these, monellin has been proven to have the properties of free SH-group (Morris and Cagan, 1972; Van Der Wel, 1972). The free carbohydrate properties confer to the fruits the potential of not inducing sugar
residue accumulation in the blood after consumption. Similarly, the free-SH properties of the fruits indicate the harmless potential of the sweetening taste of the fruits (Morris *et al.,* 1973; Van Der Wel and Loeve, 1973).

Patterns of Utilisation of Serendipity berry plants by rural populace

In traditional therapeutic systems, variable utilisations are made of Serendipity berry plants (Ibitoye *et al.,* 2017). The fruits, leaves or stems can be used as poultice on sprains and bruises and as a dressing tool for fractures. They can also be mixed with shea butter to produce a liniment for the relief of pains and stiffness.

The fruit of *D. cumminsii* is consumed by many people in the Democratic Republic of Congo (Kulik and Waszkiewicz-Robak, 2019). The younger leaves can be ground, and the filtrate used as an ingredient to prepare soup. Mature fruits and tubers are also edible and represent one of their daily diets (Hladik *et al.,* 1984; Hladik and Hladik, 1990; Kimpouni, 2001). It was also used by ancient people in African rainforest regions where its tubers were eaten either uncooked, cooked or smoked like tubers of wild yam. Its red berries were highly appreciated by the pygmies that inhabited the forest because of their high sweetening taste (Hladik *et al.,* 1984).

Extract of Serendipity berry has been tested to partially substitute sugar in the preparation of wheat bread and to assess the nutritional quality of the bread (Kayode *et al.*, 2020). Fruit extract has also been used to assess the viability of developing sweetened yoghurts without sugar. In fact, the MNEI is a modified single-chain form of the natural sweet protein, monellin, extracted from the fruit of Serendipity berry. The results revealed the enhancing effect of flavour on sweetness perception, supporting previous reports that noted the synergistic effects between sucrose or aspartame and flavours (Miele *et al.*, 2017).

Major constraints to Serendipity berry production

The major constraints that hinder the large production and consumption of Serendipity berry among the rural populace in Africa, especially in Nigeria, are summarised as follows:

a) The major challenge facing the plant is its propagation through seed. Initially, the notion was that the seed could not germinate. Surprisingly, it was observed that a small proportion of untreated seeds that had been dumped in the bush were found to have germinated after about six months. This showed that *D. cumminsii* seeds are capable of germinating (Holloway, 1977; Summerfield *et al.*, 1977; Bamigboye *et al.*, 2016; Bamigboye and Kayode, 2016);
b) Non-existence and non-accessibility to planting materials discourage many farmers willing to produce the crop (Kayode *et al.,* 2016);
c) Poor seed and tuber conservation skills by local farmers who are cultivating the crop;
d) Lesser recognition of the plant by younger farmers and consumers. The crop is poorly known because of its wild status, though it has been domesticated (Kayode *et al.*, 2016);
e) Another obstacle hampering large scale crop cultivation is the progressive destruction of its natural habitat (Obioh and Isichei, 2007).

Long seed dormancy is one of the major constraints to the cultivation of Serendipity berry. It may take several weeks or months before the seeds germinate under natural conditions (Adansi and Holloway, 1977). Many investigations have been carried out to show diverse treatments of the seed before planting to accelerate germination (Adansi and Holloway, 1977; Summerfield *et al.,* 1977; Oselebe *et al.,* 2004; Oselebe and Ene-Obong, 2007; Bamigboye *et al*., 2016). Sowing the seeds without any treatment may extend the timing of germination up to 11-15 weeks.

a) Tying the seeds in a polyethylene bag may be an option for treatment, but the first germination will be obtained after ten weeks from sowing (Adansi and Holloway, 1977; Bamigboye and Kayode, 2016);
b) An alternative way could be for researchers to investigate the use of the vegetative propagation of the plant through the re-sprouting of tubers. Studies have shown that night temperature treatment combinations (12 h for 30/27°C) have decreased the time to shoot emergence by 10 to 27 days

compared to other treatments (12 h for 30/21°C and 16 h for 30/27°C), (11 to 38 days and 21 to 50/65 days, respectively) (Summerfield *et al.*, 1977);

c) Another experiment on the length of the tuber material and the position from where it was cut from the parent material was carried out to test the ability of shoot emergence and seedling establishment. The results showed that the most successful treatment combinations were 10 and 100 ppm, applied to tuber segments 3 cm long taken from the middle-third of parent tubers. These observations have shown that

tuber lengths as short as 3 cm are capable of forming roots and that treatment of tubers with an appropriate growth regulator can promote earlier root formation as compared with untreated material (Summerfield *et al.*, 1977);

d) Replicated tuber samples, each of 20 g fresh weight, were stored in a range of media at various temperatures for different durations to determine the optimum conditions and duration for tuber storage to be viable in the successive cropping season. The results obtained indicated that a temperature of 4°C is not suitable for long-term storage; tubers deteriorated rapidly and viability was lost. Conversely, for tubers stored in moist sand at 20°C, growth of roots, and in some cases shoots, occurred after 12 and 18 weeks, respectively. The optimum storage treatment found was to surface-dry the freshly excavated tubers, wrap them in absorbent tissue paper and store them in polyethylene bags at 20°C in the dark. Under these conditions, tubers were able to stay viable for at least 18 weeks and re-sprouted within 18 to 27 days of replanting with no apparent delay consequent upon storage time (Summerfield *et al.*, 1977);

e) Other experiments have shown that when seeds were collected from the tropics, they germinated rapidly (13 days) on moist filter paper (50 % water content) at a temperature of 30°C in the dark (Adansi and Holloway, 1975; Koons, 1976; Summerfield *et al.,* 1977; Shittu, 2015);

f) The germination rate can be improved by removing the testa as it is in the case of pre-sowing immersion for 30 minutes in gibberellic acid (GA3 or GA4/7 at 100 ug/mL in each case). Seed can be stored at 20°C for as long as 12 months and can germinate after treatment with GA3 or GA4/7 but emergent radicles may be contaminated by both bacteria and fungi. Soaking the stored seed for 20 seconds in a 1:400 V/V solution of Aretan before planting can prevent subsequent microbial infection (Adansi and Holloway, 1975; Summerfield *et al*., 1977; Oselebe and Ene-Obong, 2007; Bamigboye and Kayode, 2016);

g) Bamigboye and Kayode (2016) tested the germination of Serendipity berry seed with different pre-sowing treatments and found that intact seeds soaked in GA3 and seeds soaked in GA3 for one hour, after which the gelatinous membrane was removed yielded the best performance for the number of days to germination (9 and 10 days after planting to obtain the first germinated seeds, respectively). Their findings confirmed that Serendipity berry seeds should be treated by removing the gelatinous membrane before sowing or soaking them in GA3 for one hour and removing the gelatinous membrane afterwards to achieve germination within 2 weeks after planting. But maximum germination will be obtained 2-5 weeks later (Bamigboye and Kayode, 2016). These findings were established in 1975 when Adansi and Holloway (1975) conducted a study on seed germination and establishment of the plant and found out that Serendipity berry seeds are capable of germinating only when they are treated by GA3 and then the tuber dormancy can be broken upon 16 to 20 days (Adansi and Holloway, 1975);

h) The effects of different temperatures and durations of seed storage on the viability of *D. cumminsii* have been tested to establish the optimum conditions for crop germination. The results showed that seeds stored in a cold room (-18 to -22 °C) and those under laboratory conditions (28 +-2°C) did not germinate throughout the experiment. Seeds stored in the refrigerator (-1.1 to -2.5°C) did not germinate during the first two months, and the fifth and sixth month but germinated at 10% in the third month (Bamigboye *et al.*, 2016), while seeds stored in the air-conditioned room (16°C to 24°C) yielded the best germination rates, varying from 30% to 60%. Seeds collected and planted after one month of storage had 60% germination. This was discovered to be the optimum duration for maximum seed germination. Seed storage for two months before sowing resulted in 40% of germination, while storage for three months resulted in 30% of germination. Storage for four and five months resulted in 10% of germination (Bamigboye *et al.*, 2016);

i) Other investigations have been made, targeting the number of nodes on the cuttings necessary for optimum re-sprouting, such as using 3-nodes, 1-node and tip cuttings (with a leaf at each node in each case). Results showed only 15% plant establishment. Single inter-nodal cuttings, each with a healthy, intact leaf and a short length of stem on either side were taken from tuber-bearing, male plants. The stem portion, but not the leaf, was immersed for 10 seconds in a solution of one of four growth hormones namely, 2,4-D (2,4-Dichlorophenoxyacetic acid); IAA (Indole-3-Acetic Acid, in the Auxin family); IBA (Indole-3-Butyric Acid in the Auxin family) and NAA (Naphthalene Acetic Acid in the Auxin family) at

one of two concentrations (500 or 5,000 ppm). In the more favourable treatment combinations, rooting was recorded within 14 to 21 days and plants became established, producing new aerial shoots, within 30 days. The other three chemicals resulted in better establishment than the control treatment and, in every case, the higher concentration induced greater root production than the lower one. Differences between IAA, IBA and NAA treatments were relatively small. This method of propagation is satisfactory since several hundreds of such cuttings can be obtained from a single mature plant (Adansi and Holloway, 1975; Holloway, 1977; Summerfield e*t al.,* 1977; Oselebe and Ene-Obong, 2007; Bamigboye *et al.,* 2016); Bamigboye *et al.*, 2016);

j) Another experiment tested both chemical and biological or natural hormones for seed germination of Serendipity berry. The effects of four rooting hormones (Indo butyric acid, IBA, at 1mg/mL, Indo-acetic acid or IAA, Coconut water and distilled water) were investigated. The results showed that there was significant difference between the four treatments for the growing traits of the juveniles. Indo-butyric acid resulted in the highest value for juvenile survivour percentage while the Indole-acetic acid resulted the lowest value. Coconut water resulted in the highest mean value for the number of roots and new shoot emergence. The IAA resulted in the lowest mean number of roots. The use of IBA resulted in the highest root length (Koons, 1976);

k) In the case of seedling establishment, rooting media were investigated for Serendipity berry seed germination using vermiculite/sand/gravel (at 2:1:2 by volume), and loam-based John Innes compost. It was observed that a mixture of John Innes compost (J. I. O) and 0.6 cm crushed granite grit (at 5:1 by volume) was successful to grow Serendipity berry tubers, seedlings and adult plants through to maturity (Koons, 1976; Summerfield *et al*., 1977; Oselebe and Ene-Obong, 2007; Shittu, 2015; Bamigboye *et al*., 2016).

RECOMMENDATIONS

In order to ensure adequate production of Serendipity berry fruit, the following recommendations are made:

a) Male plants of *D. cumminsii*, propagated from tubers, can be induced to flower in 10-18 weeks from planting;

b) A very warm day temperature (35°C) together with high light intensity (140 J m^{-2} sec^{-1}) and a long photoperiod (16 h) limited vegetative growth, caused leaf and stem abnormalities and reduced shoot emergence by about 50%. More than 80% of the seedlings recovered when the day temperature was lowered to 30°C after 15 days;

c) Warm day temperature (35°C) coupled with high light intensity (140 J m^{-2} sec^{-1}) prevented tuber production (at least up to 156 days from planting) but favoured earlier flowering;

d) The optimum level of inorganic nitrogen for tuber production by male plants could be between 25 and 50 ppm regardless of light intensity;

e) Vegetative growth can be manipulated using different combinations of incident light intensity and nitrogen levels. Nitrogen application of between 25 and 50 ppm given to plants grown under light intensity of ca. 36 J m^{-2} sec^{-1} will produce plants with manageable aerial vegetation and a plentiful supply of tuber material;

f) For mineral fertilisation, 200 ppm nitrogen has been shown to stimulate flowering in male plants, which could appear 83 days after germination for 60 days;
g) Since light intensity is a limiting factor for plant growth for an essential part of the year, the light-accessibility for Serendipity berry must be maximised to favour its rapid growth, and the use of opaque supporting material should be minimised for its production;
h) A systematic spacing design could be used in staking the plants;
i) Temperature between 16°C to 24°C for storage for one month is recommended as optimum storage conditions for Serendipity berry seeds (Bamigboye *et al*., 2016);
j) Germination was directly proportional to the size of the seeds, suggesting that the use of large seeds might be beneficial in the effort to propagate the seeds of this species (Bamigboye *et al.,* 2016);

k) The technique of mass propagation of planting material could be possible with callus induction using Murashige and Skoog media solidified with 10 g/l agar and supplemented with 1-5 mg/l auxin (NAA). Further addition of kinetin (15 mg/l) resulted in more active callus formation. Kinetin applied alone, however, inhibited callus formation and growth (Oselebe and Ene-Obong, 2007);
l) The GA3 treatment reduced the time from sowing to seedling emergence from the 8 weeks observed for seeds in shaded soil to 18 days with 50-70% of the total number which occurred within five days after the first seedling emergence (Adansi and Holloway, 1975; Koons, 1976; Holloway, 1977; Oselebe and Ene-Obong, 2007);
m) The use of the natural growth hormone (coconut water) might support the development of stem cuttings (Koons, 1976; Bamigboye *et al.*, 2016).

CONCLUSION

The serendipity berry plant (*D. cumminsii)* is an African indigenous fruit, which is rich in monellin (sweetener) and has many medicinal properties. However, the crop is poorly known by farmers and consumers and commands poor scientific and research attention. The nutritional and medicinal potentials of this plant could be explored if it is given desired attention and recognition by farmers and researchers. The plant faces the threat of extinction due to the destruction of its natural habitat by anthropogenic activities. There is, therefore, an urgent need to promote the domestication, cultivation, conservation and breeding of this valuable indigenous African crop. The rural populace should be sensitised on the nutritional and medicinal values of the crop so that its production and consumption can be upscaled.

ACKNOWLEDGEMENT

The authors thank the Tertiary Education Trust Fund (TETFund) and Ebonyi State University, Abakaliki, Nigeria, for their financial assistance.

REFERENCES

Abdullahi, I. N. (2013). Biotechnology Application for the Improvement of Nigerian Indigenous Tree Species: The Challenges of Micropropagation. *International Journal of Scientific Research in Environmental Sciences,* (6): 107-114.

Abiodun, O. A. and Akinoso, R. (2014). Physico-chemical properties of Serendipity berry *(Dioscoreophyllum cumminsii*) fruit. *Journal of Applied Sciences and Environmental Management, 18*(2): 218-221.

Abiodun, O. A., Amanyunose, A. A., Olosunde, O. O. and Adegbite, J. A. (2014). Sugar and alkaloid profiles of serendipity berry (*Dioscoreophyllum cumminsii*). *Food Science and Quality Management,* 28: 83-90.

Adansi, M. (1970). Indigenous plants in Ghana with taste-modifying properties or sweetening principles. *Ghana Journal of Agriculture, 3:* 207-210.

Adansi, M. and Holloway, H. (1975). Seed germination and establishment of the serendipity berry *(Dioscoreophyllum cumminsii Diels).* Paper presented at the IV *African Symposium on Horticultural Crops* 53.

Adansi, M. and Holloway, H. (1977). Seed germination and establishment of the serendipity berry (*Dioscorrophyllum cuminsii* Diels. *Acta Horticulturae,* 53: 407-411. doi:10.17660/ActaHortic.1977.53.57; http://doi.org/10.17660/ActaHortic.1977.53.57

Agboola, D., Fawibe, O., Ogunyale, O. and Ajiboye, A. (2014). Botanicals and protein sweeteners. *Journal of Advanced Laboratory Research in Biology, 5*(4) : 169-187.

Ajiboye, T., Aliyu, H., Tanimu, M., Muhammad, R. and Ibitoye, O. (2016). Dioscoreophyllum cumminsii (Stapf) Diels leaves halt high-fructose induced metabolic syndrome: Hyperglycemia, insulin resistance, inflammation and oxidative stress. *Journal of Ethnopharmacology, 192:* 471-479.

Akharaiyi, F. C. and Adegbemisipo, A. A. (2018). Medicinal vegetal use by traditional healers in Ekiti State of Nigeria for diabetes treatment. *International Journal of Pharmacy Research and Technology, 8*(1): 21-28.

Akinola, R., Pereira, L. M., Mabhaudhi, T., de Bruin, F. M. and Rusch, L. (2020). A Review of Indigenous Food Crops in Africa and the Implications for more Sustainable and Healthy Food Systems. *Sustainability,* 12(8): 1-30.

Akoègninou, A., Agbani, P. and Adomou, A. C. (2000). *Dioscoreophyllum cumminsii* (Stapf) Diels

Akoègninou, A., vander Burg, W. J. and vander Maesen, L. S. G. (Eds.) (2006). *Flore Analytique de Benin.* Bukhuys Publishers. 1034p.

Ayobami, O., Nwakego, A. O. H., Ndigwe, E. V. and Adunni, A. O. (2019). Chemical and sensory evaluation of Kunun-zaki sweetened with serendipity berry *(Dioscoresphyllum cumminsii)* and enriched with defatted moringa seed flour. *Annals of Food Science and Technology, 20*(2): 380-386.

Ayoola, M., Adebajo, A., Obuotor, E., Oladapo, T. and Fleischer, T. (2017). Anti-hyperglycaemic and anti-oxidant activities of five Nigerian antidiabetic plants. *Journal of Science and Technology (Ghana), 37*(2): 71-84.

Azlan, A., Prasad, K. N., Khoo, H. E., Abdul-Aziz, N., Mohamad, A., Ismail, A. and Amom, Z. (2010). Comparison of fatty acids, vitamin E and physicochemical properties of *Canarium odontophyllum* Miq.(dabai), olive and palm oils. *Journal of Food Composition and Analysis, 23*(8): 772-776.

Balogun, A. M. and Fetuga, B. L. (1988). Tannin, phytin and oxalate contents of some wild under-utilised crop seeds in Nigeria. *Food Chemistry, 30*(1): 37-43.

Bamigboye, T., Kayode, J. and Obembe, M. (2016). Effects of Rooting Hormones on the Juvenile Stem Cuttings of *Dioscoreophyllum cumminssii* (Stapf) Diels (Serendipity Berry). *International Journal of Research in Agricultural Sciences, 3*(2): 2348-3997.

Bamigboye, T. O. and Kayode, J. (2016). Effects of seed pre-treatments on the germination of *Dioscoreophyllum cumminsii. International Journal of Biological Research.* 4.138.10.14419/ijbr.v.4i2.6454

Bamigboye, T. O., Kayode, J. and Ayeni, M. J. (2016). The effect of seed size on the germination of *Dioscoreophyllum cumminsii* (Stapf). *New York Science Journal,* 9(5): 1-3.

Bamigboye, T. O., Kayode, J. and Ayeni, M. J. (2016). Effects of Different Temperatures and Duration of Storage on the Viability of *Dioscoreophyllum cumminsii*. *Journal of Biotechnological Research, 1*(2): 76-80.

Caballe, G. (1994). Ramet proliferation by longitudinal splitting in the Gabonese rainforest liana *Dalhousiea africana* S. Moore (Papilionaceae). *Biotropica*, 26 (3) : 266-275.

Cagan, R. H. (1973). Chemostimulatory protein: a new type of taste stimulus. *Science, 181*(4094): 32-35.

Cagan, R. H., Kare, M. R. and Morris, J. A. (1976). Monellin, a sweet polypeptide derived from fruit of *Dioscoreophyllum cumminsii*. United State Patents, US19750610677.05 September.

Chung, K.T., Wong, T. Y., Wei, C.I., Huang, Y.M. W. and Lin, Y. (1998). Tannins and human health: a review. *Critical Reviews in Food Science and Nutrition, 38*(6): 421-464.

Dauda, A., Abiodun, O., Maiyaki, T. and Kayode, R. (2017). Microbiological evaluation of watermelon juice treated with serendipity berry (*Dioscoreophyllum cumminsii)* extract. *Croatian Journal of Food Science and Technology, 9*(1): 19-24.

Debnath, B., Singh, W. S., Das, M., Goswami, S., Singh, M. K., Maiti, D. and Manna, K. (2018). Role of plant alkaloids on human health: A review of biological activities. *Materials Today Chemistry, 9:*56-72.

Department of Agriculture and Forestry (1995). *Country Report to the FAO International Technical Conference on Plant Genetic Resources*. Leizpig, Germany, 17-23 June, 1995 Retrieved from Freetown:

Eghianruwa, K. I., Oridupa, O. A. and Saba, A. B. (2016). Medicinal Plants Used for Management of Hypertension in Nigeria. *Annual Research and Review in Biology*, 11(3):1-10.

Faus, I. (2000). Recent developments in the characterisation and biotechnological production of sweet-tasting proteins. *Applied Microbiology and Biotechnology, 53*(2): 145-151.

Ford, J. D. and Pearce, T. (2010). What we know, do not know and need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review. *Environmental Research Letters, 5*(1): 014008. DOI: 10.1088/1748-9326/5/1/014008.

Furuya, T., Yoshikawa, T. and Kiyohara, H. (1983). Alkaloid production in cultured cells of *Dioscoreophyllum cumminsii*. *Phytochemistry, 22*(7): 1671-1673.

Gbile, Z. and Adesina, S. (1987). Nigerian flora and its pharmaceutical potential. *Journal of Ethnopharmacology, 19*(1): 1-16.

Hladik, A., Bahuchet, S., Ducatillion, C. and Hladik, C. M. (1984). Les plantes à tubercules de la forêt dense d'Afrique Centrale. *Revue d'écologie*, 39 (3): 249-290

Hladik, C. M. and Hladik, A. (1990). Food resources of the rain forest. In: S. C. M. Hladik and B. I. D. Garine (Eds.). *Food and Nutrition in the African Rain Forest*. UNESCO, Paris, pp.14-17, 1990. hal-00578704.

Holloway, H. (1977). Seed propagation of *Dioscoreophyllum cumminsii,* source of an intense natural sweetener. *Economic Botany, 31*(1): 47-50.

Hopkins, B. and Jenkin, R. N. (1962). Vegetation of the Olokemeji Forest Reserve, Nigeria: I. General Features of the Reserve and the Research Sites. *British Ecological Society, 50*(3): 20.

Hyde, M. A., Wursten, B. T., Ballings, P. and Coates, P. M. (2018,). Flora of Zimbabwe: Species information: *Dioscoreophyllum cuminsii* (Stapf) Diels var. Leptotrichos *http://www.zimbabweflora.co.zw/speciesdata/species.php?species_id=123750,retrieved.*

Ibitoye, O., Ghali, U., Adekunle, J., Uwazie, J. and Ajiboye, T. (2017). Antidyslipidemic, anti-inflammatory and antioxidant activities of aqueous leaf extract of *Dioscoreophyllum cumminsii* (Stapf) Diels in high-fat

diet-fed rats. *Evidence-Based Complementary and Alternative Medicine, 2017*: eCAM, 217,8128125. https:/doi.org/10.1155/2017/8128125.

Ichikawa, M. (1991). *A Flora Catalog of Useful Plants of Tropical Africa: Forest areas*. Centre for African Area Studies, Kyoto University.

Ikram, E. H. K., Eng, K. H., Jalil, A. M. M., Ismail, A., Idris, S., Azlan, A. and Mokhtar, R. A. M. (2009). Antioxidant capacity and total phenolic content of Malaysian underutilised fruits. *Journal of Food Composition and Analysis, 22*(5): 388-393.

Inglett, G. E. and May, J. F. (1968). Tropical plants with unusual taste properties. *Economic Botany, 22*(4):326-331.

Inglett, G. E. and May, J. F. (1969). Serendipity Berries–Source of a new intense sweetener. *Journal of Food Science, 34*(5): 408-411. doi:10.1111/j.1365-2621.1969.tb12791.x

Inglett, G. E. (1976). A history of sweeteners-natural and synthetic. *Journal of Toxicology and Environmental Health, 2*(1): 207-214. doi:10.1080/15287397609529427

Isichei, A. O. (1995). Omo Biosphere reserves, current status, utilisation of biological resources and sustainable management (Nigeria). In UNESCO (Ed.), *South-South Cooperation Programme on Environmentally Sound Socio-Economic Development in the Humid Tropics*: Working paper No. 11, 1995 UNESCO (South-South Cooperation Programme), Paris France.

Jimoh, S. (2005). *Non-timber forest products in phytomedicine and culinary uses*. Springer Link pp 209-224.

Kant, R. (2005). Sweet proteins–potential replacement for artificial low calorie sweeteners. *Nutrition Journal, 4*(1): 4-5, https//doi.org/10.1186/1475-2891

Kayode, J. and Bamigboye, T. O. (2016). Assessment of on-farm cultivation and conservation of indigenous fruit species in Ekiti State, Nigeria. *Journal of Agriculture and Ecology Research International*, 7(3): 1-6.

Kayode, J., Bamigboye, T. O., Ayeni, M. J. and Obembe, O. M. (2016). The assessment of the indigenous knowledge of the rural farmers in Ekiti State, Nigeria on *Dioscoreophyllum cumminsii. Journal of Global Ecology and Environment, 5*(1): 33-37.

Kayode, R. M. O., Abiodun, O. A., Akeem, S. A. and Oyeneye, H. O. (2020). Influence of partial substitution of sugar with serendipity berry (*Dioscoreophyllum cumminsii*) extract on the quality attributes and shelf-life of wheat bread. *Journal of Microbiology, Biotechnology and Food Sciences, 9*(5): 115-120.

Khoo, H. E., Azlan, A., Tang, S. T. and Lim, S. M. (2017). Anthocyanidins and anthocyanins: coloured pigments as food, pharmaceutical ingredients and the potential health benefits. *Food and Nutrition Research,* Vol. 61 Retrieved from https://foodandnutritionresearch.net/index.php/fnr/article/view/1257

Kimpouni, V. (2001). Contribution aux études ethnobotaniques et floristiques de la forêt de Lossi (RP Congo): les plantes de cueillette à usage alimentaire. *Systematics and Geography of Plants*, 71 (2): 679-686.

Kohmura, M., Nio, N. and Ariyoshi, Y. (1990). Complete amino acid sequence of the sweet protein, monellin. *Agricultural and Biological Chemistry, 54*(9): 2219-2224.

Kohmura, M., Nio, N., and Ariyoshi, Y. (1991). Solid-phase synthesis of crystalline monellin, a sweet protein. *Agricultural and Biological Chemistry, 55*(2): 539-545.

Komolafe, E., Timilehin, O. O., Oke, O., Odeleye, A. and Olatunji, O. (2017). Floristic Composition and Structural Diversity of Ibodi Monkey Forest, Ibodi, Southwestern Nigeria. *Pakistan Journal of Botany,* 49: 1359-1371.

Koons, J. L. (1976). Tissue culture of *Dioscoreophyllum cumminsii.* semantischolar.org

Kulik, K. and Waszkiewicz-Robak, B. (2019). Sweet Nutraceuticals in Plants. *Polish Journal of Applied Sciences, 4*(2): 65-71.

Lapolla, A., Seraglia, R., Molin, L., Williams, K., Cosma, C., Reitano, R. and Traldi, P. (2009). Low molecular weight proteins in urines from healthy subjects as well as diabetic, nephropathic and diabetic-nephropathic patients: a MALDI study. *Journal of Mass Spectrometry, 44*(3): 419-425.

Leipzig, Germany (1996). Country Report to the FAO International Technical Conference on Plant Genetic Resources by Department of Agriculture and Forestry, Freetown, 17-23rd June, 1996.

Leone, S., Pica, A. and Merlino, A. (2016). Sweeter and stronger: enhancing sweetness and stability of the single chain monellin MNEI through molecular design. *Scientific Report,* 6, 34045 (2016). https://doi.org/10.1038/srep34045

Malleson, R. (1999). Community management of nonwood forest resources: a case study from the Korup Forest, Cameroon. *The non-wood forest products of Central Africa: current research issues and prospects for conservation and development. Rome: Food and Agriculture Organisation*, 117-122.

Miele, N. A., Cabisidan, E. K., Blaiotta, G., Leone, S., Masi, P., Di Monaco, R. and Cavella, S. (2017). Rheological and sensory performance of a protein-based sweetener (MNEI), sucrose and aspartame in yoghurt. *Journal of Dairy Science, 100*(12): 9539-9550.

Mizukoshi, T., Kohmura, M., Suzuki, E. I. and Ariyoshi, Y. (1997). Structure and dynamic studies by NMR of the potent sweet protein monellin and a non-sweet analog: Evidence on the importance of residue AspB7 for sweet taste. *FEBS LETTERS, 413*(3): 409-416.

Morris, J. A. and Cagan, R. H. (1972). Purification of monellin, the sweet principle of *Dioscoreophyllum cumminsii*. *Biochimica et Biophysica Acta (BBA)-General Subjects, 261*(1): 114-122.

Morris, J. A., Martenson, R., Deibler, G. and Cagan, R. H. (1973). Characterisation of monellin, a protein that tastes sweet. *Journal of Biological Chemistry, 248*(2): 534-539.

Nwadinigwe, A. O. (2000). Pharmacognostical comparison of *Dioscoreophyllum cumminsii* and *Dioscoreophyllum volkensii. Pharmaceutical Biology, 38*(5): 330-339.

Obioh, G. I., Illoh, H. C. and Isichei, A. O. (2006). Utilisation of Medicinal Plants and Its Implications for Conservation in Omo Biosphere Reserve, Nigeria. Retrieved from https://ir.oauife.edu.ng/handle/123456789/9

Obioh, G. I. and Isichei, A. O. (2006). Species Profiles of Some Useful Plants in Omo Biosphere Reserve in Nigeria. Enviriontropica, 3 (1&2): 16-34.

Obioh, G. I. B. and Isichei, A. O. (2007). A population viability analysis of serendipity berry (Dioscoreophyllum cumminsii) in a semi-deciduous forest in Nigeria. *Ecological Modelling, 201*(3-4): 558-562. doi:10.1016/j.ecolmodel.2006.10.007

Ojo, A., Enujiugha, V. N., Ayo-Omogie, H. N. and Abiodun, O. A. (2017). Comparative study on the effect of *Thaumatococcus daniellii* (Benn) Benth sweetener on the physicochemical and sensory properties of Sorghum-based Kunun-zaki Drink. *Journal of Appllied Science and Environmental Management, 21*(6): 1073-1078.

Okafor, J. and Lamb, A. (1994). *Fruit trees: diversity and conservation strategies.* Paper presented at the Institute for Terrestrial Ecology Symposium. pp 38-41.

Oloyede, H., Bello, T., Ajiboye, T. and Salawu, M. (2015). Antidiabetic and antidyslipidemic activities of aqueous leaf extract of *Dioscoreophyllum cumminsii* (Stapf) Diels in alloxan-induced diabetic rats. *Journal of Ethnopharmacology, 166*: 313-322.

Oselebe, H., Ene-Obong, E. and Nwankiti, O. (2004). The biology of *Dioscoreophyllum cumminsii* (Stapf) Diels. *Nigerian Journal of Botany, 17:* 17-28.

Oselebe, H. and Nwankiti, O. (2007). Cytology of root tips of *Dioscoreophyllum cumminsii* (Stapf) Diel. *Agro-Science, 4*(1): 43-45.

Oselebe, H. O. and Ene-Obong, E. (2007). Organogenesis in *Dioscoreophyllum cumminsii* (Stapf) Diels. *Tropicultura, 25*(1): 37-43.

Ramstad, E., Powell, J. W., Wilson, B. J., Adesina, S. K., Higginbotham, J. D. and Harborne, J. B. (1975). The bitter principles of *Dioscoreophyllum cumminsii* seed. *Phytochemistry, 14*(12): 2719-2720.

Rotimi, S., Rotimi, O., Omotosho, E., Iyanda-Joel, W. and Chinedu, S. (2014). In silico Assessment of Antihypertensive Potential of Sweet Proteins (LB542). *The FASEB Journal, 28*, LB542. DOI: https://doi.org/10.1096/fasebj.28.1_suppliment.16542

Sardesai, V. M. and Waldshan, T. H. (1991). Natural and synthetic intense sweeteners. *The Journal of Nutritional Biochemistry, 2*(5): 236-244.

Shittu, H. (2015). *In Vitro* Morphogenetic Responses of *Dioscoreophyllum cumminsii* (Stapf) Diels Seed Explant. *International Journal, 1*(1): 1-6.

Spencer, G. and Earle, F. (1972). The abundance of cis-5-octadecenoic acid in *Dioscoreophyllum cumminsii* seed oil. *Lipids, 7*(6): 435-436.

Summerfield, R., Most, B. and Boxall, M. (1977). Tropical Plants with Sweetening Properties: Physiological and Agronomic Problems of Protected Cropping I. *Dioscoreophyllum cumminsii. Economic Botany, 31*(3): 331-339.

Świąder, K., Wegner, K., Piotrowska, A., Fa-Jui, T. and Sadowska, A. (2019). Plants as a source of natural high-intensity sweeteners: a review. *Journal of Applied Botany and Food Quality, 92:* 160-171.

Tapsoba, P. K., Aoudji, A. K., Kabore, M., Kestemont, M. P., Legay, C. and Achigan-Dako, E. G. (2020). Sociotechnical Context and Agroecological Transition for Smallholder Farms in Benin and Burkina Faso. *Agronomy, 10*(9): 1447. DOI: https://doi.org/10.3390/agronomy/0091447

Tee, E., Young, S., Ho, S. and Mizura, S. S. (1988). Determination of vitamin C in fresh fruits and vegetables using the dye-titration and microfluorometric methods. *Pertanika, 11*(1): 39-44.

USDA (2016). Natural resources conservation service. *United States Department of Agriculture*.

van der Wel, H. (1972). Isolation and characterization of the sweet principle from *Dioscoreophyllum cumminsii* (Stapf) Diels. *FEBS LETTERS, 21*(1):88-90.

van der Wel, and Loeve, K. (1973). Characterisation of sweet-tasting protein from *Dioscoreophyllum cumminsii* (Stapf) Diels. 2. *FEBS LETTERS, 29*(2): 181-184.

van der Wel, H., Brouwer, J. and de Iongh, H. (1974). Sweet-tasting and sweetness-inducing proteins from fruits of African plants. In: *Natürliche und Synthetische Zusatzstoffe in der Nahrung des Menschen* (pp. 154-161): Springer.

Vincent, J. L., Hall, J. B. and Vincent, J. (2012). *Encyclopedia of Intensive Care Medicine*. (Vincent J. L. and Hall J. B. Eds). Springer.

Vines, G. (1992). Sweet serendipity. *New Scientist*.

Wiebe, N., Padwal, R., Field, C., Marks, S., Jacobs, R. and Tonelli, M. (2011). A systematic review on the effect of sweeteners on glycemic response and clinically relevant outcomes. *BMC Medicine, 9*(1): 123. DOI: 10.1186/1741-7015-9-123

Witty, M. (1998). New technologies for taste-modifying proteins. *Trends in Food Science and Technology, 9*(7): 275-280.

Yang, Y., Seyler, B. C., Feng, M. and Tang, Y. (2020). A systematic review of scientific research focused on farmers in agricultural adaptation to climate change (2008-2017). *bioRxiv*.

Yusuf Dogara, J. and Abd Hamid, H. (2020). A Systematic Literature Review on Cash Crop Production. *Asian Proceedings of Social Sciences*, *6*(1): 75–79. https://doi.org/10.31580/apss.v6i1.1256.