Dioscorea alata

Scientific Name

***Dioscorea alata* L.**

Synonyms

Dioscorea alata var. *globosa* (Roxb.) Prain, *Dioscorea alata* var. *purpurea* (Roxb.) A. Pouchet, *Dioscorea alata* var. *tarri* Prain & Burkill, *Dioscorea alata* var. *vera* Prain & Burkill, *Dioscorea atropurpurea* Roxb., *Dioscorea colocasiifolia* Pax, *Dioscorea eburina* Lour., *Dioscorea eburnea* Lour., *Dioscorea globosa* Roxb., *Dioscorea javanica* Queva, *Dioscorea purpurea* Roxb., *Dioscorea rubella* Roxb., *Dioscorea sapinii* De Wild., *Dioscorea sapinii* De Wild., *Dioscorea vulgaris* Miq., *Elephantodon eburnea* (Lour.) Salisb., *Polynome alata* (L.) Salisb.

Family

Dioscoreaceae

Common/English Names

Asiatic yam, Greater Yam, Guyana Arrowroot, Manila Yam, Purple Yam, Ten Months Yam, Water Yam, Winged Yam

Vernacular Names

Arabic: Batata Maee;
Argentina: Batatilla;
Burmese: Myauk Uu Ni, Taw Myauk Uu, Mautinsong, Myauk-U, Taw-Myauk-U;
Cambodia: Damlong Dong, Damlong Chime Moan, Dmalong Phluk;
Cameroon: Joma;
Chinese: Man Bo, Shen Shu, Tai Shue, Da Shu;
Chuuk: Eep, Kááp;
Cuba: Ñame Peludo;
Czech: Jam Křídlatý;
Danish: Jams, Yam;
Estonian: Vesijamss;
Ethiopia: Boyye;
Fiji: Uvi, 'Uhi, The Iam;
French: Igname De Chine, Pacala, Grande Igname, Igname Ailee;
Gambia: Nyamba Ba;
German: Geflügelter Yam, Yamswurzel, Wasseryam Wasser, Yamswurzel;
Ghana: Adzugo, Droboli, Gaga;
Guam: Dago;
Guinea: Gbara-Gué;
Hawaiian: Uhi, Puku'i;
India: Bengo Nari, Chupri Alu, Kham Alu (Bengali), Chupri Alu, Kada Kanda, Kada-Kanda, Khamalu, Ratalu (Hindi), Dandaanu, Dappa Genasu, Hennu Genasu, Mudigenasu, Noorele Genasu, Shigenasu, Thoona Genasu, Tuna Genasu, Tuna-Genasu, Tunakereng

T.K. Lim, *Edible Medicinal and Non-Medicinal Plants: Volume 10, Modified Stems, Roots, Bulbs*,
DOI 10.1007/978-94-017-7276-1_9

(Kannada), Kaccil, Kacil, Katsjikelengu, Katsjil-Kelengu, Kavattu, Peruvallikkilannu, Peruvallikkizhannu (Malayalam), Chinem, Chipari-Aalu, Goradu, Khanphal, Pindaalu (Marathi), Desia Alu, Kambo Alu, Kham Alu (Oriya), Alukam, Dandalu, Kandaka, Kasthaluka, Raktaluka (Sanskrit), Cirakavalli, Iyamkilanku, Kappa-Kavali, Kappan Kaccil, Kayavalli, Kayvalli, Mullu Valli, Mullu-Valli, Perumvallikilanku, Siru-Valli, Siruvalli, Vettilai-Valli (Tamil), Daeshavaali Pendalam, Dukka Pendalam, Gadimidondapendalam, Gadimidondapendalamu, Gadinidonda Pendalamu, Guna Pendalamu, Gunapendalamu, Kavili-Gadda, Naarathega, Nelavupandalum, Niluvapendalamu, Niluvu Pendalam, Niluvupendalam, Pendalam, Pendalamu, Yadduthoka Dumpa (Telugu);

Indonesia: Uwi, Uwi Klapa, Uwi Legi, Uwi Manis (Javanese), Ubi (Madurese), Ubi, Ubi Kalapa, Ubi Manis (Malay), Huwi, Huwi Kalapa, Huwi Tehang (Sundanese);

Italian: Igname;

Japanese: Daisho, Daijo, Daijyo;

Kosrae: Muta;

Laotian: Man Man Hliemx, Houo;

Malaysia: Pokok Ubi, Ubi Tiyang, Ubi Kipas, Ubi Kemali;

Nepalese: Ghara Tarul Kukur Tarul;

Nigeria: Agadaga, Agbo, Sakata, and Mbala, Nvula (Igbo);

Papua New Guinea: Yam Tru, Nyaing, Kolpur;

Philippines: Knamap, Kinampai Ubi (Bisaya), Ubi (Iloko) Ubi (tagalog);

Pohnpei: Kehp;

Portuguese: Cará De Angola, Cará Branco, Inhame Bravo, Inhame Da India, Cará Da Terra;

Russian: Iams Krylatyi, Dioscoreia krylataia, Iams Belyi;

Satawal: Wot Omalu;

Spanish: Cabeza De Negro, Cará Branco, Ñame Blanco, Ñame Blanco Grande, Ñame Blanco De Agua, Ñame Branco, Ñame De Agua, Ñame Grande, Ñame De Gua, Tabena;

Sri Lanka: Hingurala, Raja-Ala

Tahitian: Uhi;

Thailand: Man-Sao (Central Thailand), Noi (Chiang Mai), Man Bak Hep (Don Daeng), Man liam (Northern Thailand), Man-Thu;

Ulithi: Ioth;

Venezuela: Ñame Asiatico;

Vietnamese: Cậm Kệnh, Cň Sa, Củ Cái, Củ Cầm, Củ Canh, Củ đỏ, Củ lỗ, Củ Mỡ, Củ Ngŕ, Củ Nhŕ, Củ Tía, Củ Vạc, Khoai Bướu, Khoai Long, Khoai Mỡ, Khoai Ngŕ, Khoai Ngọt, Khoai Tía, Khoai Trắng, Khoai Trút, Khoai Vạc, Mắn Hăm;

Yapese: Du'og

Origin/Distribution

Dioscorea alata is native to Southeast Asia and has been distributed throughout the tropics worldwide. It is the most important yam for Southeast Asia and is also a staple food crop in New Guinea and is widely grown in tropical Asia. In Africa, it is second to white yam (*Dioscorea rotunda*) in popularity.

Agroecology

Greater yam thrives in the warm, humid tropics with annual precipitation of 1000–15,000 mm per year. It flourishes in the lowlands to an elevation of 2500 m. It tolerates soils of low fertility but is sensitive to aluminium toxicity.

Marcos et al. (2009) found that small changes in photoperiod and temperature, very usual in the tropics, had a big effect on the tested *D. alata* yam varieties. Emergence to tuber initiation was mainly affected by photoperiod and to a lesser extent by temperature. Both factors also affected the duration of tuber initiation to harvest but their effects were less noticeable.

Edible Plant Parts and Uses

The starchy tubers are eaten boiled, roasted, fried or pounded and eaten with various sauces (Burkill 1966; Ochse and van den Brink 1980; Udensi et al. 2008; South Pacific Commission 1990). Yams are eaten with other meat, shellfish, vegetables and green leaves. Yams can be mashed and added to other fruits and green leaves, fish and are good food for babies. Tubers of certain cultivars are suitable for production of chips and flakes. Purple-flesh varieties are used for ice cream, cakes and other confectioneries. Water yam can be processed into flour and reconstituted into *fufu* dough in Africa (Udensi et al. 2008). Young leaves are eaten in Congo. Yam can be converted into a meal and used as a substitute for wheat flour, although rarely used for this (Burkill 1966). In Indonesia, the tubers are often eaten cooked as a delicacy, although they may also be eaten raw (Ochse and van den Brink 1980). Tubers are cut into slices and fried in oil. Thinly cut slices of the yam dried in the sun can be made into *kripik* (chips). The tubers are also used for *sayur*. In Odisha, India the tubers, bulbils and leaves are consumed as vegetables (Kumar et al. 2012).

Some popular yam dishes in the South Pacific (South Pacific Commission 1990) are:

(a) Yam salad—cooked yam, chopped onions, salad cream lettuce, tomatoes and hard-boiled eggs
(b) Boiled yam in coconut cream—yam pieces, dilute coconut cream and aibika (*Abelmoschus manihot*) leaves
(c) Stuffed yam with cheese
(d) Small yam, cooked fish, chopped tomato, coconut milk or cream with grated cheese
(e) Yam and vegetable curry—chopped yam, sliced onion, chopped chillies, curry powder, cloves garlic crushed, chopped vegetables (e.g. beans, tomato, pumpkin carrots),
(f) Baked yam and pawpaw savoury—chopped yams, coconut cream, ripe pawpaw, onion, wrap in banana leaf and bake or steam
(g) Yam delicious—yam pieces mix with eggs, chopped onion, seasoning and fry
(h) Yam fritters
(i) Grated yams raw mixed with eggs, flour, baking powder and fry in oil.

Studies in Puerto Rico showed that *D. alata* yams can be used to produce instant flakes (Rodríguez-Sosa et al. 1972). Addition of 0–2 % of okra powder to reconstituted *D. alata* yam flake reduced the sensory impairments of *ojojo*—a fried yam (*D. alata*) snack, which compared favourably with those made from raw yam (*D. alata*) in terms of colour, flavour and taste (Shittu and Olaitan 2014).

Dioscorea alata yams can be used as a fat replacer in the manufacture of Chinese sausages up to a level of 5 %, resulting in the production of Chinese sausages with about 22 % less fat content (Tan et al. 2007). The products with 5 % yams added had no significant difference in colour, flavour, hardness, juiciness and overall acceptability when comparing with the control. Results of studies suggested that micronization by ball milling treatments could improve functional properties of the fibre components of micronized peels of yam (*Dioscorea alata*), taro (*Colocasia esculenta*) and sweet potato (*Ipomoea batatas*), thus providing a good source of dietary fibre in food applications (Huang et al. 2010). The micronization treatments decreased the bulk density but increased the solubility and water-holding capacities of the micronized peels.

Botany

A climbing, perennial herbaceous unisexual–dioecious vine. Tubers are subterranean, large, variable in shape, oblate, globose, conical, cylindric or branched; externally, the epidermis is corky brown or purplish and the internal flesh colour is white or purplish (Plates 1, 2, and 3). Stem twining to right, glabrous, ridged, with four narrow, membranous wings. Bulblets present at leaf axils, small and variable in shape subglobose to narrowly ovoid. Leaves alternate basally on stem, distally opposite on stem, on 9–18 cm long petioles, simple; petiole green or purplish red, 4–15 cm; leaf blade green or purplish red, ovate, 6–20×4–13 cm, papery, glabrous, with 7–9 distinct veins, base sagittate to deeply, narrowly cordate, apex shortly acuminate or caudate (Plate 4). Inflorescences glabrous. Male spikes solitary or a few together, 1.54 cm, sometimes forming an axillary terminal panicle from axils of bracts; rachis distinctly zigzag. Male flowers: outer perianth lobes broadly ovate, 1.52 mm, pale yellow to greenish yellow; fertile stamens 6. Female spikes solitary or 2 or 3 together, lax and unbranched. Female flowers: staminodes 6; perianth delate-subglobose, 5 mm across, yellow;

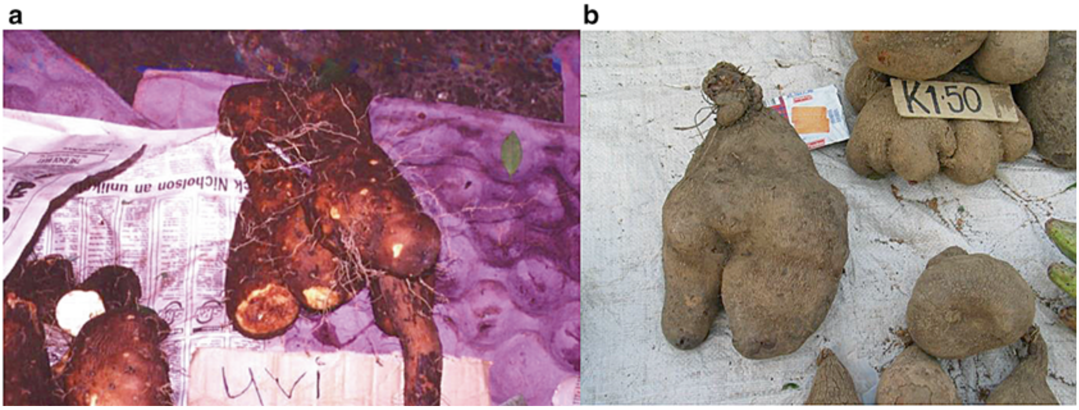

Plate 1 (**a**, **b**) variously and irregularly shaped, massive, white-fleshed tubers

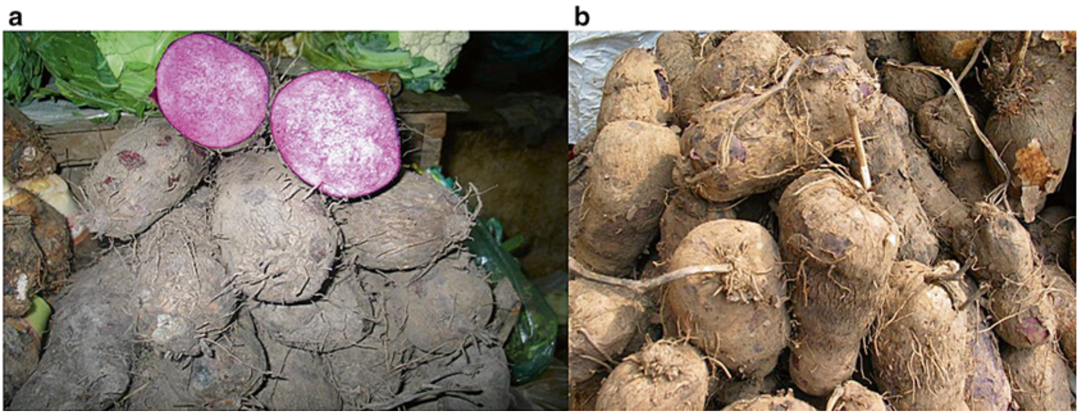

Plate 2 (**a**, **b**) variously and irregularly shaped, massive, purple-fleshed tubers

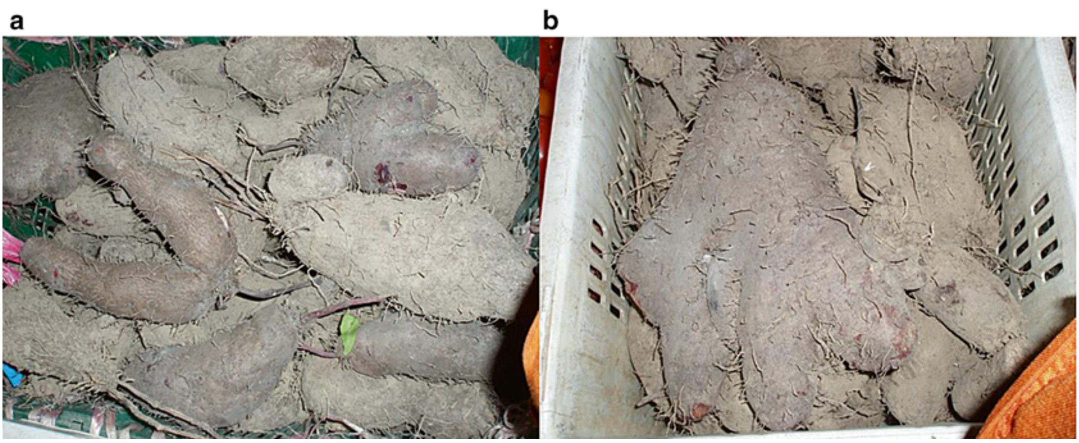

Plate 3 (**a**, **b**) variously and irregularly shaped, massive, purple- fleshed tubers

Plate 4 Narrowly cordate leaves with 7–9 veins

ovary glabrous. Capsule not reflexed, oblate, sometimes obcordate, 15–25 mm; wings 1.2–2.2 cm wide. Seeds winged all round.

Nutritive/Medicinal Properties

Tuber Nutrients/Phytochemicals

Nutrient composition of the raw tuber per 100 g edible portion was reported as: energy 87 cal, moisture 76.4 g, protein 1.9 g, fat 0.2 g, total carbohydrates 19.9 g, dietary fibre 0.6 g, ash 1.6 g, Ca 38 mg, P 28 mg, Fe 1.1 mg, Na 12 mg, K 397 mg, β-carotene equivalent 5 μg, thiamin 0.10 mg, riboflavin 0.04 mg, niacin 0.5 mg, and ascorbic acid 6 mg (Leung et al. 1972). Brand et al. (1993) reported the proximate value nutrient composition per 100 g edible portion of water yam as follows: water 72.4 g, energy 86 KJ, protein 1.4 g, fat 0.02 g, ash 0.9 g, available carbohydrate 0.0 g, total dietary fibre 6.8 g, minerals—Ca 15 mg, Fe 0.8 mg, Mg 15 mg, K 256 mg, Na 9 g, Zn 0.33 mg, Cu 0.29 mg, vitamins—vitamin C 62 mg, thiamine 0.02 mg, riboflavin 0.2 mg, niacin 0.2 mg. Shajeela et al. (2011) reported the following proximate nutrient composition of *D. alata* tubers (g/100 g): moisture 82.91 %, crude protein 7.57 g, crude lipid 5.28 g, crude fibre 3.96 g, ash 3.56 g, starch 49.13 g, NFE (nitrogen free extract) 79.63 g, energy 1655.30 kJ/100 g DM, niacin 36.20 mg, ascorbic acid 74.56 mg, and minerals mg/100 g Na 44.56 mg, K 786.30 mg, Ca 448.36 mg, Mg 656.31 mg, P 140.14 mg, Zn 2.26 mg, Mn 6.36 mg, Fe 34.30 mg and Cu 11.20 mg. The anti-nutritional factors were per 100 g: total free phenolics 0.68 g, tannins 0.41 g, hydrogen cyanide 0.17 mg, total oxalate 0.58, amylase inhibitor 6.21 AIU/mg soluble starch, and trypsin inhibitor 3.65 TIU/mg protein (Shajeela et al. 2011). The in-vitro protein digestibility was 5.23 % and the in-vitro starch digestibility was 39.40 %.

The total dietary fibre (TDF) content of 20 varieties of *Dioscorea alata* varied widely ranging from 4.10 to 11.00 % (Faustina Dufie et al. 2013). The dry matter composition ranged from 19.10 to 33.80 % and amylose was from 27.90 to 32.30 %. Mineral contents (mg/kg) were from 10.10 to 17.60 for Zn, 10,550 to 20,100 for K, 83 to 131 for Na, 260 to 535 for Ca and 390 to 595 for Mg. Physico-chemical characteristics of tubers of 48 *D. alata* accessions from Vanuatu in terms of mean and range were found respectively as follows: dry matter 23.44 % (13.64–31.42 %), starch 73.1 % (63.6–78.6 %), amylase 17.2 % (13.4–20.7 %), amylase/starch ratio 0.17 (0.13–0.21), minerals 3.3 % (2.5–4.9 %), lipids 0.3 % (0.2–0.5 %), proteins 11.95 % (8.8–17 %), sugars 1.85 % (0.6–5.71 %), and mean gelatinization temperature 74.9 °C to 84.2 °C (Lebot et al. 2006). The TDF content of 20 varieties of

Dioscorea alata varied widely ranging from 4.10 to 11 % (Dufie et al. 2013). The dry matter composition ranged from 19.10 to 33.80 % and amylose was from 27.90 to 32.30 %. Mineral contents (mg/kg) of the varieties were from 10.10 to 17.60 for Zn, 10,550 to 20,100 for K, 83 to 131 for Na, 260 to 535 for Ca, and 390 to 595 for Mg. Chemical composition of 18 *D. alata* varieties tubers were: moisture 56.47–79.31 %, mean 69.07; dry matter 20.7–43.53 %, mean 30.93 %; protein 5.07–.05 %, mean 6.51 %; sugar 2.43–6.91 %, mean 4.28 % (Wireko-Manu et al. 2011).

Studies conducted by Udensi et al. (2008) reported tubers of *D. alata* varieties contained 2.25–3.155 ash, 5.69–8.31 % crude protein, 81.6–87.6 % carbohydrates, 0.75–1.13 % crude fibre and 361-01-385.33 Kcal/100 g energy. The mineral contents mg/100 g ranged from 240 to 400 mg; with 240–400 mg K, 190–380 mg Na, 100–340 mg P, 20.04–80.16 mg Ca and 20.22–35.20 mg Mg. Vitamin C content of the yam tubers ranged from 16.72 to 35.20 mg/100 g, fresh weight. Functional property levels in the yam tubers were found to be in the range of 0.64–0.76 g/cm^3 (bulk density); 2.90–3.65 g/g (water absorption capacity); 27.0–3.5 s (wettability) and 30–50 % w/v (gelation capacity). Huang et al. (2007) found tubers of four *D. alata* cultivars had a substantial amount of protein 10.4–13.0 g/100 g (dry basis (db)) at time of harvest (day 260 post-emergence) when compared with other root and tuber crops. Starch content of the yam tubers increased as growth progressed and remained in the range of 70.5–85.3 g/100 g (db) during their growth period. The activity of yam-contained polyphenol oxidase (PPO) decreased markedly over the early period of harvest (day 155–225 post-emergence), and subsequently decreased only slightly as growth progressed to harvest. In contrast, the activity of α-amylase and dioscorin content of yam tuber increased significantly over the growth period for all cultivars. All the yam cultivars contained substantial levels of essential amino acids, all of which were superior to the FAO reference pattern for such amino acids except for sulphur-containing amino acids and lysine contents.

Wanasundera and Ravindran (1994) reported the following nutrient composition of tubers of several *D. alata* cultivars (mean values on percent DW basis): moisture 72.7 %, crude protein 7.4 %, crude fat 1.0 %, crude fibre 1.5 %, ash 3.4 %, starch 79.5 %, soluble sugars 1.2 %, total energy 365 Kcal/100 g; minerals (mg/100 g DM) K 1620 mg, Na 66.6 mg, P163 mg, Ca 68.6 mg, Mg 69.6 mg, Cu 6.6 mg, Fe 10.4 mg, Mn 3.6 mg, and Zn 3.9 mg. They also reported the presence of antinutrients (DM basis): low phytic acid 131 mg/100 g (range 58.6–198 mg/100 g), phytin as % of total phytin 383 %, water-soluble oxalates and total oxalates 334 mg and 585 mg/100 g. Phytic acid contributed 9.7–35.9 % of total phytin. They found that crude fat, crude fibre, starch and total sugar contents of tubers were unaffected by cooking but crude protein tended to decrease with cooking but not significantly (Wanasundera and Ravindran 1992). Water-soluble minerals leached out during boiling, thus causing a reduction in the ash content of boiled tubers. All cooking methods lowered the vitamin C content of the tubers. Phytate contents were unaffected, whereas total oxalate contents were significantly lowered by the cooking methods employed. The loss of oxalates was greater with boiling (40–50 %) compared to steaming (20–25 %) and baking (12–15 %). Ezeocha and Ojimelukwe (2012) found that the crude protein contents (10.27 %), ash (2.93 %) and lipid (0.15 %) were significantly lowered in the boiled tubers while the carbohydrate (76.57 %) significantly increased in the boiled tubers. The antinutrients; alkaloids (2.77 %), saponins (2.71 %), flavonoids (1.38 %) and tannins (0.21 %) were significantly reduced in the boiled tubers. They concluded that boiling had both positive and negative effect on water yam. A cooking time of between 30 and 60 min at 100 °C was recommended for *D. alata*.

Although yam proteins from *D. alata* and *D. alata* var. *purpurea* consisted of similar amino acid residues, they still exhibited significant differences in conformational arrangement (Liao et al. 2004). The secondary structure of *D. alata* was mainly an alpha-helix, while *D. alata* var. *purpurea* was mostly in antiparallel beta-sheets.

FT-Raman spectroscopy directly proved the existence of S-S in yam proteins, implying that oligomer formation in yam proteins might be due to disulfide linking of dioscorin (32 kDa).

Akissoe et al. (2005) found that polyphenoloxidase activity was 50 % higher in nonprocessed freeze-dried Florido (*Dioscorea alata*) than in nonprocessed freeze-dried Deba (*Dioscorea rotundata*). Polyphenoloxidase activity decreased progressively during blanching. Forty-five percent of polyphenoloxidase activity remained after 50 min of blanching at 60 or 65 °C, whereas the peroxidase activity declined sharply to less than 20 % of the initial activity after 10 min of blanching, whatever the blanching temperature. No anthocyanidins could be detected in nonprocessed freeze-dried yam. Flavanols and cinnamic acid compounds were detected. Catechin was identified as the major flavanol with concentrations ranging from 0.26 to 0.41 μM/g. One cinnamic compound, ferulic acid, was identified and assessed in both yams (0.03–0.04 μM/g). Total phenol, flavanol and cinnamic contents decreased during blanching independently of temperature.

D. alata tuber was reported to contain 0–0.25 % sapogenin (Anzaldo et al. 1956). The recoveries of furostanol and spirostanol glycosides were above 92 % in the three Taiwanese yam cultivars (two *D. alata* and one *D. pseudojaponica*), the contents of furostanol glycosides in the two *D. alata* cultivars were 34.81 and 97.58 μg/g dw, while the contents of spirostanol glycosides were 46 and 79.67 μg/g dw (Yang et al. 2003). The furostanol glycosides were: 26-*O*-β-D-glucopyranosyl-22α-methoxyl-25-(*R*)-furost-5-en-3β,26-diol3-*O*-α-L-rhamnopyranosyl-(1 → 2)-*O*-{[α-L-rhamnopyranosyl-(1 → 4)]-*O*-[β-L-rhamnopyranosyl-(1 → 4)]}-β-D-glucopyranoside; methyl protodioscin and methyl protogracillin. The spirostanol glycosides were 25(*R*)-spirost-5-en-3β-ol 3-*O*-α-L-rhamnopyranosyl-(1 → 2)-*O*-{[α-L-rhamnopyranosyl-(1 → 4)]-*O*-[α-L-rhamnopyranosyl-(1 → 4)]}-β-D-glucopyranoside; dioscin and gracillin. From the tubers, hydro-Q(9) chromene and γ-tocopherol-9, together with three known compounds, RRR-α-tocopherol, coenzyme Q(9) and 1-feruloylglycerol were silated (Cheng et al. 2007).

Two anthocyanins, cyanidin and peonidin 3-gentiobioside acylated with sinapic acid, were isolated from *Dioscorea alata* 'King yam' tuber from Sri Lanka (Shoyama et al. 1990). Three anthocyanins, alatanins A, B and C, were isolated from the tuber of purple yam *Dioscorea alata* (Yoshida et al. 1991b). Alatanin C was found to be an unusually stable monoacyalated anthocyanin in neutral aqueous solutions (Yoshida et al. 1991a). The stability was ascribed to the intramolecular stacking of sinapic acid and to the chiral self-association of anthocyanidin nuclei. The choline contents of Yangmingshan yam (*D. alata*) and Ming-Chien yam (*D. purpurea*) tubers determined using the original AACC method and the modified AACC method through coupling an additional bubble separation procedure, respectively, were 0.77 and 1.78 mg/g solid for *D. alata* and 0.44 and 1.35 mg/g solid for *D. purpurea* (Fu et al. 2005).

D. alata tuber peel was found to have high levels of macro-minerals (Na, K, Ca and P) compared to micro-minerals (Mg, Zn, Fe, Cu and Cr) (Yahaya et al. 2012). The micro-nutrients were found to be generally lower than the dietary mineral requirement for animal feeds. The peel contained 4.59–12.2 % protein, 9.71–41.7 % fibre, 37.5–45.5 % carbohydrate and 0.62–1.86 % lipid. The peels collected during dry season contained higher levels of phytate (2.41–4.18 %), hydrogen cyanide (4.69–5.05 %), soluble oxalate (1.15–1.34 %) and tannin (1.54–2.45 %) than the peels collected during wet season.

Two forms of phosphorylase were purified from *Dioscorea alata* (Oluoha and Ugochukwu 1995). The molecular masses obtained for fractions I and II of *D. alata* phosphorylase were 120,000 and 170,000, respectively. The catecholase enzyme was also found in *D. alata* (Adamson and Abigor 1980).

Ireland and Passam (1984) found a gradual decrease in growth inhibitory phenolics in tubers of *Dioscorea alata* and *D. esculenta* during dormancy and in *D. alata* this closely paralleled a decrease in batatasin content. It was found that batatasin-type growth inhibitory phenolics accumulated rapidly in developing tubers just prior to the onset of dormancy and were asymmetrically distributed, being concentrated in the proximal (head) region and in the peripheral zone just beneath the periderm. Gibberellin A_3 treatment produced a promotion of the dormant period and a correlative rise in the growth inhibitory phenolic level. Effects of maleic hydrazide and ethylene chlorohydrin were also reported.

Tuber Starch/Flour

Jayakody et al. (2006) reported the chemical and physical composition and granule morphology of the Hingurala and Raja-ala varieties of *D. alata* native starches, respectively, as follows: starch yield (based on tuber weight) 14.25 %, 18.80 %, moisture 8.25 %, 8.75 %, ash 0.13 %, 0.17 %, nitrogen 0.02 %, 0.01 %, phosphorus 0.05 %, 0.04 %, lipids (extract by chloroform-methanol) 0.05 %, 0.08 %, lipids (extracted by *n*-propanol-water) 0.25 %, 0.20 %, total amylose content 26.98 %, 31.02 %, amylose complexed with lipids 8.34 %, 5.58 %, granule size range 30–40 µm, 35–45 µm, granule morphology, truncated oval, truncated spade, crystallinity 43 %, 43 % and crystalline type C-type, B-type. The gelatinization temperatures for Hingurala and Raja-ala varieties were, respectively, as follows: onset (To) 78.17, 75.45 °C, mid point (Tp) 85.13,78.49 °C and conclusion (Tc) 92.87,85.70 °C, gelatinization temperature range (Tc–To) 14.7, 12.25 °C and gelatinization enthalpy (ΔH) 18.98, 18.60 J/g. The hydrolysis percentage of Hingurala and Raja-ala starches by porcine pancreatic a-amylase were 56.14 %, 56.63 %, respectively. Both starches differed significantly from each other with respect to peak viscosity (Raja-ala > Hingurala), viscosity breakdown (Hingurala > Raja-ala) set-back (Hingurala > Raja-ala) and pasting temperature (Hingurala > Raja-ala). Percent amylose leaching was higher for Raja-ala than Hingurala. Melting enthalpies (ΔH_R) of amylopectin recrystallisation (reflecting the extent of retrogradation during the storage period of 40 °C for a week) was higher for Hingurala than Raja-ala. Huang et al. (2006) found the starch content of tubers of four *D. alata* cultivars tubers ranged from 70.5 to 85.3 % on a dry basis. The shapes of the starch granules were round to oval or angular. The size of starch granule increased, with growth time ranging from 10 to 40 µm. The X-ray diffraction patterns could be classified as typical of B-type starch for the four cultivars. The transition temperature of gelatinization of the four yam starches decreased during maturity The starch paste showed a lower breakdown at an early harvest time. It appeared to be thermo-stable during heating but had a high setback after cooling, which might result in a tendency towards high retrogradation. The results for pasting behaviours showed that higher amylose content was associated with a lower pasting temperature and a higher peak viscosity in these starches. Amylograms of *D. alata* tuber starch showed that starch pastes maintained a high viscosity under heat treatment and mechanical stirring in neutral to slightly acidic conditions (Mali et al. 2003). Brabender viscosity increased when gums were added; the effect of guar gum on viscosity was more marked than that of xanthan gum. Xanthan gum, at a concentration of 0.5/100 g suspension, showed higher effectiveness than guar gum in reducing exudate production during refrigerated storage. The results suggested the addition of hydrocolloids could allow yam starch to be used in foods requiring low temperatures. Fifteen test varieties of *D. alata* had lower starch content (68.3 %), swelling power (9.9), peak viscosity (283.9 RVU), trough (221.5 RVU), breakdown (20.2 RVU), final viscosity (283.9 RVU) and setback (62.4 RVU) but higher sugar (5.4 %), solubility (11.9 %), peak time (6.3 min) and pasting temperature (89.2 °C) than the control variety (Baah et al. 2009). Multiple comparison sensory tests by a trained panel showed poor quality of pounded yam from test varieties relative to the control, however, TDa 98–159 and TDa 291 compared well with the control. Starch characteristics of 18 *D. alata* varieties tuber flour were starch 60.42–77.56 %, mean 76.2 %, amylose 2.69–31.56 %, mean 26.41 %; swelling power 6.23–9.75 % mean 7.6 % (Wireko-Manu et al. 2011). The pasting characteristics of the starch were peak viscosity 74.80–284.60 RVU (rapid visco units), mean 157.66 RVU; final viscosity 112.25–317.20 RVU, mean 195.08 RVU; setback 27.45–308.10 RVU, mean 59.56 RVY, and pasting temperature 83.60–90.10 °C, mean 85.89 °C.

Significant associations were found, through canonical correlation analysis, between pasting characteristics of fresh yams from six varieties, each, of *Dioscorea rotundata* and *Dioscorea alata* and the textural quality of pounded yam samples prepared from them (Otegbayo et al. 2006). Good textural quality of pounded yam was associated with high peak viscosity, breakdown, final viscosity, holding strength and setback viscosity but with low pasting temperature in the fresh yam. Otegbayo et al. (2011) found that *D. alata* yam starch with high amylase content, water-binding capacity and low swelling power gave pounded yam samples, which were very soft, unstretchable, sticky and incohesive compared to *D. rotundata*.

Kpodo and Plahar (1992) found that *D. alata* yam flour (starch) could be successfully extruded with maximum expansion at a feed moisture range of 8–10 % using extrusion temperatures of 100–115 °C. Steam pressure treatment of *Dioscorea alata* and *Dioscorea rotundata* starches led to vast changes in physico-chemical properties content (Moorthy 1999). The treatment did not significantly affect the total amylose but the soluble amylose content decreased threefold to fivefold. Reducing values and lambda (max) of the iodine complexes were unaffected. Viscosity of the starch paste was reduced by the treatments, and at higher pressures and longer time of treatments, the peak viscosity values were reduced to very low values. Pasting temperatures were enhanced considerably. Swelling volumes underwent reduction, but no change in solubility occurred. Clarity and paste stability were markedly lowered. Studies revealed that carboxymethylation improved thermal stability of *Dioscorea alata* native starch (Lawal et al. 2008). The degree of substitution (DS) increased progressively as the steps of carboxymethylation increased from 2 to 9 and an optimal DS of 2.24 was obtained. Initial increases in carboxymethylation step increased the reaction efficiency progressively up to 82.1 % after the seventh carboxymethylation step but declined with further increases in the carboxymethylation step. Starch crystallinity reduced significantly after carboxymethylation. Thermogram of native starch showed a characteristic three-step decomposition with 13.16 %, 61.54 % and 24.79 % weight losses progressively, while carboxymethyl derivative showed four decomposition stages with 9.86 %, 36.57 %, 3.04 % and 23.07 % weight losses progressively.

Dioscorea alata purpurea yam contained starch granules mostly in the range of 10–80 μm, and about 1 % of starch granules was smaller than 1 μm (Yeh et al. 2009). Decreasing water content from 90 % to 40 % did not significantly alter the onset temperature (To) and peak temperature (Tp), but raised the conclusion temperature (Tc). Mucilage exhibited greater storage modulus (G′) and smaller loss modulus (G″) than the isolated yam starch at water content of 90 %. Water content also influenced the effect of mucilage on the rheological properties of starch–mucilage mixture, but did not significantly affect To and Tp.

After defatting, *Dioscorea alata* yam and cassava starches were found to have amylose contents of 36.2 and 24.2 %, respectively (Freitas et al. 2004). *D. alata* starch showed a more energetic gelatinization process when compared to cassava starch and also had a lower rate constant, indicating a relatively slow gelatinization process at higher temperatures. *D. alata* yam gels formed by autoclaving a suspension (50 g/L) showed after 24 h of refrigeration, a stronger structure than for a cassava gel.

Antioxidant Activity

Peel portions of *D. alata* yam were found to have a better effect on scavenging DPPH free radical than flesh portions, especially for the ethyl acetate partition of the peel portion of Tainung #2 yam (Chen et al. 2004). Its EC_{50} value (14.5 μg/mL) was even lower than that of ascorbic acid (21.4 μg/mL). Various extracts of *D. alata* rhizome, viz. aqueous, 30 % ethanol and boiled 30 % ethanolic extracts effectively inhibited the copper-driven Fenton reaction-induced damage of calf thymus DNA, while inhibition was less pronounced in the case of X-ray induced strand breakage of plasmid DNA (Wang et al. 2004). While boiled aqueous extract potently inhibited X-ray induced strand breaks in plasmid pGL3 DNA, it failed to inhibit, and even greatly enhanced, copper-H2O2 induced damage of calf thymus DNA. The results demonstrated strong copper chelating and weak hydroxyl radical scavenging activities in *D. alata* rhizome extracts, and these activities may vary depending on the procedures used in preparing the extract.

Aqueous methanolic (50 % MeOH) extracts of the tubers (peel and flesh) of nine cultivars of *Dioscorea alata* were found to have relatively high antioxidant activities among which two cultivars (Ubong upo, purple, LA096, white) had activities as high as those of α-tocopherol and butylhydroxyanisole (BHA) (Lubag et al. 2008). Serial fractionation of the extract yielded two compounds P1 and P2, which showed antioxidant activities higher than those of BHA and α-tocopherol . P1 was established to be a purple anthocyanidin very similar to alatanin C. Initial results for P2 indicated its phenolic nature with a glucose moiety and a molecular weight of 306.

Dioscorea alata yam peel showed antioxidant activity in mouse liver cell lines (Hsu et al. 2011b). The peel water extract augmented tert-butylhydroperoxide (t-BHP)-induced cytotoxicity in mouse Hepa 1–6 cells, while the Yam peel ethanol extract reduced t-BHP -induced cytotoxicity in mouse FL83B cells. GPx activity was found to play important role on reducing t-BHP-induced oxidative stress. The methanol extract of *Dioscorea alata* tuber showed potent hydroxyl, superoxide, ABTS radical cation scavenging activities while the ethanol tuber extract showed strong DPPH radical scavenging activity (Sakthidevi and Mohan 2013). The maximum inhibitory concentration (IC50) in all models viz. DPPH, hydroxyl, superoxide and ABTs radical cation scavenging activity of tuber of *D. alata* were found to be 27.16, 26.12, 30.65 and 25.53 μg/mL, respectively, at 1 μg/mL concentration. The total phenolics and flavonoids in methanol extract were found to be 0.68 g/100 g and 1.21 g/100 g respectively.

Antidiabetic Activity

Ramdath et al. (2004) reported on the glycaemic index (GI) of eight staple foods eaten in the Caribbean: high GI food cassava (*Manihot esculenta*) 94, dasheen (*Colocasia esculenta*) 77, moderate GI food: breadfruit (*Artocarpus altilis*) 60, cooking green banana (*Musa* spp.) 65, 'sadha roti' 65, eddoes (*Colocasia esculenta* var. *antiquorum*) 61, Irish potato (*Solanum tuberosum*) 71, tannia (*Xanthosoma sagittifolium*) 60 and white yam (*Dioscorea alata*) 62. Crushing did not significantly affect the GI of dasheen, tannia or Irish potato. Studies by Bahado-Singh et al. (2006) found that 14 commonly eaten carbohydrate-rich foods, including *D. alata*, processed by roasting or baking may result in higher GI. Conversely, boiling of foods may contribute to a lower GI diet.

Treatment of glucose-loaded normal rats with *D. alata* tuber extract, at dose levels of 100 and 200 mg/kg, significantly reduced blood glucose levels (Maithili et al. 2011). The extract did not produce hypoglycemic activity at both dose levels in normal, fasted rats. In alloxan-induced diabetic rats treated with the extract, the body weight significantly increased after 21 days treatment; blood glucose level was reduced significantly by 47.48 % and 52.09 % after 21 days of treatment at dose levels 100 and 200 mg/kg, respectively. Serum lipid levels, total protein, albumin and creatinine were reversed towards near normal in treated rats as compared to diabetic control.

Dispo85E (*D. alata* rhizome extract) enhanced the endocytosis and degradation activity of advanced glycation end products (AGEs) in murine hepatic nonparenchymal cells (NPCs) (Peng et al. 2011b). Further, the hepatocyte growth factor (HGF) expression level was positively correlated with the clearance capacity of the AGEs in NPCs after Dispo85E treatment. It was also shown that recombinant mouse HGF could enhance the endocytosis and autophagic clearance of AGEs in NPCs. The in-vivo data indicated that Dispo85E increased hepatic HGF messenger RNA expression levels and decreased serum AGEs level in diabetic mice. Also, the function of retina and kidneys was improved by

Dispo85E treatment in AGEs-induced diabetic mice. The study suggested that Dispo85E enhanced the clearance of AGEs through HGF-induced autophagic-lysosomal pathway and could be a candidate drug for the treatment of diabetic vascular complications. Studies showed that administration of *Dioscorea alata* L. (*DA*) extract at 100, 200 and 300 mg/kg of body weight to male wistar rats significantly reduced food intake, fasting blood glucose level and body weight when compared with the control group (Helen et al. 2013). The results suggested that *Dioscorea alata* could serve as a great therapeutic diet in the management of diabetes.

Antiosteoporotic Activity

Extracts from *D. alata* roots and leaves were found to strongly stimulate proliferation of both bone marrow cells and splenocytes, significantly increasing cell concentrations (Tulin and Ecleo 2007). A cytokine mimetic with molecular weight of 35 kDa was isolated from greater yam root and found to be biologically active, stimulating a dose-dependent proliferative response. Studies showed that 2 weeks of feeding *D. alata* yam prevented loss of bone mineral density and improved bone calcium status without stimulating uterine hypertrophy in ovariectomised female BALB/c mice (Chen et al. 2009). Phyto rhizomes (Dispo85E) increased the activity of alkaline phosphatase (ALP) and bone nodule formation in primary bone marrow cultures (Peng et al. 2011a). The extract promoted osteoblastogenesis by increasing ALP activity and bone nodule formation in both intact and ovariectomised (OVX) mice. It ameliorated the deterioration of trabecular bone mineral density, trabecular bone volume/total volume, and trabecular bone number in OVX mice.

Antiallergic Activity

All the dioscorins from *D. alata* or *D. japonica* suppressed allergic reactions by decreasing the serum IgE and histamine levels in ovalbumin-induced allergy mice (Hsu et al. 2013). The IL-5 levels decreased to basal levels in dioscorin-treated mice and in most of the lymphoid cells of the dioscorin-treated mice in response to ConA stimulation. The spleen cells from the dioscorin-treated mice also exhibited an up-regulation of IFN-γ secretion in response to ConA stimulation The decrease of IgE and histamine levels was concomitant with an increase in IFN-γ and IgG2a levels and with a decrease in IL-5 levels, suggesting that dioscorins suppressed the ovalbumin -induced allergic reactions, possibly through modulating an imbalanced Th1/Th2 immune response.

Antihyperhomocysteinemia Activity

The results of studies indicated that hyperhomocysteinemia (HHcy) induced by methionine in rats could be reversed by *D. alata* feeding (Chang et al. 2004). *D. alata* powder feeding for 12 weeks significantly decreased plasma homocysteine levels and exhibited its antioxidative effects in HHcy. *D. alata* also alleviated thrombin-induced platelet aggregation, lipid peroxidation and oxidative stress, but did not induce activity of antioxidant enzymes, which had already adaptively increased by hyperhomocysteinemia.

Antihypertensive Activity

Dioscorin, the tuber storage protein of *Dioscorea alata* yam, inhibited dose-dependently 12.5–750 μg angiotensin converting enzyme (ACE), producing 20.83–62.5 % inhibition (Hsu et al. 2002). The 50 % inhibition (IC_{50}) of ACE activity was 6.404 μM dioscorin (250 μg corresponding to 7.81 nmol) compared to that of 0.00781 μM (0.0095 nmol) for captopril. The ACE inhibitory activity was increased from 51.32 % to about 75 % during 32 h hydrolysis with pepsin. The results suggested that dioscorin and its hydrolysates may have potential for hypertension control when people consume yam tuber.

Powdered yam product of *D. alata*, which included alcohol-insoluble solids of yam tuber, hot air drying (HAD) of yam tuber slices, steam cooked once or twice followed by HAD, which were subsequently powdered, and liquid yam products of *D. alata* heated at 90 or 95 °C were found to effectively reduce the blood pressure of to spontaneously hypertensive rats (SHRs) and should be beneficial in food processing in the development of functional foods for blood pressure regulation (Liu et al. 2009).

Estrogenic Activity

Ethyl acetate extracts of various species/varieties of yam, including *D. alata*, were found to activate estrogen receptors alpha and beta to various extents (Cheng et al. 2007). Fractionation of *D. alata* cv. Tainung No. 2 tuber extract afforded two new compounds, hydro-Q(9) chromene and γ-tocopherol-9, together with three known compounds, RRR-α-tocopherol, coenzyme Q(9) and 1-feruloylglycerol; all were shown to activate human ERalpha and beta. These results confirmed the beneficial effect of yam for menopausal women.

Menopausal Symptoms Amelioration Activity

In a study of 22 apparently healthy postmenopausal women who completed the study, replacing two-thirds of staple food (rice for the most part) with 390 g of yam (*Dioscorea alata*) for 30 days improved the status of sex hormones, lipids and antioxidants (Wu et al. 2005). After yam ingestion, there were significant increases in serum concentrations of estrone (26 %), sex hormone binding globulin (SHBG) (9.5 %), and near significant increase in estradiol (27 %). Free androgen index estimated from the ratio of serum concentrations of total testosterone to SHBG decreased. Urinary concentrations of the genotoxic metabolite of estrogen, 16α-hydroxyestrone, decreased significantly by 37 %. Plasma cholesterol concentration decreased significantly by 5.9 %. Lag time of low-density lipoprotein oxidation prolonged significantly by 5.8 % and urinary isoprostane levels decreased significantly by 42 %.

In a two-centre, randomised, double-blind, placebo-controlled clinical investigation on 50 menopausal women, intake of *Dioscorea alata* improved menopausal symptoms, particularly the psychological parameters in menopausal women, compared with placebo (Hsu et al. 2011a). Apparent improvements were noted in the parameters 'feeling tense or nervous', 'insomnia', 'excitable' and 'musculoskeletal pain,' among those receiving *Dioscorea* yam. *Dioscorea* consumption also resulted in positive effects on blood hormone profiles. Safety monitoring indicated that standardised extracts of *D. alata* were safe during daily administration over a period of 12 months.

Antihypercholesterolemic Activity

Chen et al. (2003) found the *Dioscorea alata* 50 % yam diet consistently improved cholesterol profile in the plasma and liver in adult Balb/c mice. Also, faecal excretions of neutral steroid and bile acids were increased and fat absorption was decreased in mice fed on 50 % yam diet. The 25 % yam diet was sufficient to modulate intestinal enzyme activities, but not the plasma and hepatic cholesterol levels. The leucine-aminopeptidase activity in the small intestine was increased for 79 % and 102 % with 25 % and 50 % yam diet, respectively. In contrast, the sucrase activities were decreased by both yam diets. The results suggested that the reducing effects of 50 % yam diet on the plasma and hepatic cholesterol levels could be mediated through the inflated faecal fat and steroid excretion. Another study showed that male Wistar rats fed with high cholesterol (10 %) diet supplemented by 40 % *D. alata* yam significantly reduced plasma triglyceride and cholesterol (Yeh et al. 2007). Plasma aspartate transaminase and alanine transaminase activities were significantly increased. The results suggested that yam may inhibit hypertriglyceridemia induced by a high cholesterol diet in rats.

Anti-fibrosis Activity

D. alata aqueous extract treatment of murine fibroblast cells (NRK-49F) with cellular fibrosis induced by β-hydroxybutyrate, attenuated renal interstitial cellular fibrosis by suppressed β-hydroxybutyrate -induced expression of fibronectin concomitantly with the inhibition of Smad2/3, pSmad2/3 and Smad4 (Liu et al. 2012). The extract also caused a decrease in α-smooth muscle actin and MMP-2 levels, and an increase in E-cadherin expression. They proposed that d. alata extract might act as a novel fibrosis antagonist, which acts partly by down-regulating the transforming growth factor-beta (TGF-β)/smad signalling pathway and modulating epithelial-mesenchymal transition.

Immunomodulatory Activity

Dioscorin isolated from *Dioscorea alata* induced cytokine expression in macrophages by activating Toll-like receptor 4 (TLR4)- signalling pathways crucial for both innate and adaptive immunity (Fu et al. 2006). Dioscorin from *D. alata* tuber (5–100 μg/ml) was able to stimulate nitric oxide production (expressed as nitrite concentrations) in RAW264.7 cells (Liu et al. 2007). The stimulation index on the phagocytosis of RAW264.7 cells against *Escherichia coli* and the oxidative burst (determined by the intensity of rhodamine fluorescence) of RAW264.7 cells were both enhanced by different concentrations of dioscorin (5–100 μg/ml). Dioscorin (5–100 μg/ml) was found able to induce IL-6, TNF-alpha and IL-1beta production in RAW264.7 cells and human monocytes. The stimulated proliferation index of splenic cells from BALB/c mice, ranged from 1.38- to 1.48-fold for phytohemagglutinin alone or for phytohemagglutinin mixed with different concentrations of dioscorin (10, 25 and 50 μg/ml). The results suggested that the tuber storage protein of yam dioscorin functioned as an immunomodulatory substance. Another study found that yam storage protein dioscorins from *Dioscorea alata* and *D. japonica* exhibit distinct immunomodulatory activities in mice (Lin et al. 2009). Intraperitoneal injection of the *D. alata*-dioscorins was found to have a higher ability to stimulate the phagocytic activity of the lymphoid cells than *D. japonica* -dioscorins, whereas *D. japonica* -dioscorins possessed more abilities than *D. alata* -dioscorins to enhance the proliferation of the lymphoid cells.

The phytoextract from 50 to 75 % ethanol-precipitated fraction of *Dioscorea alata* var. *purpurea* Tainung no. 5 tuber, designated as DsII-TN5 was found to confer immunomodulatory activities ex-vivo and improve regeneration of bone marrow cells in- vivo (Chang et al. 2013). The extract showed a strong augmentation of tumour cell lysate- (TCL-) loaded dendritic cell-mediated activation of T-cell proliferation. It stimulated the expression of CD40, CD80, CD86 and IL-1 β in TCL-loaded DCs and down-regulated the expression of TGF- β 1. The extract as a dendritic cell vaccine adjuvant showed strong antimelanoma activity and reduced myeloid-derived suppressor cell population in tested mice. The extract could also activate dendritic cells to enhance Th1- and Th17-related cytokine expressions. Biochemical analysis showed that the extract consisted mainly of polysaccharides containing a high level (53 %) of mannose residues.

Hepatoprotective and Nephroprotective Activities

Feeding of crude water extract of *D. alata* yam to rats with acute hepato-nephrotoxicity induced by acetaminophen ameliorated renal tubular degranulation changes, necrosis and disintegration; and protected against the inflammation of central vein and necrosis of liver tissue (Lee et al. 2002).

In-vivo studies showed that ethanol extract *D. alata* (ethanol extract) treatment of Wistar rats aniline-induced spleen toxicity (oxidative and nitrosative stress) for a month resulted in significant recovery in aniline-induced splenic toxicity (Khan et al. 2014). The protection may be due to its antioxidant property and the presence of different phytochemicals. Earlier studies by Liu et al. (2012)

reported that *Dioscorea alata* attenuated renal interstitial cellular fibrosis by regulating Smad- and epithelial mesenchymal transition signaling pathway.

Traditional Medicinal Uses

Dioscorea alata is an important herb in Chinese medicine, widely used for the treatment of clinical diabetes mellitus (Liu et al. 2012). In Indian ethnomedicine, decoction of tubers is used in leprosy, piles and gonorrhoea.

Other Uses

Okunlola and Odeku (2011) found *D. alata* yam starch had high brittle fracture index and friability and could be useful in chloroquine phosphate tablet formulation when faster disintegration time of tablets is desired.

Studies showed that *D. alata* meal could replace up to 80 % of maize or constitute 40 % of a laying chicken diet, provided the rations are isocaloric and isonitrogenous (Agwunobi 1999).

Beta-sitosterol from *D. alata* tuber peel exhibited antifungal activity towards spore germination of two yam pathogens with an inhibition of less than 57 % at a concentration of 50 mg/L, while inhibition on the elongation of germ tubes of *Fusarium moniliforme* was as high as 82 % at the same concentration (Aderiye et al. 1996).

In Papua New Guinea, *D. alata* is also used for ceremonial purposes (Onwueme and Ganga 1996).

Comments

Dioscorea alata is a polyploid species with a ploidy level ranging from diploid ($2n=2x=40$) to tetraploid ($2n=4x=80$) (Nemorin et al. 2013). It was found that the polyploids of *D. alata* would have appeared through the formation of unreduced gametes. Triploids could be derived through the formation of 2n gametes in diploid females as the result of the non-viability of seeds resulting from the formation of 2n sperm and of the non-viability of inter-cytotype crosses. The tetraploids would have appeared through bilateral sexual polyploidization via the union of two unreduced gametes due to the sterility of triploids.

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