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Functional properties and effective phytochemicals of yam (Dioscorea spp.)

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Yams are perennial trailing rhizome plants of the *Dioscorea* species and a staple food around the world. Yams contain many nutrients and exhibit hypoglycemic, antioxidative, antitumor, antibacterial, antimutagenic, and antineoplastic activities. Saponins (furostanol and spirostanol glycosides), phytosterols (sitosterol, stigmasterol and campesterol), glycans (dioscorans), dioscoretine, diosbulins, (+)-*ß*-eudesmol and paeonol are the active phytochemicals in yams. The aim of this study is to review the biological activities and relevant components of yam.

Key words: Yam, *Dioscorea* spp., Functional property, Phytochemical

Introduction

Yams are perennial trailing rhizome plants of the *Dioscorea* species and the Dioscoraceae family. Yams are staple food for about 400 million people around the world, especially in Africa[1]. The tuber of yam (*Dioscorea* species) contains many nutrients and physiologically active components and is widely used in traditional Chinese medicine[2]. Yams are believed to be of benefit in the treatment of diabetes mellitus and to promote the health of women after menopause[3,4]. Various kinds of yam cultivars are found throughout Taiwan and yam has been one of the important plants for producing functional foods. Various agricultural research organizations in Taiwan have carried out seed-bank collection and establishment, as well as cultivation, in addition to development of harvesting technologies and post-harvest treatment of yams[2]. Diosgenin in yam is an important raw material for industrial production of steroidal drugs and can be obtained by acid hydrolysis of yam tubers. Approximately 400 tons of diosgenin are produced annually in China[5]. In the US, yam alcohol extracts are sold as women's daily supplements in drug stores[3]. Herein, the biological activities and relevant components of yam are reviewed.

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Nutrients of Yam

Yams are good sources of energy, primarily as their dry material consists largely of carbohydrates (69.9~77.5 %). Crude protein, crude fat, crude fiber and ash content of yams are in the ranges of 6.7~7.9%, 1.0~1.2%, 1.2~1.8%, and 2.8~3.8%, respectively. The water content of fresh yam is about 70%[6]. Arginine is the amino acid found in the highest amount in yams. Other essential amino acids in yams include leucine, threonine, lysine and valine[6,7]. In addition, yams contain vitamin C (13.0-24.7 mg/100g dw)[6] and minerals (K, P, Ca,

Table 1. Properties of the 6 glycans from *Dioscorea japonica* (Hikino et al.[10])

Glycans	M. W.	Neutral sugar components	Peptide moiety (%)
Dioscoran A	8.4×10^4	arabinose, mannose, galactose, glucose (7.1: 48.9: 1.0: 0.8)	2.5
Dioscoran B	3.9×10^3	rhamnose, arabinose, xylose, mannose, galactose, glucose (0.5: 0.5: 0.2: 1.6: 1.0: 0.4)	12.0
Dioscoran C	1.1×10^4	rhamnose, arabinose, mannose, galactose, glucose (1.8: 1.9: 66.0: 1.0: 1.7)	24.5
Dioscoran D	7.8×10^4	rhamnose, arabinose, mannose, galactose, glucose (0.4: 0.9: 57.0: 1.0: 0.6)	5.1
Dioscoran E	6.6×10^4	mannose	3.9
Dioscoran F	1.1×10^5	mannose	3.3

Mg, Fe, Cu, Co)[6,8,9].

Physiological Activities and Components of Yam

Hypoglycemic activity

Hikino et al.[10] indicated that the methanol/water (1/1, v/v) and water extracts of yam rhizophors (*Dioscorea japonica*) exhibit hypoglycemic effects when administered intraperitoneally (*i.p.*) at a dose of 100 mg/kg in normal mice. They treated the extracts with ethanol to yield precipitates and isolated six glycans, dioscorans A, B, C, D, E and F, via DEAE-Toyopearl, Sephacryl S-200 and Sephacryl S-500 column chromatography. The molecular weights and neutral sugar components of these glycans are shown in Table 1. When injected *i.p.* (10~100 mg/kg) into normal mice, all of these glycans exerted hypoglycemic effects, with the largest effect following dioscoran C treatment. In alloxan-induced hyperglycemic mice, administration of dioscoran C resulted in significant reduction in blood glucose levels in a dose dependent manner at 7 hrs post-treatment.

Dioscoretine (Figure 1) isolated from aqueous fraction of the methanol extract of yam tubers (*Dioscorea demetorum*) showed hypoglycemic activity when administered *i.p.* to normal Wistar rats and normal and alloxan-diabetic rabbits at a dose of 20 mg/kg. The maximum percent reduction in blood glucose levels was observed in the 4th hour post-treatment[11,12].

Antioxidant activity

Polysaccharide (M. W. = 8.1×10^4) was obtained from yams (*Dioscorea opposita* Thunb.) via a process of hot water extraction, alcoholic precipitation and Sephadex G-100 purification. It was found to be composed mainly of glucose and a trace of fucose. This polysaccharide decreased NADPH-Vit.C and cysteine-Fe^{2+}-induced malondialdehyde formation in the brain, liver and kidney microsomes in rats. It also eliminated the superoxide radical generated by hypoxanthine/xanthine oxidase reaction system and hydroxyl radical produced by Fenton reaction system. The degrees of inhibition were observed to decrease in a polysaccharide dose dependent manner from 1 to 100 μg/ ml[13]. Total antioxidant activity (TAA) of ethyl acetate in aqueous extracts of browned yam flour were determined by the horseradish peroxidase catalyzed oxidation of 2, 2 azino-bis-(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS). The reaction mixture contained 2 mM ABTS 0.1mM H_2O_2 in 50 mM glycine-HCl buffer, pH

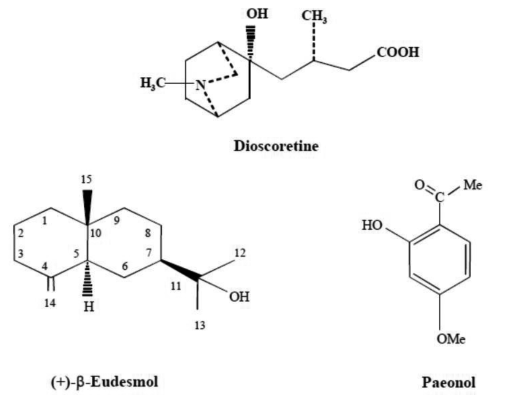


Fig. 1. Structures of dioscoretine, (+)-ß-eudesmol and phytosterols (Iwu et al.[11,12]; Miyazawa et al.[23])

4.5 and 5 mg of the extract in a total volume 2 ml. Results showed 7.5 mM equivalent of Vitamin C in ethyl acetate extract, which is higher than in aqueous extract (3.7 mM equivalent of Vitamin C) and butylated hydroxylanisole (BHA) (5.7 mM equivalent of Vitamin C)[14]. In another study[15], dioscorea, a commercial wild yam extract available in capsules was given to healthy humans aged between 65 and 82 years (mean age of 73.5 years) for 3 weeks (2 pills/day for one week, 4 pills/day for one week and 8 pills/day for one week). Dioscorea was found to significantly lower serum lipid peroxidation and serum triglycerides and phospholipids, as well as increase HDL levels, in elderly people.

Hypocholesterolemic activity

Šavikin-Fodulovic et al.[16] examined diosgenin and phytosterols (sitosterol, stigmasterol and campesterol) in five callus lines of Dioscorea balcanica. They found that diosgenin (0.03-0.15% of dw), stigmasterol (0.05-0.30% of dw) and campesterol (0.02-0.06% of dw) increase under dark conditions, while sitosterol (0.02-0.10% of dw) increases under light conditions. Singh et al.[17] noted that the highest quantity of diosgenin is in the median portion of the yam (*Dioscorea floribunda* Mart. & Gal.) tuber. Moreover, the male line of the yam (3.78% of dw) contains less diosgenin than the female line (4.66% of dw). Diosgenin, the aglycone part of the yam steroidal saponin, is a principal raw material for the industrial production of steroidal drugs[5]. Phytosterols are also useful in the pharmaceutical industry as a natural source of steroidal hormones[18]. Their structures are shown in Figure 2. Diosgenin and phytosterols have been reported to exhibit hypocholesterolemic activity. They increase biliary secretion and fecal excretion of cholesterol and decrease cholesterol absorption and liver cholesterol level[19-22].

Antimutagenic activity

Miyazawa et al.[23] pointed out that the methanol extract of *Dioscorea japonica* has a suppressive effect on *umu* gene expression in the SOS response of *Samonella typhimurium* TA1535/pSK1002 against the mutagen 2-(2-furyl)-3-(5-nitro-2-furryl) acrylamine (furylfuramide). This

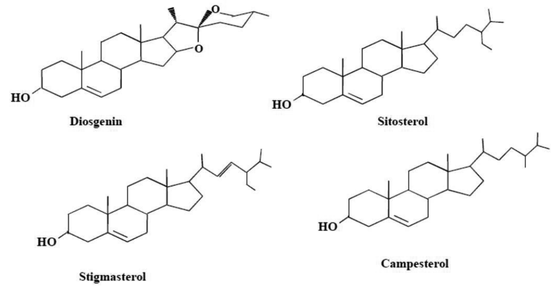


Fig. 2. Structures of diosgenin and phytosterols (Chen et al.[5]; Morgan and Moynihan[18])

extract was suspended in water and partitioned with dichromethane and *n*-butanol. Suppressive compounds, (+)-β-eudesmol and paeonol (2-hydroxy-4-methoxyacetophenone) (Figure 1), were prepared by SiO_2 column chromatography from dichromethane fraction. On *umu* test, (+)-β-eudesmol and paeonol suppressed 80% (at < 0.18μmol/mL) and 60% (at < 1.2 μmol/mL) of gene expression, with ID_{50} values of 0.09 and 0.99 μmol/mL, respectively, following the addition of furylfuramide. When the mutagen was replaced with 3-amino-1, 4-dimethyl-5H-pyrido[4,3-*b*]indole (Trp-P-1), *umu* gene expression was restrained 48 and 76% with (+)-β-eudesmol and paeonol (ID_{50} value of 0.41 μmol/mL), respectively. The antimutagenic activities of these compounds against furylfuramide and Trp-P-1 were also examined using Ames test and *Samonella typhimurium* TA 100. (+)-β-Eudesmol inhibited 93% of the mutagenicity of furylfuramide with 0.45 μmol/plate more strength than Paeonol (20%) and ID_{50} value of 0.13 μmol/plate. It also repressed 70% of the mutagenicity of Trp-P-1 at 0.56 μmol/plate with an ID_{50} value of 0.39 μmol/plate.

Antitumor activity

The antitumor effects of three diosbulbins (Figure 3) separated from methanol extract of *Dioscorea bulbifera* L. were determined in solid Sarcoma 180 tumors. Sarcoma 180 cells (2×10^6) were inoculated subcutaneously (*s.c.*) into male ddy mice. Diosbulbin A (0.2 mg/head/day), diosbulbin B (0.2 mg/head/day) and diosbulbin A 2-O-β-D-glucopyranoside (0.1 and 0.2 mg/head/day) were administered *i.p.* daily for 5 days. The tumors

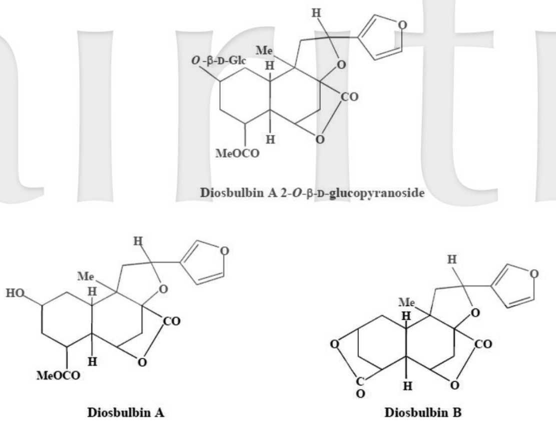
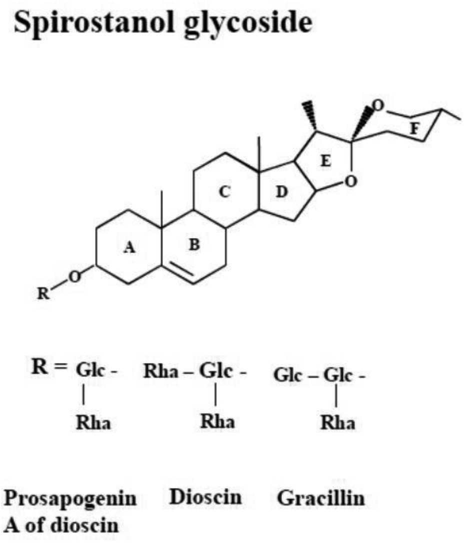


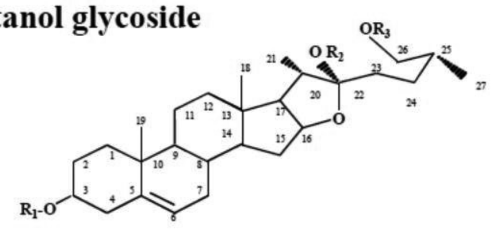
Fig. 3. Structures of diosbulbins (Komori[24])

were removed and weighed on the 16th day after inoculation. The results indicated a remarkable growth inhibition effect for all diosbulbins with suppressive ratios ranging from 29.5% to 49.81%[24].

Antibacterial activity

Aqueous, methanol and ethyl acetate extracts of *Dioscorea dregeana* (tuber) or *Dioscorea sylvatica* (tuber, roots and tuber bark) were dissolved in water or methanol to yield 100 mg/ml on disc-diffusion assay. The studied bacteria were *Staphylococcus epidermidis*, *Staphylococcus aureus*, *Micrococcus luteus*, *Pseudomonas aeruginosa*, *Escherichia coli*, *Bacillus subtilis* and *Kleibsiella pneumoniae*. The antibacterial activity was expressed as the ratio of inhibition zone of the extract (1 mg/ml) to inhibition zone of the reference (neomycin 200 mg/ml). Kelmanson et al.[25] reported that methanol extracts exhibit higher activity than aqueous and ethyl acetate extracts, with the highest activity demonstrated by tuber bark extracts of *Dioscorea sylvatica*. Hu et al.[26,27] isolated seven steroidal saponins from methanol extract of *Dioscorea colletti* var. *hypoglauca* using solvent fractions and column chromatography. Steroidal saponins can be divided into two groups: furostanol glycosides (F-ring opened) (protoneodioscin, protodioscin, protoneogracillin and protogracillin) and spirostanol glycosides (F-ring closed) (prosapogenin A of dioscin, dioscin and gracillin). Moreover, 22-methoxy furostanol glycosides (methyl protoneodioscin, methyl protodioscin, methyl protoneogracillin and methyl protogracillin) are derived from 22-hydroxy furostanol glycosides during methanol extraction. Their structures are shown in Figure 4. Steroidal saponins caused





Compound	R1	R2	R3	Config. of C-25	Config. of C-22	Aglycone
Protoneodioscin	Rha-Glc-Rha	H	Glc	S	R	yamogenin
Protodioscin	Rha-Glc-Rha	H	Glc	R	R	diosgenin
Protoneogracillin	Glc-Glc-Rha	H	Glc	S	R	yamogenin
Protogracillin	Glc-Glc-Rha	H	Glc	R	R	diosgenin
Methyl protoneodioscin	Rha-Glc-Rha	CH_3	Glc	S		yamogenin
Methyl protodioscin	Rha-Glc-Rha	CH_3	Glc	R		diosgenin
Methyl protoneogracillin	Glc-Glc-Rha	CH_3	Glc	S		yamogenin
Methyl protogracillin	Glc-Glc-Rha	CH_3	Glc	R		diosgenin

The R or S configurations of C-22 in compounds 8-11 are not sure.

Fig. 4. Structures of furostanol and spirostanol glycosides in Dioscorea collettii var. hypoglauca (Hu et al.[26,27])

morphological abnormality of *Pyricularia oryzae* mycelia. The active intensities (minimum morphological deformation concentrations) of spirostanol glycosides (2.3-9.0 μM) were higher than those of 22-methoxy furostanol glycosides (14.8-15.1 μM) and 22-hydroxy furostanol glycosides (94.0-95.4 μM).

Antineoplastic activity

Steroidal saponins also possess cytototoxic activities against the K562 cancer cell line. The IC_{50} values for spirostanol glycosides were in the range of 1.0 to 7.0 μM, similar to 22-hydroxy furostanol glycosides (1.6~6.6 μM) and 22-methoxy furostanol glycosides (1.6~6.6 μM)[26,27]. A spirostanol glycoside, (25R)-spirost-5-en-3β-ol 3-O-α-L-rhamnopyranosyl-(1→2)-O-[β-D-glucopyranosyl-(1→4)]-β-D-glucopyranoside, isolated from wild yam (*Dioscorea villosa*) showed cytostatic activities in cancer cell lines. IC_{50} values of the isolated spirostanol glycoside were 9.02 μM for Hep G2 cells, 13.21 μM for HEK293 cells, and 16.74 for MCF7 cells[28].

Steroidal saponin is one of the most important bioactive compounds in yam. It is often the index component for yam products[3]. We isolated three furostanol glycosides and three spirostanol glycosides from Taiwanese yam cultivar (*Dioscorea psedojaponica* Yamamoto)[29]. In addition, in another study, we showed that thermal processing and light exposure do not affect yam saponins during food processing[30]. 26-O-β-Glucosidase (F26G) prepared from yam removed the glucose from position C-26 on furostanol glycoside structure and converted it to the respective spirostanol glycoside[31].

Steroidal saponins in other plants also exhibit hemolytic[32,33], hypocholesterolemic[34,35], hypoglycemic[36], anti-thrombotic[33,37], anti-viral[38] and anti-cancer[39, 40] activities.

Conclusions

Yams (*Dioscorea* spp.) contain plentiful nutrients and exhibit many beneficial biological activities such as hypoglycemic, antioxidative, antitumor, antibacterial and antimutagenic activities. The active components in yams are saponins, phytosterols, glycans, dioscoretine, diosbulins, (+)-β-eudesmol and paeonol. Yam saponins remain stable during thermal processing and under light exposure. However, they can be hydrolyzed by glucosidases.

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