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STUDIES ON THE STEROIDAL COMPONENTS OF DOMESTIC PLANTS—XLIV.

STEROIDAL SAPOGENINS CONTAINED IN JAPANESE *DIOSCOREA* SP.

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Abstract—The steroidal sapogenins of 12 Japanese *Dioscorea* sp. were analysed. Three species do not contain sapogenins. The other nine species contain diosgenin abundantly as the aglycone of its saponins in their underground parts but very little in their aerial parts. Other steroidal sapogenins are found only in two species, *D. tokoro* Makino and *D. tenuipes* Franch. et Savat. These two species also contain the sapogenins as free sapigenins in their aerial parts. A new trihidroxysapogenin, m.p. 276–278°, was isolated from *D. tenuipes* and named diotigenin.

With regard to the species examined, the chemical composition of the sapogenins they contain corresponds to their morphological features: (1) Dioscoreas, which have opposite leaves, stems twining to the right and edible roots, do not contain sapogenins. (2) *D. bulbifera* L., which has stems twining to the left and globose tuber and forms bulbils, also do not contain sapogenins. (3) The other Dioscoreas have alternate leaves, stems twining to the left and form no bulbils. They contain diosgenin. (4) Of these nine Dioscoreas, *D. tokoro* Makino and *D. tenuipes* Franch. et Savat. have similar morphological features, and they contain the sapogenins possessing an α-OH at C_3 and the free sapogenins.

ALTHOUGH the Japanese Dioscoreas had been considered to be thoroughly examined and completely classified, the existence of several unsolved problems was pointed out by the present author.[1,2] Makino[3] had identified 10 species of Japanese Dioscoreas. Ohwi[4] added *D. asclepiadea* Prain et Burkill to them and excluded *D. Zentaroana* Koidz. because the Amami Islands where it occurred were placed beyond the limits of Japanese territory at the time of the publication of his work. Knuth[5] added several new species to Japanese Dioscoreas in his monograph. He divided *D. tokoro* Makino into *D. tokoro* Makino, *D. Wichurae* Uline and *D. Saidae* R. Knuth. According to him, the number of the male flowers, which are grouped cymosely at the axis of the raceme, are 2–4 in *D. tokoro* Makino and 6–12 in *D. Wichurae* Uline, while the male inflorescences of *D. Saidae* R. Knuth are branched and each branch is composed racemelike from 10–20 flowers. Prain and Burkill,[6] however, could not recognize the difference between these species after surveying the type specimen held in Dahlem, and treated them as synonymies of *D. tokoro* Makino. The present author cannot entirely exclude Knuth's view because he has had no chance to examine Knuth's type specimens. However, it is observed that the number of male flowers grouped are usually 4–6 but sometimes reach 10 or more. Furthermore, *D. Saidae* R. Knuth, according to Knuth's view, does not differ from *D. tokoro* Makino in any point except branching of the axis. Thus Knuth's three species should be treated as one species. Knuth also differentiated

[1] A. AKAHORI, *Acta Phytotax., Kyoto* **19**, 161 (1963).
[2] A. AKAHORI, *Acta Phytotax., Kyoto*. In press.
[3] T. MAKINO, *Tokyo Bot. Mag.* 3, 111 (1889).
[4] J. OHWI, *Flora of Japan*, p. 329 "Shibundo". (1958).
[5] R. KNUTH, Dioscoreaceae. In *Das Pflanzenreich* (Edited by A. ENGLER) Vol. IV–43, pp. 1–388 (1924).
[6] D. PRAIN and I. H. BURKILL, *Kew Bull.* 118 (1926).

D. tenuipes Franch. et Savat. and *D. Maximowiczii* Uline after the number of nerves of the leaves, and *D. japonica* Thunb. and *D. Fauriei* R. Knuth after the difference in shape of the leaf blades. However, because both the number of nerves and shape of leaves show fairly wide variances even in the same plant, the study of Prain and Burkill,[6] in which *D. Maximoczii* Uline and *D. Fauriei* R. Knuth are treated as the synonymies of *D. tenuipes* Franch. et Savat. and *D. japonica* Thunb. respectively, is considered to be correct. *D. sititoana* Honda et Jotani was treated as a variety of *D. septemloba* Thunb. by Ohwi, but these should be treated rather as different species. Furthermore, *D. izuensis* Akahori was recently discovered on the Izu Peninsula, Honshu. From the above described reasons, the number of Japanese Dioscoreas is at present considered to be 13.

The steroidal sapogenins contained in Dioscoreas are one of the most valuable commercial sources for synthesis of steroidal hormones. From Japanese Dioscoreas several sapogenins are obtained. Tsukamoto *et al.*[7-9] isolated diosegenin from the rhizomes of *D. gracillima* Miq., *D. quinqueloba* Thunb., *D. septemloba* Thunb., *D. nipponica* Makino, *D. tokoro* Makino, and *D. tenuipes* Franch. et Savat., but could not obtain sapogenins from the roots of *D. japonica* Thunb. and *D. bulbifera* L. The chemical constituents of *D. bulbifera* L. differ according to workers. Some workers[10,11] isolated diosgenin from it while others[12-15] did not. The difference may be partly due to misidentification of the materials. The most interesting steroidal sapogenins contained in Japanese Dioscoreas are yonogenin, tokorogenin and kogagenin. Tokorogenin was first isolated from the rhizome of *D. tokoro* Makino[16] and later also from the aerial parts of this plant.[17] Yonogenin and kogagenin were isolated from the aerial parts of the same plant[17,18] and later found also in its underground parts.[19] These three sapogenins have an α-hydroxyl group at C3, although the other sapogenins all have a β- one at this position. They exist as both free sapogenins and glycosides,[20,21] while the other sapogenins exist only as saponins in the plants except for a few cases.[22-25] It would be very interesting, therefore, to examine whether any other sapogenin with a 3α-hydroxyl group is present in other Dioscoreas. Search for the existence of free sapogenins is also an interesting problem. The present study was carried out with these two problems in view.

For this paper, 12 species of Dioscoreas are examined (Table 1). *D. Zentaroana* Koidz. which grows only in *Amami-Ohshima* was excluded because collection of the material is difficult. The steroidal sapogenins contained in *D. tokoro* Makino have been reported

[7] T. TSUKAMATO and T. KAWASAKI, *Yakugaku-Zasshi* **74**, 72 (1954).
[8] T. TSUKAMOTO, T. KAWASAKI, T. YAMAUCHI and J. KORENAGA, *Kyushu-Yakugakukai-kaihô* **11**, 51 (1955).
[9] T. TSUKAMOTO, T. KAWASAKI and Y. SHIMAUCHI, *Yakugaku-Zasshi* **77**, 1221 (1957).
[10] R. E. MARKER *et al.*, *J. Am. Chem. Soc.* **65**, 1199 (1943).
[11] J. J. H. SIMES, J. G. TRACEY, L. J. WEBB and W. J. DUNSTAN, *CSIRO Bull.* **281** (1951).
[12] M. E. WALL *et al.*, *Agr. Res. Serv. Circ.* **AIC**-363 U.S. Dept. Agr. (1954).
[13] M. E. WALL *et al.*, *Agr. Res. Serv. Circ.* **ARS**-73-4 U.S. Dept. Agr. (1955).
[14] M. E. WALL *et al.*, *J. Am. Pharm. Ass.* **46**, 653 (1957).
[15] D. K. Cox (Mexico, Syntex S.A.). Personal communication.
[16] M. NISHIKAWA, K. MORITA, H. HAGIWARA and M. INOUE, *J. Pharm. Soc., Japan* **74**, 1165 (1959).
[17] T. OKANISHI and A. SHIMAOKA, *Ann. Repts. Shionogi Res. Lab.* **6**, 78 (1956).
[18] K. TAKEDA, T. OKANISHI and A. SHIMAOKA, *Chem. Pharm. Bull.* **6**, 532 (1958).
[19] A. AKAHORI, *Ann. Repts. Shionogi Res. Lab.* **11**, 93 (1961).
[20] A. AKAHORI, *Ann. Repts. Shionogi Res. Lab.* **10**, 153 (1960).
[21] A. AKAHORI, *Ann. Repts. Shionogi Res. Lab.* **11**, 97 (1961).
[22] A. WINDAUS and J. BRUNKEN, *Z. physiol. Chem.* **145**, 37 (1925).
[23] R. E. MARKER *et al.*, *J. Am. Chem. Soc.* **69**, 2167 (1947).
[24] T. OKANISHI, A. AKAHORI and F. YASUDA, *Ann. Repts. Shionogi Res. Lab.* **10**, 137 (1960).
[25] T. OKANISHI, A. AKAHORI and F. YASUDA, *Ann. Repts. Shionogi Res. Lab.* **10**, 143 (1960).

already.[20, 21] The steroidal sapogenins are soluble in organic solvents and not in water, while their saponins are soluble in water and not in organic solvents. Therefore, the sapogenins were extracted from the materials with benzene, and methanol analyzed by paper chromatography and purified as reported previously.[19] It is often difficult to isolate a pure steroidal sapogenin from a mixture with its C25 epimer by recrystallization because they commonly

TABLE 1. LOCATION AND TIME OF COLLECTION OF *Dioscorea* SP.

Name of plant	Part used for extraction	Collected in	Collected at
D. japonica Thunb.	aerial	Aug.	Sumiyoshi, Kobe
D. japonica Thunb.	underground	Nov.	Fujieda, Shizuoka Pref.
D. batatas Decne.	aerial	Oct.	Toneyama, Osaka Pref.
D. batatas Decne.	underground	Nov.	Aburabi Farm, Shiga Pref.
D. bulbifera Linn. forma *spontanea* (Makino) Makino et Nemoto	aerial, underground	Aug.	Ōyamazaki, Kyoto Pref.
D. bulbifera Linn. forma *domestica* (Makino) Makino et Nemoto	tuber	Oct.	Towa-cho, Ōshima-gun, Yamaguchi Pref.
D. asclepiadea Prain et Burkill	aerial, underground	Aug. Nov.	Hitoyoshi, Kumamoto Pref. (cultivated at Aburabi Farm)
D. gracillima Miq.	aerial, underground	June	Takarazuka, Hyogo Pref.
D. izuensis Akahori	aerial, underground	Aug.	Yawatano, Izu Peninsula
D. quinqueloba Thunb.	aerial, underground	Oct.	Munehi, Nara Pref.
D. nipponica Makino	aerial, underground	Sept.	Yuzawa, Niigata Pref.
D. septemloba Thunb.	aerial, underground	Sept.	Yuzawa, Niigata Pref.
D. sititoana Honda et Jotani	aerial, underground	Sept.	Mt. Mihara, Izu-Ōshima.
D. tenuipes Franch. et Savat.	underground	Oct.	Okamoto, Kobe
D. tenuipes Franch. et Savat.	underground	Sept.	Yawatano, Izu Peninsula
D. tenuipes Franch. et Savat.	aerial	Aug.	Sumiyoshi, Kobe.

have similar solubilities. Also, the difference between the R_f values of both epimers is so little that it is almost impossible to differentiate them with paper chromatography. Therefore, i.r. spectra were used for their detection. The principal absorption bands resulting from E and F rings of the steroidal sapogenins are those observed at near 980, 920, 900 and 860 cm^{-1}.[26] In the case of 25D sapogenins, the bands at 900 cm^{-1} are stronger than those at 920 cm^{-1} while in the case of 25L sapogenins the reverse relation is observed. When a mixture of 25D and 25L epimers is examined, it is theoretically possible to calculate the proportion of their quantities from the strength of these two bands. However, when the crystals are mixed with other substances, the strength of these two bands is influenced by various impurities and it is often difficult to identify the presence of a minute quantity of a sapogenin in the presence of its 25-epimer. Therefore, the fourth band was used for this purpose in this study. This band is observed at the following wave number: diosgenin, 862–865 cm^{-1} (in Nujol); yamogenin, 849–850 cm^{-1} (in Nujol); diosgenin acetate, 860–864 cm^{-1} (in CS_2); yamogenin acetate, 846–847 cm^{-1} (in CS_2). They are not influenced by each other and are sharply differentiated even when a small amount of an epimer is mixed with another.

[26] M. E. WALL, M. L. MCCLENNAN, C. R. EDDY and M. E. KLUMPP, *Anal. Chem.* **24**, 1337 (1952).

The results obtained are summarized in Tables 2 and 3 together with the constituents of *D. tokoro* Makino. *D. japonica* Thunb., *D. batatas* Decne. and *D. bulbifera* L. do not contain steroidal sapogenins. The other Dioscoreas contain the saponins of diosgenin abundantly in their underground parts and very little in their aerial parts, except for the seeds and the

TABLE 2. FREE STEROIDAL SAPOGENINS ISOLATED FROM JAPANESE DIOSCOREAS*

	From the aerial parts		From the underground parts	
	Sapogenins† obtained as crystals	R_f values of the minor components	Sapogenins† obtained as crystals	R_f values of the minor components
D. asclepiadea	—	—	Ds	0·72 0·53
D. gracillima	—	—	—	0·91 0·61
D. quinqueloba	—	—	—	0·92
D. nipponica	—	—	—	0·89 0·56
D. tokoro	Yo To Ko	0·68	—	0·91 0·55 0·37 0·26
D. tenuipes	Dt	0·54	—	0·37 0·30

† Ds—Diosgenin, Dt—Diotigenin, Ko—Kogagenin, To—Tokorogenin, Yo—Yonogenin, Ya—Yamogenin.

* *D. japonica*, *D. batatas*, *D. bulbifera*, *D. izuensis*, *D. nipponica*, *D. septemloba*, and *D. sititoana* do not contain any free sapogenins.

TABLE 3. STEROIDAL SAPOGENINS ISOLATED AS THE AGLYCONES OF THE SAPONINS FROM JAPANESE DIOSCOREAS*

	From the aerial parts		From the underground parts	
	Sapogenins† obtained as crystals	R_f values of the minor components	Sapogenins† obtained as crystals	R_f values of the minor components
D. asclepiadea	—	0·92 0·60	Ds	0·97 0·70 0·61 0·51 0·37
D. gracillima	—	—	Ds	0·98 0·62 0·31
D. izuensis	—	0·90	Ds	0·97 0·86 0·64 0·57
D. quinqueloba	—	0·91	Ds	0·97 0·71 0·58 0·47 0·28 0·23
D. nipponica	—	0·92	Ds	0·98 0·83 0·66 0·55
D. septemloba	—	0·92 0·86 0·65 0·41	Ds	0·98 0·68 0·58 0·39 0·26
D. sititoana	—	0·90 0·67 0·62	Ds	0·97 0·81 0·68
D. tokoro	Ds Yo To Ko	—	Ds Ya Yo To	0·81 0·67 0·45
D. tenuipes	Dt To	0·90 0·67 0·57 0·51	Ds Ya To	0·98 0·81 0·67 0·16

* *D. japonica*, *D. batatas*, and *D. bulbifera* do not contain any saponins.

† See Table 2.

male flowers of *D. tokoro* Makino.[19,27] The amount of free diosgenin in these plants is so small that it is hardly detected by paper chromatography. However, a very small amount of the crystals of free diosgenin were isolated from the underground parts of *D. asclepiadea* Prain et Burkill. Only very small amounts of other steroidal sapogenins were found in these plants except for *D. tokoro* Makino and *D. tenuipes* Franch. et Savat. Their R_f values are summarized in Tables 2 and 3. *D. tenuipes* Franch. et Savat. contains the saponins of yamogenin and tokorogenin in its underground parts and the free sapogenins in its aerial

[27] A. AKAHORI, *Ann. Repts. Shionogi Res. Lab.* **13**, 68 (1963).

parts like *D. tokoro* Makino. The principal sapogenin of its aerial parts has the formula $C_{27}H_{44}O_5$, m.p. 276–278°. This sapogenin belongs to the 25L series, easily affords a triacetate, m.p. 221–223°, $C_{33}H_{50}O_8$, and is not precipitated with digitonin. This sapogenin was named diotigenin.

With regard to Japanese Dioscoreas, the species which have similar morphological characters contain similar steroidal components. *D. japonica* Thunb. and *D. batatas* Decne. differ distinctly from the other Japanese Dioscoreas. They have opposite leaves, large edible roots, stems which twine to the right, and do not contain steroidal sapogenins. Among the other species which have alternate leaves and stems twining to the left, only *D. bulbifera* L. forms bulbils and does not contain sapogenins. Other species which do not form bulbils, contain the steroidal sapogenins. *D. tokoro* Makino and *D. tenuipes* Franch. et Savat., which are phytochemically very closely related, also are so little different morphologically that the differentiation of these two species is almost impossible without examination of the steroidal sapogenins when they have neither flowers nor seeds.[2]

The systematic classification of the genus Dioscorea is difficult because the number of the plants belonging to this genus is over 500 and they have wide morphological variances. Knuth[5] divided them into four subgenera by the shape of the wings upon the seeds. According to him, *D. tokoro* Makino belongs to Sect. Eustenophora R. Knuth (Subgen. Stenophora (Uline) R. Knuth) and *D. tenuipes* Franch. et Savat. to Sect. Macropoda Uline (Subgen. Eudioscorea Pax). Prain and Burkill[28] did not regard the wings of the seeds as so valuable a character and discarded Knuth's subgenera. One of the bases of their view was the similarity of two Japanese Dioscoreas, *D. tokoro* Makino and *D. tenuipes* Franch. et Savat. However, in their work, they mentioned that some of the differences of views may be no more than the result of different personal estimates of the importance of the relevant facts. The similarities of the steroidal sapogenins observed between *D. tokoro* Makino and *D. tenuipes* Franch. et Savat. may be a valuable base to support the view proposed by Prain and Burkill. The present author considers that the view of Prain and Burkill is correct and the chemical constituents have the same values as the morphological characters in the classification of plants.

At present, it is considered that Japanese Dioscoreas should be classified as follows:

A. Leaves usually opposite; stems twining to the right; bulbils formed; male flowers white, globular; steroidal sapogenins not contained:—
  B. Leaves opposite, broadly lanceolate or deltoidly ovate-oblong; axis of male spikes straight:—

1. *D. japonica* Thunb.

  B. Leaves opposite or ternate, deltoidly ovate, often with prominent basal lobes; axis of male spikes often zigzagging:—

2. *D. batatas* Decne.

A. Leaves alternate, stems twining to the left:—
  B. Tuber globose; bulbils in leaf-axils; perianth-lobes subacute, pale purple; steroidal sapogenins not contained:—

3. *D. bulbifera* L.

[28] D. PRAIN, I. H. BURKILL, *An Account of the Genus Dioscorea in the East*, in *Ann. Royal Botanic Garden, Calcutta*, 14, 48 (1936).

B. Rhizomes horizontal elongated; bulbils not formed; perianth-lobes obtuse, yellowish green or orange; steroidal sapogenins contained:—
C. Stamens 3 in male flowers, staminodes 3 or 3 pairs of two different forms in female flowers; yamogenin not contained:—
D. Without staminodes in male flowers, staminodes 3 in female flowers:—
E. Male flowers pedicelled:—

4. *D. asclepiadea* Prain et Burkill

E. Male flowers sessile:—

5. *D. Zentaroana* Koidz.

D. With 3 staminodes in male flowers, 6 staminodes in female flowers:—
E. Glabrous; leaves broadly ovate or subdeltoid-ovate, membranous, margins finely waved, green when dry, flowering period April–May:—

6. *D. gracillima* Miq.

E. Stems more or less clad in white hairs; leaves deltoid or deltoidly lanceolate, base broadly cordate or hastate, somewhat leather-like, black when dry; connectives enlarged, anthers carried wide apart, flowering period July–August:—

7. *D. izuensis* Akahori

C. Stamens 6 in male flowers, staminodes 3 in female flowers:—
D. Leaves more or less palmately lobed; yamogenin and free sapogenins not contained:—
E. Small stipule-like processes at the bases of petiols; flowers yellow or reddish orange:—

8. *D. quinqueloba* Thunb.

E. Without processes at the bases of petiols; flowers yellowish green:—
F. With short hairs; flowers not spreading; leaves green when dry:—

9. *D. nipponica* Makino

F. Glabrous; flowers spreading; leaves black when dry:—
G. Lateral lobes of the leaves acute:—

10. *D. septemloba* Thunb.

G. Lateral lobes obtuse; capsules large:—

11. *D. sititoana* Honda et Jotani

D. Leaves not lobed; yamogenin and free sapogenins contained:—
E. Perianth-lobes of male flowers spreading; filaments curved outwards in the middle; styles evident; seeds winged upwards; yonogenin contained, diotigenin not contained:—

12. *D. tokoro* Makino

E. Perianth-lobes of male flowers reflexed; stamens erect, anthers directed upwards; styles not observed; seeds winged all around; yonogenin not contained:—

13. *D. tenuipes* French. et Savat.

EXPERIMENTAL*

Paper Chromatography

Filter paper: Toyo-Roshi No. 50, 2 × 40 cm. Developed by one-dimensional ascending method. Solvent: toluene:AcOH (50:3). Color reagent: 1% cinnamic aldehyde in EtOH and 25 g of $SbCl_3$ in 5 ml of nitrobenzene.† R_f values of the standard steroidal sapogenins: diosgenin 0·91, yonogenin 0·56, tokorogenin 0·37.

Methods of the Extraction of the Sapogenins from Dioscorea

The dried powdered materials were extracted with benzene under reflux. The residues after the extraction with benzene were again extracted with MeOH. The methanol extracts were hydrolysed with HCl. Both the benzene extracts and the hydrolysis products, sometimes after the saponification with KOH in MeOH, were analysed by paper chromatography.

The fresh materials were cut into small pieces or ground in MeOH and extracted with this solvent under reflux. The MeOH extracts were again extracted with benzene. The residues insoluble to benzene were hydrolysed with HCl. In these cases too, the benzene extracts and the hydrolysis products were treated as above. When sufficient amounts of crude sapogenins were obtained, these were chromatographed on Al_2O_3.

Extraction products obtained from the Dioscorea. The amounts recovered, the color and the R_f values of the benzene extract and hydrolysis product of the 12 Dioscoreas are shown in Table 4.

Diotigenin triacetate. Diotigenin (90 mg) was dissolved in 1 ml of pyridine, added with 0·5 ml of Ac_2O and warmed on a water-bath to yield 87 mg of white crystals. White needles, m.p. 221–223°, were obtained from these after recrystallization from MeOH. (Found: C, 69·18; H, 8·83. Calc. for $C_{33}H_{50}O_8$: C, 68·96; H, 8·77%.) $[\alpha]_D^{23.5}$ −25·0 (C = 1·172, $CHCl_3$); i.r. $\nu_{max}^{CS_2}$ cm^{-1}: (−OAc) 1751, 1251, 1227; (F-ring) 986, 924, 894, 850.

Precipitation of the Steroidal Sapogenins with Digitonin

The steroidal sapogenins and cholesterol were dissolved in EtOH as described. Digitonin (100 mg) was dissolved in 10 ml of 90% EtOH. One millilitre of the digitonin solution was added to 1 ml of the solution containing the steroidal sapogenins or cholesterol and kept at room temperature (20°). The results obtained are as follows:

	Weight dissolved (mg)	95% EtOH (ml)	Immediately after	3 min	5 min	30 min	1 hr	24 hr
Diotigenin	10	1·5	−	−	−	−	−	−
Yonogenin	11	1·5	−	−	−	−	−	−
Tokorogenin	11	1·5	−	−	−	±	±	±
Sarsasapogenin	10	1·5	−	−	−	−	−	++
Diosgenin	11	1·5	−	−	+	++	++	+++
Tigogenin	10	2·0	−	+	+	+	++	+++
Cholesterol	11	2·0	+++	+++	+++	+++	+++	+++

* The diosgenin and tokorogenin obtained were identified by analytical values, mixed melting points and i.r. spectra.

† Steroidal sapogenins and sterols are observed as orange and purple spots, respectively, with this reagent. (Cf. T. OKANISHI, A. AKAHORI and F. YASUDA, *Ann. Repts. Shionogi Res. Lab.* **8**, 153 (1958).

TABLE 4. EXTRACTION PRODUCTS OBTAINED FROM DIOSCOREA

Plant	Part of plant	Dry weight (g)	Benzene extract: Amount recovered (mg)	Benzene extract: Colour or compound present	Benzene extract: Paper-chromatograph (R_f)	Hydrolysis product: Amount recovered (mg)	Hydrolysis product: Colour or compound present	Hydrolysis product: Paper-chromato-graph (R_f)
D. japonica	aerial	142	982	reddish orange	0·95 (purple)	133	dark green	
D. japonica	underground	213*	179	yellowish brown	0·94 (purple) 0·58 (purple)	73	reddish brown	
D. batatas	aerial	25	997	dark green	0·93 (purple)	142	green	
D. batatas	underground	400*	208	yellowish brown	0·93 (purple)	91	brown	0·93 (purple)
D. bulbifera (spontanea)	aerial	310	6000	green	0·92 (purple)	87	greenish brown	
D. bulbifera (spontanea)	underground	38*	450	yellowish brown	0·92 (purple)	54	yellowish brown	0·92 (purple)
D. bulbifera (domestica)	underground	533*	1132	red	0·91 (purple)	275	orange oil	0·91 (purple) 0·50 (purple) 0·35 (red)
D. asclepiadea	aerial	25*	860	dark green		67	yellow	0·92
D. asclepiadea	underground	410*	250	(diosgenin-acetate, 9 mg)	0·96 (purple) 0·72 0·53	3497	(diosgenin, 617 mg)	0·97 (226 mg) 0·90 0·80 (purple)
D. gracillima	aerial	140	180	reddish orange	0·94 (purple)	520	reddish orange	0·91
D. gracillima	underground	900	133	yellowish	0·96 (purple) 0·91 0·81 (purple)	1815	(diosgenin)	0·98 0·62 0·31
D. izuensis	aerial	95	3101	dark greenish brown		872	dark brown	0·93 (purple) 0·90
D. izuensis	underground	65	498	yellowish brown	0·89 (purple)	681	(diosgenin)	0·97 (292 mg) 0·91 0·81 0·57

TABLE 4—continued

D. quinqueloba	aerial	160	2500	reddish brown	0·98 (purple)	1400	yellowish brown	0·91
D. quinqueloba	underground	655	1000	greenish brown	0·92	2530	(diosgenin)	0·97
								0·58
D. nipponica	aerial	120	70	yellowish orange	0·95	46	light yellow	0·92
					0·65			
D. nipponica	underground	420	200	*light yellow*	*0·63 (purple)*	1120	(diosgenin)	0·98
					0·51 (purple)			0·66
D. septemloba	aerial	280	900	reddish orange	0·98 (purple)	600	reddish orange	0·92
								0·65
D. septemloba	underground	1300				19700	(diosgenin, 1380 mg)	0·98
							(diosgenin-acetate,	0·91
							50 mg)	0·81
D. sititoana	aerial	211	644	dark brown	0·96 (purple)	182	yellow brown	0·90
D. sititoana	underground	347	3420	*yellowish brown*	0·95 (purple)	99	(diosgenin)	0·97
D. tenuipes	underground	415	400	reddish brown	0·37	7800	(diosgenin-acetate,	0·98
(Okamoto)					0·30		320 mg)	0·91
							(yamogenin-acetate,	0·67
							295 mg)	0·37
							(tokorogenin, 50 mg)	
D. tenuipes	underground	200*				1827	(diosgenin-yamgoenin,	
(Yawatano)							374 mg),	
							(tokorogenin, 4 mg)	
D. tenuipes	aerial	1950	832	(diotigenin)	0·54	36500	(diotigenin, 3081 mg)	
							(diotigenin, 1398 mg)	
							(tokorogenin-acetate,	
							17 mg)	

*Wet weight.

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