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Trace elements of Taiwanese *dioscorea* spp. using instrumental neutron activation analysis

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Abstract

Twenty-two varieties categorized into six distinct species of *dioscorea* spp. had their concentration of trace elements evaluated by instrumental neutron activation analysis. The various *dioscoreas* were planted in the same plantation area to effectively suppress the diversity from different planted land, thus, the disagreement between each trace element was concluded from the nature of various species of *dioscoreas* themselves. Nineteen trace elements were verified and a quantified index, AT, was introduced to help classify the elements. A smaller AT indicated a close consistency of the concentration for specific trace element in various *dioscorea*. Thus, K, Zn, and Rb were in Group 1, which had the minimum ATs, Cl, Na, Mg, Fe, Mn, Br, and Co were in Group 2, which had the medium ATs, while the remaining of the trace elements, V, As, Sb, Cu, Se, Al, La, Sc, and Sm were all in Group 3, which had the maximum ATs. The different ATs and various species of *dioscorea*s were also discussed. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: *Dioscorea*; Trace element; Neutron activation

1. Introduction

Dioscorea has gained increasing attention in Taiwan during the recent decade owing to its nutritional value and pleasing flavor (Ravindran & Wanasundera, 1992). *Dioscorea* was historically treated as an important medical herb to cure diarrhea and to aid body strengthening according to an ancient Chinese herb encyclopedia. The Taiwan Agricultural Research Institute (TARI) has continuously promoted *dioscorea* island-wide by surveying various species of *dioscorea*s that fulfill the nutritious requirement and satisfy the local palate. The TARI has also successfully explored the optimal circumstanices for raising various *dioscorea*s (Lui, Lin & Lu, 1998; Liu, 1999). The consumption of *dioscorea* has continuously increased over the last decade and many recipes have been developed to attract more consumers. Fig. 1 depicts the latest annual harvest in monetary value and plantation area. As shown, the steady growth trends peak at 1997 and drop afterwards due to the impact of the World Trade Organization agreement. The TARI is now focusing on popularizing a species that is both highly productive and nutritious. Thus, a connprehensive investigation for trace elements of Taiwanese *dioscorea* spp. via instrumental neutron activation analysis is performed herein to enhance the *dioscorea* spp. biochemical data and to suggest further areas of research.

2. Materials

Twenty-two varieties of *dioscorea* spp. were categorized into six distinct species and employed as the dominant samples herein (Table 1). TNG2, a new variety of *dioscorea* spp. developed by the TARI in 1996, is the most valuable among the chosen samples. TNG2 has become popular since 1997 because of its superior productivity and good taste. The distinct varieties of *dioscorea* are separated into white and red flesh categories, and each species is arranged by a number as each is assigned different code names according to their various shapes or sizes. In addition, the 22 varieties of *dioscorea* were planted and raised in the same plantation area to

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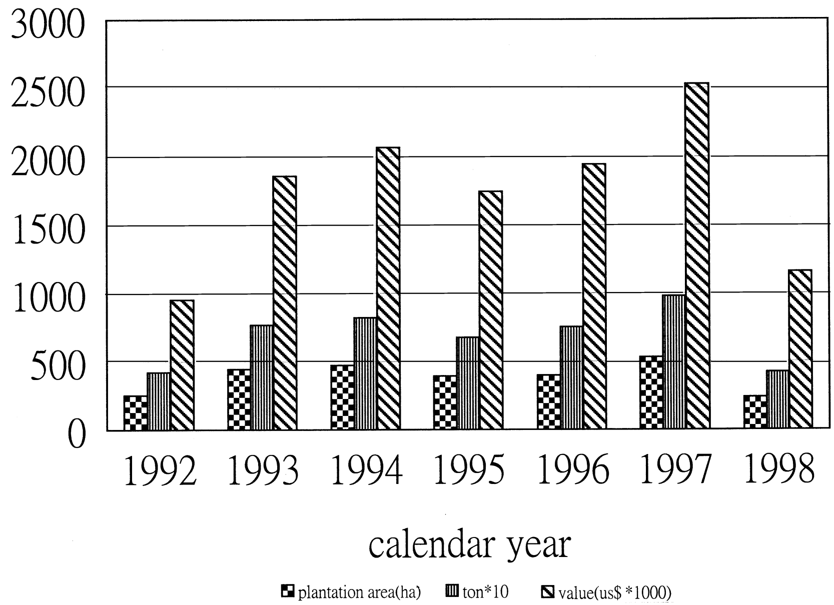

Fig. 1. Annual plantation area, harvest, and monetary value of *dioscorea* in islandwide of Taiwan.

Table 1
Various *dioscorea* elected in this work

Color of flesh	No.	Species	Code name	Size of *dioscorea*
White flesh	1	*Dioscorea alata* L.	70W01	Medium ($20 < l < 60$ cm)
	2	*Dioscorea alata* L.	70W03	Medium ($20 < l < 60$ cm)
	3	*Dioscorea alata* L.	70W09	Medium ($20 < l < 60$ cm)
	4	*Dioscorea alata* L.	70W22	Medium ($20 < l < 60$ cm)
	5	*Dioscorea alata* L.	70W34	Medium ($20 < l < 60$ cm)
	6	*Dioscorea alata* L.	70W35	Medium ($20 < l < 60$ cm)
	7	*Dioscorea alata* L.	70W47	Long ($l > 60$ m)
	8	*Dioscorea alata* L.	80W02	Medium ($20 < l < 60$ cm)
	9	*Dioscorea alata* L.	83CM302	Medium ($20 < l < 60$ cm)
	10	*Dioscorea alata* L.	TNG1	Short ($l < 20$ cm)
	11	*Dioscorea alata* L.	TNG2	Medium ($20 < l < 60$ cm)
	12	*Dioscorea batatas* Decne.	70W41A	Long ($l > 60$ cm)
	13	*Dioscorea batatas* Decne.	70W41B	Long ($l > 60$ cm)
	14	*Dioscorea batatas* Decne.	70W44	Long ($l > 60$ cm)
	15	*Dioscorea esculenta* (Lour.) Burk.	82US15	Short ($l < 20$ cm)
	16	*Dioscorea esculenta* (Lour.) Burk.	70W19	Short ($l < 20$ cm)
	17	*Dioscorea doryophora* Hance	70W20	Long ($l > 60$ cm)
	18	*Dioscorea japonica* Thunb.	70W49	Long ($l > 60$ cm)
Red flesh	19	*Dioscorea alata* L. var. *purpurea* M. Pouch	7016	Medium ($20 < l < 60$ cm)
	20	*Dioscorea alata* L. var. *purpurea* M. Pouch	70R20	Medium ($20 < l < 60$ cm)
	21	*Dioscorea alata* L. var. *purpurea* M. Pouch	70R22	Medium ($20 < l < 60$ cm)
	22	*Dioscorea alata* L. var. *purpurea* M. Pouch	83CM201	Medium ($20 < l < 60$ cm)

overcome any possible planted land diversity. Further, each species was sampled from part of 10–12 different *dioscorea* for roughly 5 kg of raw weight to maintain the homogeneity. The elected samples were washed, peeled, cut into pieces, dried (70°C for 36 h) and then smashed into powder. All powder samples were sealed, labeled, and placed into 22 glass vials that were kept in a refrigerator to maintain dryness for further application (Ibrahim, 1987).

3. Experimental methods

3.1. Preparation of activated samples

Each treated *dioscorea* sample, weighing 150–200 mg, was packed into a 3×3 cm^2 polyethylene bag for neutron irradiation. An empty bag of identical size was employed as a blank correction. Each bag was subsequently enveloped in a host polyethylene to prevent contamination prior to irradiation. The samples of each *dioscorea* species were prepared in triplicate to minimize the statistical uncertainty (Chung & Wei, 1997).

3.2. Activation and measurement of samples

The samples were irradiated in a Tsing Hua Open-pool Reactor with a neutron flux of 10^{12} n cm^{-2} s^{-1}. The activated samples were divided into short irradiation (5 min) and long irradiation (24 h). The short irradiation samples were counted after 2 min cooling. The 10 mg nickel powder irradiated together with each of the samples was also counted to correct the neutron fluctuation during irradiation. The long irradiation samples were counted in two stages according to the radio nuclide decay property in the activated sample. One group of samples were counted for 30 min after a 7–10 day decay period, while the other was counted for 2 h after a 30–45 day cooling period (Friedman & Tanner, 1977; Chuang Wang, Liu & Chung, 1991; Parr, Chatt, Reis & Abdulla, 1994). The activated sample was analyzed by a γ-ray detecting system that consisted of a 15% relative efficiency high purity germanium (HpGe) detector and a multichannel analyzer. In addition, the evaluated results were calibrated to a 160 mg standard lichen powder offered by IAEA336 in the same geometry form. The decay properties for the relevant radio nuclides are listed in Table 2 (Knoll, 1989; Shirley & Lederer, 1978).

Table 2
Radioactive decay properties of nuclides assayed in this work (the Ni-65 flux monitors are used for neutron fluence measurement)

Radionuclide	$T_{1/2}$[a]	E_γ keV	I_γ γ/decay
K-42	12.36 h	1524.7	0.179
Cl-38	37.21 m	2167.5	0.440
Na-24	15.00 h	1368.5	0.999
Mg-27	9.46 m	843.8	0.718
A1-28	2.24 m	1778.8	1.000
Fe-59	44.63 d	1099.2	0.565
Zn-65	244.4 d	1115.5	0.508
Cu-66	5.10 m	1039.0	0.090
Rb-86	18.66 d	1076.6	0.088
Mn-56	2.58 h	846.8	0.989
Br-82	35.3 h	776.5	0.833
V-52	3.75 m	1434.1	1.000
Co-60	5.27 y	1173.2	1.000
As-76	26.32 h	559.1	0.447
Se-75	120.4 d	280.0	0.23
La-140	40.22 h	1596.5	0.955
Sb-122	2.70 d	563.9	0.706
Sc-46	83.83 d	889.2	1.000
Sm-153	46.7 h	103.2	0.283
Ni-65*	2.52 h	1481.8	0.235

[a] m, minutes; h, hours; d, days; y, years.

4. Results

The *dioscorea* spp. data are classified and averaged according to their own species which are 11, 3, 2, 1, 1, and 4 varieties for *D. alata* L., *D. batatas* Decne., *D. esculenta* (Lour.) Burk., *D. doryophora* Hance, *D. japonica* Thunb. and *D. alata* L. var. *purpurea* M. Pouch. Table 3 illustrates that there is a total of 19 trace elements which were detected. Among these, K, Cl, and Na are indicated ml the unit of mg/g due to their abundant concentrations, whereas the others are indicated in μg/g. In addition, the last two columns of the table depicts (1) the average values plus/minus 1 standard deviation of the six *dioscorea*s species, and (2) the ratio of 1 standard deviation to the mean value which is defined as an agreement (AT) herein (Tsao & Pan, 1993, 2000) for easy classification. A larger AT value indicates a larger fluctuation of the specific trace element in the *dioscorea* spp. since the mean value ± 1 standard deviation may include approximately 68% of the total samples (Bevington, 1992).

5. Discussion

The AT (cf. Table 3) of each trace element is replotted in Fig. 2. The ATs can be roughly categorized into three groups: Group 1, AT < 30; Group 2, 30 < AT < 60; and Group 3, AT > 60. Thus, the trace elements K, Zn, Rb. V, As, and Sb are in Group 1; Cl, Na, Mg, Fe, Cu, Mn, Br, Co, and Se are in Group 2; while Al, La, Sc, and Sm are in Group 3. However, the evaluated concentrations of V, As, Sb (Group 1) and Cu, Se (Group 2) are treated as Group 3 trace elements because they are below the detection limit in some species which may cause significant discrepancy with others. Thus, the following discussions and recommendations focus on the basis of various groups and detail the unique varieties of the *dioscorea* evaluated herein.

5.1. Various groups of AT

5.1.1. AT < 30

Trace elements in this group do not contribute much to the judging of superior *dioscorea*s because they have similar concentration in each *dioscorea* species.

5.1.2. 30 < AT < 60

The fluctuation of various trace elements concentrations in this group is comparatively larger than that in Group 1. More specifically, the concentration of Cl in *D. alata* L. var. *purpurea* M. Pouch. is approximately 5.12 timnes more than that in *D. esculenta* (Lour.) Burk., whereas it is also around 3.80 times difference in the concentration of *D. batatas* Decne. and *D. japonica* Thunb.

Table 3
Evaluated concentration of trace elements for various species of *dioscorea*[a]

Trace element	Species (no. of variety)							
	Dioscorea alata L. (11)	*Dioscorea hatatas* Decne. (3)	*Dioscorea escaleota* (Lour.) Burk. (2)	*Dioscorea doryophora* Hance (1)	*Dioscorea japonica* Thunb. (1)	*Dioscorea alata* L. var. *purpurea* M. Pouch (4)	Average±σ	$AT\left(\frac{\sigma}{avg.}\times 100\%\right)$
K (mg/g)	1942±0.52	20.20±095	17.60±1.18	14.40±1.40	23.30±0.80	24.98±1.29	19.98±3.82	194
Cl (mg/g)	1.43±0.05	1.61±0.14	0.62±0.13	1.73±0.33	2.70±0.21	3.18±0.81	1.88±0.92	49.0
Na (mg/g)	0.20±0.01	0.15±0.01	0.20±0.01	0.34±0.01	0.11±0.02	0.20±0.01	0.20±0.01	39.0
Mg (μg/g)	364.4±19.0	759.3±25.2	339.5±29.1	493.0±5.00	591.0±61.0	426.5±18.0	495.6±158.2	31.9
Al (μg/g)	154.10±5.97	38.00±6.45	97.00±4.00	27.00±12.00	209.0±28.0	44.75±1.37	94.97±73.34	77.2
Fe (μg/g)	87.68±1.73	66.03±1.87	126.50±5.62	67.20±4.80	45.90±1.10	47.75±1.49	73.51±30.10	41.0
Zn (μg/g)	24.82±0.77	29.70±1.51	16.00±0.80	21.20±2.60	23.40±2.40	20.80±1.49	22.65±4.58	20.2
Cu (μg/g)	2.163±0.078	1.737±0.107	1.205±0.050	<LLD	0.300±0.080	2.088±0.162	1.498±0.769	51.3
Rb (μg/g)	2.680±0.081	2.577±0.152	2.490±0.55	3.270±0.350	4.700±0.090	3.345±0.161	3.177±0.829	26.1
Mn (μg/g)	1.636±0.067	3.577±0.109	2.615±0.114	1.390±0.280	0.940±0.100	2.328±0.081	2081±0.955	45.9
Br (μg/g)	1.505±0.044	1.667±0.043	1.045±0.0.57	0.350±0.020	1.360±0.100	1.423±0.064	1.225±0.475	38.8
V (μg/g)	0.306±0.014	<LLD	0.405±0.060	<LLD	0.300±0.040	0.450±0.062	0.365±0.074	20.3
Co (μg/g)	0.098±0.002	0.074±0.002	0.083±0.104	0.046±0.004	0.042±0.003	0.103±0.004	0.074±0.026	34.5
As (μg/g)	0.099±0.007	0.092±0.007	<LLD	0.113±0.024	0.075±0.013	<LLD	0.095±0.016	16.6
Se (μg/g)	0.049±0.004	0.059±0.011	0.058±0.15	<LLD	0.042±0.004	0.092±0.012	0.060±0.019	32.1
La (μg/g)	0.099±0.005	0.083±0.004	0.118±0.010	0.021±0.002	0.025±0.006	0.028±0.002	0.062±0.043	68.8
Sb (μg/g)	0.017±0.001	0.014±0.002	0.013±0.002	<LLD	<LLD	0.018±0.003	0.015±0.002	15.2
Sc (μg/g)	0.028±0.001	0.011±0.003	0.056±0.003	0.010±0001	0.010±0.002	0.011±0.001	0.021 ±0.019	877
Sm (μg/g)	0.022±0.001	0.005±0.001	0.015±0.004	0.005±0.001	<LLD	0.006±0.001	0.010±0.007	72.4

[a] The right-hand column shows the average and 1 standard deviation of these six species to imply the fluctuation of each trace element in various *dioscoreas*.

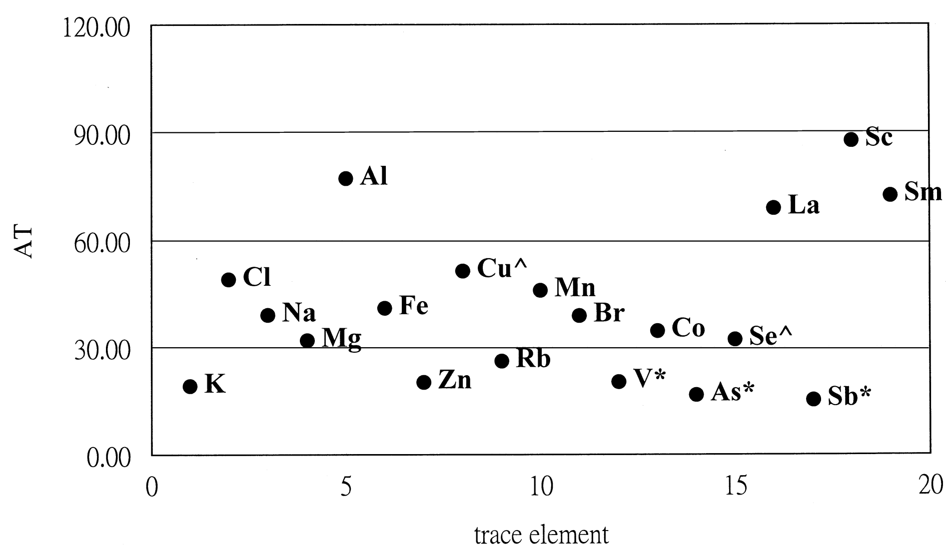

Fig. 2. AT of various trace elements verified in this study.

5.1.3. *AT>60*

Concentrations of trace elements in this group have apparently giant fluctuations. For instance, the maximum concentration of Cu is 0.300 μg/g in *D. japonica* Thunb but is negligible in *D. doryophora* Hance. The Sb cannot be verified in both *D. japonica* Thunb and *D. doryophora* Hance, but the concentration of Sb is consistent in other species (the AT of Sb is 15.2). The La, Sc can be verified in all the species except the concentration deviated from 0.021 to 0.118 μg/g and 0.010 to 0.056 μg/g, respectively. The disagreement between the trace elements in various species does imply significant difference in trace element absorption because all 22 varieties of *dioscorea* were planted in the same plantation area.

5.2. *Various species of* dioscorea

The following discussion focuses on the nature of various *dioscorea*s species because the absorption of trace elements in various species of *dioscorea*s do have giant discrepancies as previously mentioned.

5.2.1. D. alata *L.*

The most popular choice in Taiwan, *D. alata* L. has all 19 trace elements evaluated in this work. Concentrations for 18 out of 19 trace elenients were between the average with 1 standard deviation, yet the Sm had the highest concentration. The 11 varieties included in this species have a similar concentration in most nuclides whereas As can only be measured in 70W01, 70W09, 70W47, 80W02, and the TNG2 varieties. The TNG2 variety has a moderate concentration of those trace elements within this species. The precise data of the TNG2 and another major variety, TNG1, which is also a unique variety developed by TARI with elliptic shape and smaller size, are displayed in Table 4. In addition, the data of *D. alata* L. planted in Malaysia and Sri Lanka are listed in the same table for comparison (Ibrahim, 1994; Ravindran & Wanasundera, 1992).

5.2.2. D. batatas *Decne*

Planted mostly in northern Taiwan, and recommended by traditional Chinese medical doctors as the most reputable species of *dioscorea*, *D. batatas* Decne contains many of the trace elements verified in this study. The coiiceritrations of Mg, Zn, or Mn are above average with 1 standard deviation, although the quantity of V is negligible.

5.2.3. D. esculenta *(Lour.) Burk.*

Although this species is internationally accepted, TARI has still stepped in to localize its production and popularity (Figueiredo-Ribeiro & Chu, 1991; Shoemaker, 1989). While the deficiency of Cl arid As must be examined, the bountiful concentrations of Fe, La and Sc demonstrates this species is very nutritious.

5.2.4. D. doryophora *Hance*

This variety has been planted in southern Taiwan and the deficiency of more than eight trace elements argues against extending the plantation area. The same holds true for *D. japonica* Thunb. since more than seven trace elements are below average with 1 standard deviation.

5.2.5. D. alata *L. var.* purpurea *M. Pouch*

Although this species is only planted in the middle part of Taiwan, unlike the rest of the species being evaluated herein this species has been widely accepted by Taiwanese consumers because of its unique red flesh and taste. Furthermore, the plentiful concentrations of K, Cl, V, and Co also supports its merits.

The existence of all 19 trace elements verified in the *dioscorea* spp. shows the essential role of this food in the Taiwanese diet. *Dioscorea* spp. is consumed both as a daily food and as a traditional medical herb. In addition, the TARI has revised the conventional planting process to upgrade both the qualitative and quantitative attributes of this product. The unique variety, TNG2

Table 4
Evaluated concentration of trace elements for TNG1, TNG2 and quoted data for *D. alata* L. which were planted in Malaysia and Sri Lanka, respectively

Trace element	Sample			
	TNGI	TNG2	*D. alata* L. (Malaysia)	*D. alata* L. (Sri Lanka)
K (mg/g)	26.30±0.31	24.90±0.23	17.00±2.00	16.00±3.00
Cl (mg/g)	1.20±0.16	0.48±0.02	–	–
Na (mg/g)	0.10±0.01	0.20±0.02	2.30±0.20	0.68±0.10
Mg (μg/g)	537.0±93.0	267.0±53.0	–	700.0±30.0
Al (μg/g)	59.0±11.0	312.0±30.0	–	–
Fe (μg/g)	85. 10±5.20	36.90±0.90	150.0±2.0	105.0±3.0
Zn (μg/g)	34.10±6.00	22.20±1.10	52.0±4.0	40.0±3.0
Cu (μg/g)	2.360±0.220	1.380±0.300	–	66.0±11.0
Rb (μg/g)	0.890±0.100	3.520±0.350	7.0±1.0	–
Mn (μg/g)	1.120±0.090	3.080±0.300	–	–
Br (μg/g)	0.930±0.060	1.630±0.070	14.0±2.0	–
V (μg/g)	0.530±0.010	0.520±0.090	–	–
Co (μg/g)	0.064±0.005	0.142±0.010	–	–
As (μg/g)	<LLD	0.142±0.021	–	–
Se (μg/g)	0.042±0.015	0.054±0.014	–	–
La (μg/g)	<LLD	0.039±0.007	0.180±0.090	–
Sb (μg/g)	0.014±0.002	0.027±0.005	0.014±0.002	–
Sc (μg/g)	0.011±0.001	0.096±0.004	0.030±0.005	–
Sm (μg/g)	0.021±0.004	0.054±0.006	0.030±0.010	–

fertilized with organic mixture (cowpat compound 33%, cane draff 64%) can produce as much as 63.2 t/ha a year. In contrast, the annual productive quantity for TNG2 can still reach 26.6 t/ha using conventional fertilizer, which is superior to any other species under the same circumstances. The long-standing application of *dioscorea* as an important medical herb has also been supported by modern researchers (Nakamura, Kameoka, Miazawa & Shimamura, 1996; Nelson-White, Eskelson, Araghininam & Chung 1996; Wang, Liu & Tseng, 1999). *Dioscorea* can compete with other miedicinal herbs, such as ganoderma lucidum or ginseng, because it is just a fraction of the price (Chang, Yang, Wang & Duo, 1996; Pardeshi & Rajurkar, 1997).

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