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ORIGINAL ARTICLE

Rice traceability system in Taiwan

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Keywords
brown rice; ICP; Japonica rice; NIR; rice traceability.

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Abstract

Introduction Taiwan utilizes a voluntary Agricultural Products Traceability Certification System. This system was implemented in 2007 under the 'Agricultural Production and Certification Act.' Since then, certain agricultural products have been certified using a label that includes product name, trace code, public information, and the Traceability Agricultural Product logo. Consumers can easily identify the traceability information through the bar code reader in the store. Being the staple food in Taiwan, rice plays an important role in the Traceability Certification System. In the east part of Taiwan, where there is a well-established rice traceability system, the rice provides higher added value in both the local market and international markets. *Methods* Generally speaking, the traceability system is based on the document and recording systems used on farms and in food-processing plants. In order to use scientific evidence to identify rice origins, near-infrared spectroscopy and inductively coupled plasma element analysis were used to determine rice origins from the north, middle, south, and east parts of the island. Rice varieties and planting methods were considered as well as geographic origins. Eighty-three paddy rice samples were collected island wide, including japonica cultivars of TK2, TK9, TN11, and T71. During processing, all samples were hulled and milled under the same conditions. Brown rice and milled rice were analyzed separately using both near-infrared and inductively coupled plasma methods. *Results* Results show that near-infrared and inductively coupled plasma methods are able to statistically significantly distinguish the rice geographic authenticity for the same rice cultivars, regardless of whether the samples were brown rice or milled rice. *Conclusions* When testing different cultivars of japonica rice from different areas, the near-infrared method produced more accurate results for brown rice, whereas the inductively coupled plasma method produced better results for milled rice from different areas.

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Introduction

Today the geographical origin tracing of major agricultural products plays an important issue in commerce. The earlier studies on the geographical origin of rice were carried out by distinctions of morphology, or by some physical and chemical indicators to analyze the parameters related to location of their agricultural production. Near-infrared (NIR) spectrum profiles may be applied to discriminate the geographical origins of rice by slight differences in organic functional groups and chemical bonding. Previous studies have provided illustrations of crops origin tracing using an NIR spectrum photometer. The origins of coconut oil were identified geographically by NIR measurement (Chaiseri & Dimick, 1989). Furthermore, Natsuga and Kawamura (2006) analyzed the NIR spectra of herbs to distinguish their origins.

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In origin studies on rice, reflective NIR technology was used to analyze chemical and physical properties such as moisture, protein, fatty acids, starch (amylogram), and others, offering rapid information to indirectly trace rice origins (Natsuga & Kawamura, 2006). In a similar instance, NIR technology had been used to differentiate Indian Basmati from other rice cultivars through statistical analysis of scanning profiles (Osborne *et al*., 1993). Reflective NIR analysis can characterize between domestic and imported rice in South Korea (Kim *et al*., 2003). It also could check the adulteration ratio during the milling process in Japan (Rittiron *et al*., 2005).

Research on rice origin tracing began as early as the year 2000, and distinguished different rice origins through their composition of trace elements. To measure the precise differences in trace elements, inductively coupled plasma-atomic emission spectrometer (ICP-AES) or inductively coupled plasma-mass spectrometer (ICP-MS) were used to analyze the variance of mineral element contents. Experimental results revealed that trace element distributions could identify the origins of the brown rice from different geographical regions in Japan (Yasui & Shindoh, 2000). Kelly *et al*. (2002) utilized both trace element and isotope methods to analyze the compositional differences in rice. The consequences were that by combining both kinds of element ratio analyses, they were able to detect Basmati from different originating countries. Using the stable isotope and trace element studies with radar chart analysis, they found that Koshihikari rice with different geographic origins could be distinguished (Suzuki *et al*., 2008a, b).

Rice is a staple food in Taiwan, with multiple cultivars of rice being bred and planted. However, cultivars are considered to influence the results of rice origin studies of authenticity. For *Oryza sativa* japonica rice, ICP-AES was used to detect trace elements. Those results presented significant differentiation of rice samples of western origin from those higher priced samples having an eastern origin in Taiwan (Chen, 2005).

In this study, ICP-AES element analysis and NIR technology are both used to detect and resolve the geographical origin of same and different cultivars for both brown and milled rice samples.

Materials and methods

Sample collection and preparation

Paddy rice samples were collected from two sources. The first sample set was obtained from the District Agricultural Research and Extension Stations (DARES) in Taoyuan, Miaoli, Taichung, Tainan, Kaohsiung, Hualien, and Taitung, and the Taiwan Agriculture Research Institute, as identified in Table 1. Every DARES collected at least two paddy samples from each of their responsible counties. There were 39 paddy rice samples from the DARES set. The second source was samples collected from the rice farming groups, as shown in Table 2. In total 44 paddy rice samples were provided from two farming groups and were pure cultivars produced under uniform planting procedures. Samples from these two farming groups stood as authenticity for eastern and western origins. The cultivars of paddy rice sample included mainly TK2, TK9, with some TN11 and T71.

All the paddy rice samples were hulled using a Satake Paddy Husker (Satake USA Inc, Stafford, TX, USA) at a 20% hulling rate. Half of each de-hulled sample was milled by a McGill No. 2 (Rapsilver Supply Co. Inc, Brookshire, TX, USA) rice miller to remove 10% by weight of the brown rice. Both brown and milled rice samples were then analyzed.

NIR classified analysis

All the brown and milled rice samples were scanned by a Buchi NIRFlex N-500 (Buchi Co., New Castle, DE, USA),

Table 1 Samples collected from local District Agricultural Research and Extension Stations (DARES)

Geographic regions	DARES	Sample code	Cultivar
North	Taoyuan, TY	TY01-TY05	TK9
	Miaoli, ML	ML01-ML04	TK9
Middle	Taichung, TZ	TZ01, TZ03, TZ05, TZ07, TZ09, NS02	TK9
		TZ02, TZ04, TZ06, TZ08, TZ10	TN11
		NS01	T71
South	Tainan, TN	TN01-TN04	TN11
		TN05-TN06	TK9
	Kuohsiung, GX	GX01-GX03	TK2
		GX04-GX05	TN11
East	Hualien, HL	HL01-HL03	TK9
		HL04	TN11
	Taitung, TD	TD01-TD03	TK9

Table 2 Samples collected from rice Farming Groups (FG)

Geographic regions	FG	Sample code	Cultivar
South	Fengrong, FR	FR01-FR04, FR08, FR10-FR15	T71
		FR05-FR07, FR09	TK2
East	Dongfeng, DF	DF01-DF24, DF51-DF55	TK2

with spectral range from 10 000–4000 cm^{-1} (1000–2500 nm) in 8 cm^{-1} intervals. Each sample was automatically scanned 32 times and then repeated five times to reduce the deviation from non-homogeneous samples. All the NIR spectra were calibrated by built-in software, NIRCal 5.2, and clustered through principle component analysis. The protocol of well-separated clusters is to pre-treat the spectra by their first derivative (First Derivative BCAP) and then regress using closure normalization. The recommended spectral ranges were 4400–4800, 5400–6600, and 7800–10 000 cm^{-1} for classified analysis.

ICP/AES analysis

ICP/AES (JOBIN YVON JY 50 P & JOBIN YVON ULTIMA 2C; Horiba International Co., Kyoto, Japan) was used to measure multiple elements. The macro-elements (calcium, magnesium, potassium, and phosphorus) were measured in percentage, and the micro-elements (iron, manganese, copper, and zinc) were measured in milligrams per kilogram. All the samples were pre-treated by acidic digestion as in the general Kjeldahl method. Duplicate ICP/AES measurements were taken for each sample. The elemental contents from ICP/AES were classified and analyzed by SPSS software for canonical discriminant analysis.

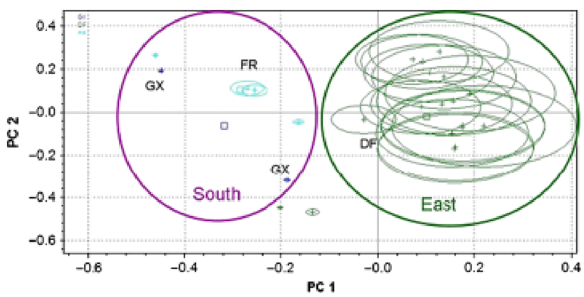

Figure 1 NIR classified analysis for TK2 brown rice.

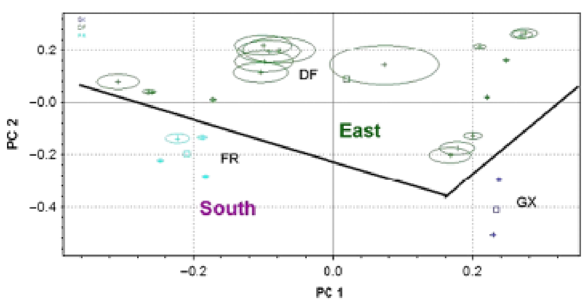

Figure 2 NIR classified analysis for TK2 milled rice.

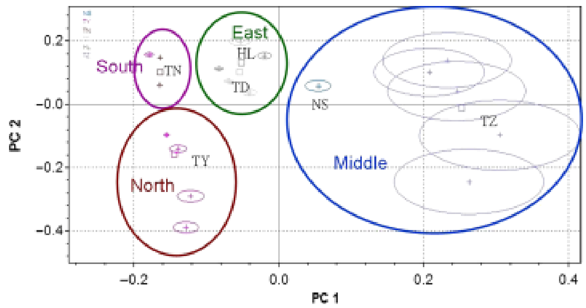

Figure 3 NIR classified analysis for TK9 brown rice.

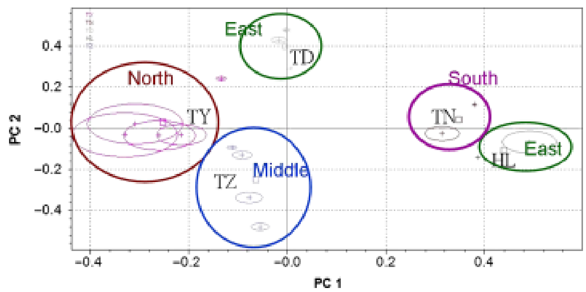

Figure 4 NIR classified analysis for TK9 milled rice.

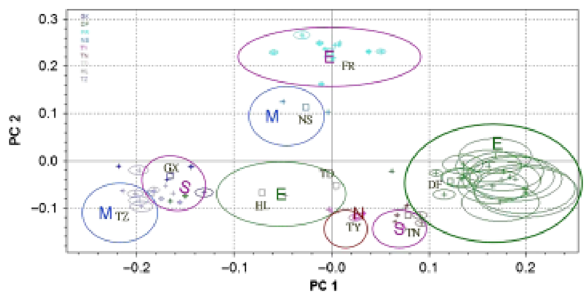

Figure 5 NIR classified analysis for brown rice with all cultivars.

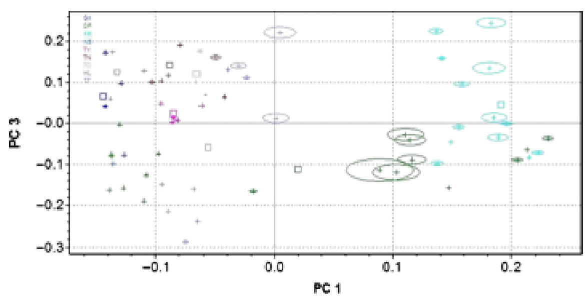

Figure 6 NIR classified analysis for milled rice with all cultivars.

Statistical analysis

To identify the influences of cultivars on the differentiation of rice origins, data from both NIR classified analysis and ICP/AES discriminant analysis were analyzed statistically

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Table 3 Element contents of brown rice samples

Area	Samples	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
North	TY01-B	0.27061	0.284608	0.020698	0.102396	10.731	23.680	4.659	29.850
	TY02-B	0.30091	0.268508	0.021496	0.112776	11.430	24.490	4.720	32.920
	TY03-B	0.29221	0.277108	0.024596	0.105466	11.105	31.030	4.834	31.440
	TY04-B	0.26851	0.272208	0.021986	0.096936	10.743	28.650	5.565	32.370
	TY05-B	0.25661	0.245008	0.021647	0.095696	9.254	18.887	3.814	23.940
Middle	NS02-B	0.31981	0.285208	0.020812	0.108856	8.699	22.010	4.509	23.970
South	TN01-B	0.26611	0.249108	0.020253	0.084676	8.490	15.557	3.173	17.605
	TN02-B	0.32181	0.296008	0.018212	0.111706	13.703	25.590	3.607	25.860
	TN03-B	0.28051	0.241508	0.016837	0.095426	10.123	18.757	3.573	24.510
	TN04-B	0.26951	0.256908	0.016233	0.090106	9.665	16.564	3.963	20.628
	TN05-B	0.27211	0.249408	0.019109	0.098176	9.714	27.690	4.661	25.930
	TN06-B	0.27481	0.241108	0.020045	0.093316	9.352	25.610	3.897	25.490
	FR01-B	0.31681	0.264108	0.020774	0.119096	12.159	26.330	4.833	24.560
	FR02-B	0.29421	0.257408	0.016818	0.092736	9.120	33.800	4.503	22.770
	FR03-B	0.29891	0.255808	0.019781	0.095486	12.153	18.662	4.373	23.240
	FR04-B	0.30261	0.270308	0.019949	0.100386	12.523	19.998	4.030	24.940
	FR05-B	0.29681	0.254708	0.017385	0.103866	8.997	22.690	3.542	24.510
	FR06-B	0.27391	0.230808	0.020145	0.094916	8.961	20.262	3.855	25.140
	FR07-B	0.28001	0.247508	0.019928	0.098506	9.879	21.460	3.139	21.603
	FR08-B	0.28881	0.265408	0.018075	0.094426	14.418	22.590	4.103	23.740
	FR09-B	0.27171	0.253208	0.018374	0.098266	9.228	21.820	3.645	25.580
	GX02-B	0.28031	0.242908	0.017533	0.098826	9.841	16.455	4.597	23.230
	GX03-B	0.26641	0.262008	0.020706	0.090106	9.157	28.280	3.597	20.785
	GX04-B	0.25771	0.227908	0.015000	0.093056	8.828	15.754	4.637	17.963
	GX05-B	0.25291	0.241008	0.020671	0.092116	10.921	23.610	5.427	23.180
East	HL02-B	0.31191	0.263008	0.020024	0.114226	9.695	19.137	4.031	22.510
	HL03-B	0.28951	0.266108	0.019471	0.095966	11.513	17.883	4.539	21.891
	HL04-B	0.31271	0.260308	0.019350	0.114806	10.736	21.790	4.958	29.290
	DF01-B	0.30991	0.269108	0.020993	0.111606	9.332	16.573	3.783	26.140
	DF02-B	0.28991	0.253608	0.018792	0.100386	9.008	18.968	4.093	26.760
	DF03-B	0.28721	0.241408	0.021786	0.102266	9.890	15.208	3.813	25.020
	DF04-B	0.31781	0.267408	0.019505	0.114276	10.823	23.830	3.803	23.730
	DF05-B	0.28621	0.242908	0.017816	0.101406	8.962	21.297	3.858	22.200
	DF06-B	0.29131	0.250908	0.021906	0.103206	10.253	15.073	3.644	24.230
	DF07-B	0.31861	0.271808	0.019384	0.111846	9.981	19.389	4.718	30.370
	DF08-B	0.30701	0.257808	0.018136	0.102516	8.856	19.025	5.005	34.080
	DF12-B	0.30591	0.258608	0.021206	0.105726	9.164	16.184	4.257	31.230
	DF14-B	0.32121	0.271708	0.020078	0.108606	10.112	17.673	4.239	29.320
	DF21-B	0.33691	0.278708	0.021706	0.117236	10.571	22.910	4.496	34.750
	DF23-B	0.34031	0.282308	0.020548	0.118346	12.492	25.210	4.433	25.210
	DF24-B	0.31711	0.262508	0.017878	0.109646	9.516	22.520	3.924	23.730
	TD01-B	0.32201	0.263908	0.021725	0.117876	10.675	21.670	5.013	30.190
	TD02-B	0.30441	0.251708	0.018940	0.110976	9.866	20.610	4.984	29.390
	TD03-B	0.28811	0.246308	0.019775	0.100566	11.208	21.273	4.698	25.170

for both brown and milled rice with TK2, TK9, and all cultivars.

Results and discussion

NIR spectroscopy

NIR spectroscopy was used to scan all brown and milled rice samples. All the data were finally clustered by classified analysis. The NIR classified analysis of brown and milled rice samples for Tk2, Tk9, and all cultivars are discussed separately. From the plant breeders' information, TK2, with higher resistance to rice blast disease and insect damage, is good for organic planting. It can be distinguished from FR samples to DF samples for both brown and milled rice (Figures 1 and 2). Another sample of cultivar TK2 from GX

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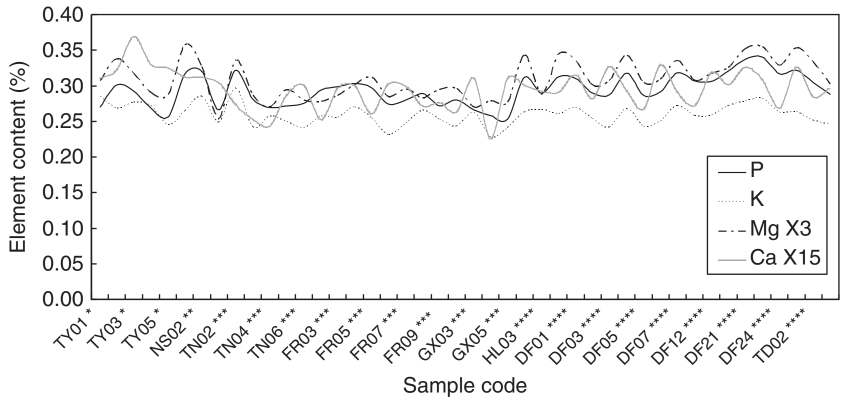

Figure 7 Macro-elements (P, K, Mg, Ca) contents of brown rice. Samples from north area, **samples from middle area, ***samples from south area, **** samples from east area.

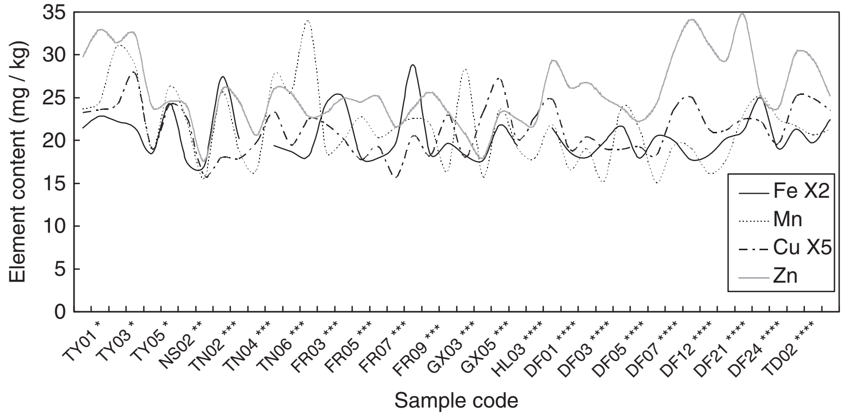

Figure 8 Micro-elements (Fe, Mn, Cu, Zn) contents of brown rice. *Samples from north area, **samples from middle area, ***samples from south area, ****samples from east area.

is classified to the group of samples FR, which are both from the south of Taiwan.

TK9 is a common cultivar planted among the north, middle, south, and east areas. For both brown and milled rice sample, their origins can be identified discriminately, as shown in Figures 3 and 4.

If samples from all the cultivars are analyzed by NIR classified analysis, brown rice samples are easier to be distinguished for their origins than are milled rice samples, as shown in Figures 5 and 6.

Multiple element analysis

The contents of macro-elements (calcium, magnesium, potassium, and phosphorus) and micro-elements (iron, manganese, copper, and zinc) of brown rice samples (Table 3) are grouped by their planting regions including north, middle, south, and east parts of Taiwan, as shown in Figures 7 and 8. The calcium contents of brown rice samples from the northern area are higher than those from the southern area. The magnesium, zinc, and copper contents of brown rice samples from the north and east regions are comparatively higher. It was also observed that the bran layers of rice samples from the north are thicker than those from other regions.

For the milled rice samples, the contents of macro- and micro-elements (Table 4) are shown as Figures 9 and 10, according to their origins. In comparing brown and milled rice for most elements their contents were reduced by milling, except for calcium. For magnesium, zinc, and copper, the milled rice from the southern area is generally lower. The data for multiple element analyses were then subjected to canonical discriminant analysis. TK9 rice samples were selected to run the discriminant analysis in order to remove the cultivar influence. Canonical discriminant analysis discriminated between both TK9 brown and milled rice samples from Taoyuan (TY, north), Tainan (TN, South), Taitung (TD, east), and Hualien (HL, east), as

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Table 4 Element contents of milled rice samples

Area	Samples	P (%)	K (%)	Ca (%)	Mg (%)	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Cu (mg kg^{-1})	Zn (mg kg^{-1})
North	TY01-A	0.07856	0.096068	0.014900	0.017645	2.480	6.631	4.294	22.720
	TY02-A	0.10706	0.114208	0.015852	0.027576	3.314	8.348	4.232	22.970
	TY03-A	0.14787	0.141508	0.017470	0.042646	7.863	14.080	4.370	25.080
	TY04-A	0.11896	0.122778	0.015115	0.033406	5.183	10.488	5.250	24.620
	TY05-A	0.08971	0.099308	0.014693	0.022786	2.210	6.408	3.455	17.241
South	TN01-A	0.08229	0.100268	0.013297	0.015034	4.347	6.106	2.846	10.909
	TN02-A	0.09813	0.105588	0.012778	0.021446	3.295	8.664	3.036	15.738
	TN03-A	0.10032	0.090168	0.012737	0.023066	2.732	7.499	3.316	16.274
	TN04-A	0.07804	0.083448	0.012538	0.014626	2.126	4.940	3.307	11.058
	TN05-A	0.07527	0.079998	0.013170	0.014375	4.178	7.572	4.135	17.267
	TN06-A	0.08407	0.085308	0.012882	0.017583	2.278	7.592	3.241	16.840
	FR01-A	0.09286	0.080118	0.014787	0.021216	2.530	7.227	3.869	13.288
	FR02-A	0.07595	0.073828	0.013258	0.011299	2.944	8.865	7.800	14.237
	FR03-A	0.09456	0.080028	0.012344	0.018473	3.258	5.875	3.733	14.043
	FR04-A	0.07700	0.074378	0.012502	0.012255	2.964	5.637	3.272	16.259
	FR05-A	0.08326	0.082948	0.012511	0.017308	4.684	7.794	2.726	16.350
	FR06-A	0.09396	0.085198	0.013826	0.021606	2.866	7.433	3.359	18.697
	FR07-A	0.10746	0.098648	0.014206	0.027066	4.022	8.486	2.557	15.559
	FR08-A	0.07880	0.083938	0.012703	0.013312	3.570	6.339	3.279	14.423
	FR09-A	0.07244	0.079418	0.012910	0.014996	2.255	6.718	3.238	16.221
	GX02-A	0.09649	0.098808	0.011967	0.021656	2.477	6.243	3.913	15.938
	GX03-A	0.09699	0.104748	0.013266	0.022456	1.775	9.424	3.172	14.035
	GX04-A	0.09042	0.100568	0.011688	0.020226	2.682	6.212	4.195	11.526
	GX05-A	0.09344	0.098238	0.011236	0.021956	2.340	8.748	4.298	15.443
East	HL02-A	0.10206	0.092338	0.014350	0.025266	3.295	6.515	3.520	16.406
	HL03-A	0.11131	0.107528	0.013536	0.026956	2.713	7.223	4.150	16.451
	HL04-A	0.10967	0.095768	0.012936	0.030006	2.502	7.738	4.172	20.284
	DF01-A	0.09765	0.092728	0.014364	0.023746	3.241	5.294	3.320	19.059
	DF02-A	0.10115	0.097278	0.014050	0.023436	3.131	7.048	3.630	18.568
	DF03-A	0.09632	0.090228	0.013043	0.021566	1.515	5.828	3.240	18.352
	DF04-A	0.09806	0.095208	0.013123	0.022646	2.054	7.727	3.268	16.531
	DF05-A	0.09765	0.094388	0.013920	0.022556	3.033	7.851	3.408	16.496
	DF06-A	0.09850	0.094788	0.014707	0.022796	2.080	5.461	3.480	17.922
	DF07-A	0.11164	0.099708	0.013445	0.027706	3.073	7.419	4.279	21.514
	DF08-A	0.09439	0.088098	0.014735	0.020156	3.092	6.870	4.149	21.371
	DF12-A	0.09348	0.083828	0.014542	0.021106	2.999	4.973	3.553	19.819
	DF14-A	0.09223	0.080048	0.013385	0.018976	2.497	6.045	3.633	20.237
	DF21-A	0.08213	0.078628	0.013717	0.016718	2.102	6.124	3.677	20.559
	DF23-A	0.12256	0.107618	0.015418	0.031556	4.041	8.521	4.039	19.189
	DF24-A	0.13626	0.122188	0.014581	0.036326	4.462	9.382	3.822	19.430
	TD01-A	0.12466	0.127428	0.020246	0.031806	5.017	7.248	4.035	21.414
	TD02-A	0.10255	0.085988	0.014029	0.025586	2.602	6.676	4.439	21.269
	TD03-A	0.10401	0.088668	0.014352	0.025866	1.937	6.516	4.076	18.957

shown in Figure 11. For samples of all cultivars, Figure 12, the ICP/AES identification for milled rice was better than for brown rice when considering different origins.

Conclusions

Results show that NIR and ICP methods are able to distinguish rice geographic authenticity for the same cultivar, regardless of whether they are brown or milled rice. When testing different varieties of japonica rice from different origins, the NIR method produced more accurate results for brown rice, whereas the ICP method produced better results for milled rice. Further study and more data will be necessary to establish a comprehensive database for authentically identifying a rice sample's origin.

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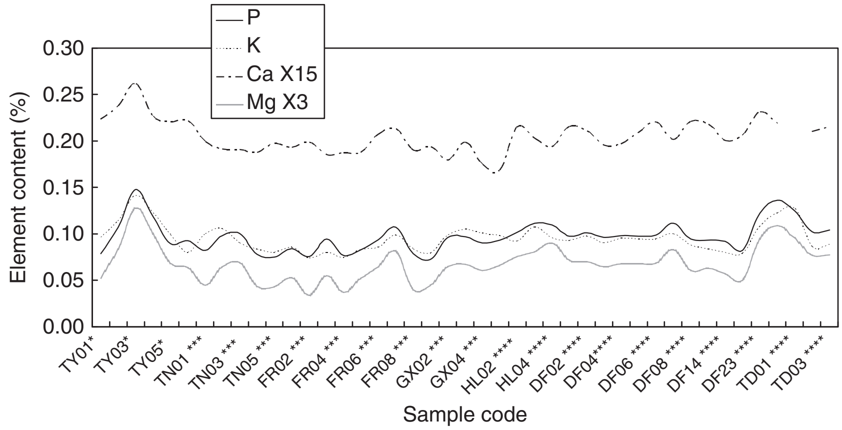

Figure 9 Macro-elements (P, K, Mg, Ca) contents of milled rice. *Samples from north area, **samples from middle area, ***samples from south area, ****samples from east area.

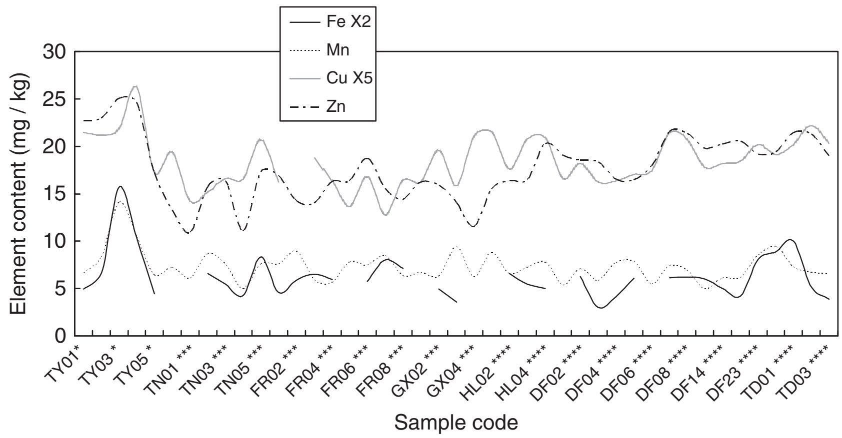

Figure 10 Micro-elements (Fe, Mn, Cu, Zn) contents of milled rice. *Samples from north area, **samples from middle area, ***samples from south area, ****samples from east area.

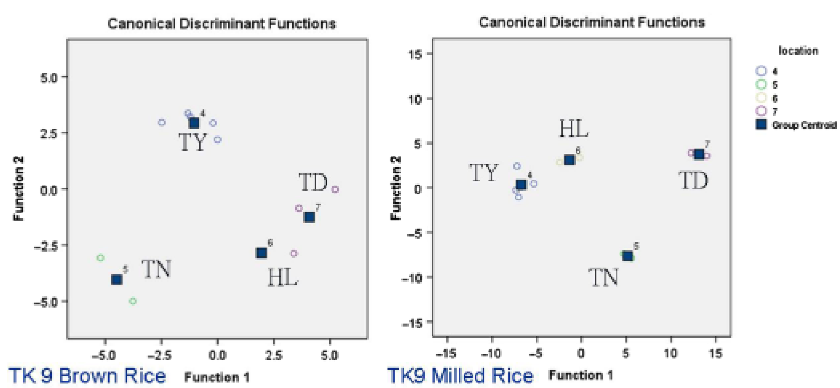

Figure 11 Canonical discriminant analysis for TK9 brown and milled rice. (A) For TK9 brown rice, (B) for TK9 milled rice.

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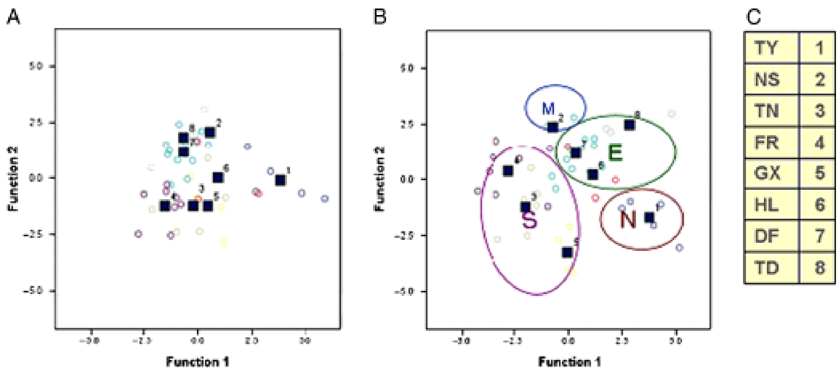

Figure 12 Canonical discriminant analysis for brown and milled rice of all cultivars. (A) For brown rice of all cultivars, (B) for milled rice of all cultivars, (C) sample codes of different area.

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