African Crop Science Journal, Vol. 12. No. 3, pp. 205-216, 2004
Printed in Uganda.
ISSN 1021-9730/2004 $ 4.00

GENOTYPE X ENVIROMENT INTERACTION EFFECTS ON NATIVE CASSAVA STARCH QUALITY AND POTENTIAL FOR STARCH USE IN THE COMMERCIAL SECTOR

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ABSTRACT

Cassava (*Manihot esculenta* Crantz) is the second most important staple food crop in sub-Saharan Africa, providing upto 285 calories per person per day. Cassava starch is a potentially important industrial material in Malawi. Industries hesitate to use cassava starch because the powder sold by some suppliers has been grossly inadequate. This study was conducted to evaluate native cassava starch qualities for different Malawi cassava genotypes, determine the appropriate stability parameter to deal with GxE for starch quality traits, and potential for use of cassava starch by the main industries in Malawi. Trials were conducted in Malawi to examine starch quality parameters, root dry mater and starch extraction. Based on the results, the moisture and ash content were much lower than the recommended allowable maximum. The pH for cassava starch was within the recommended range. Additive main effects and multiplicative interaction (AMMI) were strongly correlated with other stability parameters such as Wi-ecovalence and stability variance–no covariate. From the results, genotype has a greater influence on root dry matter than the environment. Native cassava starch can be used in the pharmaceutical, battery and packaging material making and textile industries in Malawi.

Key Words: Ash, Malawi, *Manihot esculenta*, sub-Saharan Africa

RÉSUMÉ

Le manioc (*Manihot esculenta* Crantz) est la deuxième plus importante plante d'aliment de base en Afrique sub-Saharienne, pourvoyant jusqu'à 285 calories par personne par jour. L'amidon de manioc est un produit industriel potentiellement important en Malawi. Les industries hésitent d'utiliser l'amidon de manioc parce que la poudre vendue par certains fournisseurs a été grossièrement inadéquate. Cette étude était conduite pour évaluer les qualités d'amidon de manioc autochtone pour les différents génotypes de manioc de Malawi, déterminer le paramètre approprié de stabilité de GXE à traiter pour les traits de qualité d'amidon, et le potentiel d'usage d'amidon de manioc par les principales industries en Malawi. Les essais étaient conduits en Malawi pour examiner les paramètres de qualité de l'amidon, la matière sèche de racine et l'extraction d'amidon. Basé sur les résultats, les génotypes de manioc ont produit l'amidon mais pas de protéine. Les teneurs d'humidité et de cendre étaient très basses que le maximum admissible recommandé. Le pH d'amidon de manioc était dans l'intervalle recommandé. Les principaux effets additifs et multiplicatifs d'interaction étaient fortement corrélés avec les autres paramètres de stabilité tels que Wi-ecovalence et variance- no covariante de stabilité. A partir des résultats, le génotype a une grande influence sur la matière sèche de racine que l'environnement. L'amidon de manioc autochtone peut être utilisé dans les industries pharmaceutiques, de batterie, dans les fabriques de matériel d'emballage et industries textiles en Malawi.

Mots Clés: Cendre, Malawi, *Manihot esculenta*, Afrique sub-Saharienne

INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is the second most important staple food crop in sub-Saharan Africa providing an average of 285 calories per person per day (FAO, 2000). The most important feature of cassava is its adaptability to various ecological and agronomic conditions. In contrast to other staples, it grows well under marginal conditions (Silvestre, 1989). Apart from this ecological versatility, cassava also displays certain characteristics that makes it adaptable to a variety of socio-economic conditions (De Vries, 1978; Moyo *et al.*, 1998; Silvestre, 1989; Hallack, 2001; IITA, 2001).

Cassava starch is used directly in different ways or as a raw material for further processing (FAO, 2000) for products such as food, textile, paper, adhesives, chemicals, glucose, soap, detergent, laundry, ethanol, cosmetic powders, sausage making, pharmaceuticals and insecticides. Unfortunately, industries that use starch in Malawi have a negative attitude towards cassava starch, because some industries have been buying local products in the name of cassava starch which have not been efficient as corn starch, which is normally used (Fungulani and Maseko 2001; Itaye, 2001). There was, therefore, a need to determine the quality of cassava starch from different genotypes grown in Malawi. In addition, industries were interested in supply of native cassava starch.

Dry matter content is closely related to starch content in cassava (CIAT, 1995). This makes dry matter an important trait to cassava producers since it is a crop grown largely for its carbohydrate content. Dry matter varies widely in cassava over years and environments (CIAT, 1995).

Genotype x environment interaction (GxE) is an important issue for plant breeders and agronomists in Malawi in the face of a wide range of agroecologies and variable climate. Breeders constantly strive to develop genotypes that are superior in a number of agronomic and quality traits, for wide range of environmental conditions. Plant breeders generally agree on the importance of high and stable yield, but there is less agreement on the most appropriate definition of stability and the means to improve yield stability.

Industries in Malawi have had a negative attitude towards the use of cassava starch. This is because some industries bought local products labelled cassava starch which were either inefficient relative to corn starch, which is normally used, or in some industries, led to a total failure (Fungulani and Maseko, 2001; Itaye, 2001).

This study was, therefore, designed to: (1) evaluate the elite Malawi cassava genotypes for dry matter content; (2) evaluate the native starch extraction rate for elite Malawi cassava genotypes; (3) evaluate the elite Malawi cassava genotypes for quality of the native starch extracted from them; (4) assess GxE interaction of the starch quality traits included in this study, (5) determine the appropriate stability measure for dealing with GxE interactions, and (6) assess the possibility of use of native cassava starch in the major industries in Malawi.

MATERIALS AND METHODS

Five recommended varieties, six locally bred clones, and nine introduced clones were evaluated at Chitedze and Makoka Research Stations in 2000. A randomised complete block design was used with four replicates. Plot size was four ridges, each with 12 plants (gross) and a net of two inner ridges each with 10 middle plants. Planting was done on ridges at a spacing of 0.9 m by 0.9 m. Stakes of 25 cm were used. They were planted in a slanting position at about 45°.

Storage root dry matter content was determined gravimetically using undamaged roots. Thin slices were dried at 65°C for 72 hr after fresh weighing with and without the containers.

Native starch extraction was done using the method of Numfor and Walter (1996). Ash content was determined using the CRA standard analytical method (1999), ISO (1997a) and ISI (2002a). The pH of starch was determined using the method of ISI (2002c) which is applicable to native and modified starch, glucose syrups and hydrolysates. Moisture content for starch was determined using the method of ISO (1976) which is applicable to starch, dextrose - anhydrous and monohydrate - and total sugar. Protein content of starch was analysed using an automatic protein/nitrogen determinator LECO FP-528. Duplicate starch samples of about 3 g were dried in an oven at 105° C for 72 hours. Samples of 0.30 g were weighed immediately after removal from the desiccator and then loaded into the protein analyser.

Whiteness of starch was measured using a HunterLab ColorFlex 45°/0°. Colour values measured using the ColorFlex are relative to the absolute value of a perfect reflecting diffuser as measured under the same geometric conditions (ASTM Method E 308). The Hunter scale (L) measures lightness and varies from 100 for perfect white to zero for black, as the eye would approximately evaluate it.

Industrial use of cassava products was evaluated using secondary data related to cassava commercialisation (Fungulani and Maseko, 2001; Itaye, 2001; Mataya, 2001). In addition, various industries in Malawi were assessed for use of native cassava starch. Trials were also set up with these industries using cassava starch, namely, David Whitehead and Sons in the textile industry, Nzeru radio company in the battery making industry, and Malawi Pharmacies Limited (MPL) in the pharmaceutical industry. Cassava starch, which was produced at Chitedze research station, was used for all the trials in the different industries.

Analysis of variance was performed on all characteristics of the individual trials. Thereafter, combined analyses of variance were performed on the pooled data of both trials for Chitedze and Makoka. The GxE interactions for the traits that were significant were managed using different stability methods.

All computations were performed with Agrobase 20 (Agrobase, 2000). Stability variance for each genotype across environments was determined (Shukla, 1972). The data set was also analysed according to the procedure recommended by Lin and Binn (1988). Wricke's ecovalence (1962) was also done. The additive main effects multiplicative interactions (AMMI) which combines analysis of variance for genotype and environment main effects with principal components analysis of the GxE interaction into a unified approach, and is especially useful in analysing multi-location trials (Gauch, 1988; Zobel, 1988) was used. To statistically compare the four stability analysis procedures, Spearman's coefficient of rank correlation was used (Steel and Torrie, 1980), where it applies to data in the form of ranks.

RESULTS AND DISCUSSIONS

Dry matter content in cassava roots. There were significant ($P>0.05$) differences among genotypes at Makoka, and the highest root dry matter content was for 30786, Silira, Mbundumali and Mkondezi (Table 1). Their dry matter was significantly ($P<0.05$) higher than for CH92/112 and 83350. There were no significant differences between genotypes at Chitedze. Mbundumali and Silira had the highest dry matter, while CH92/112 had the lowest at both locations (Table 1). There were significant ($P<0.05$) differences in the main effects for root dry matter content for locations, and for the genotypes. However, there was no significant ($P>0.05$) GxE interaction (Table 2). Although the locations gave highly significant ($P<0.01$) differences in root dry matter content, its contribution to the variation was only 7.94%, while genotypes contributed 36%. The low contribution of variation of the locations, coupled with insignificant GxE interaction, and the main effects for the replicates (Table 2) suggests that dry matter content is not as much influenced by environment as by genetic differences. These results agree with other studies of Pérez *et al.* (2001) that dry matter content in cassava roots is likely to be controlled by one or a few major genes. However, this differs with the suggestions of CIAT (1995) that the performance of genotypes on root dry matter content strongly depend on edaphic, climatic and agronomic conditions.

Starch yield by cassava roots. There were no significant differences in starch yield among genotypes for both locations (Table 1). However, there were highly significant differences between locations, with Makoka having the highest starch yield. These differences could be attributed to the differences in the distribution of rainfall over the locations. Extended dry weather might have forced plants at Chitedze to over-use their food reserves by breaking down some of the starch into sugars for survival during the dry season. Locations made the largest contribution to the variation (Table 2). This suggests that when and where cassava is grown and harvested for starch matters, if one wants to maximise starch yield from the tubers. There was no significant GxE interaction on this parameter (Table 2). Therefore the performance of the cassava genotypes for starch extraction did not depend on the locality.

Protein content in cassava starch. All cassava genotypes produced starch without protein. This is similar to corn starch used in various industries in Malawi. The lower the protein content, the higher the quality of starch (African Products

TABLE 1. Root dry matter and starch extraction for 20 Malawi cassava genotypes evaluated at Chitedze and Makoka

Cassava genotype	Root dry matter			Starch yield		
	Chitedze	Makoka	Mean	Chitedze	Makoka	Mean
Silira	46.10	46.85	46.48	30.68	42.88	36.78
Sauti	39.05	41.25	40.15	43.43	42.49	42.96
CH92/082	42.75	41.53	42.14	39.04	47.35	43.19
TMS4(2)1425	39.23	43.03	41.13	41.27	45.68	43.47
CH92/112	37.63	38.85	38.24	27.35	41.33	34.34
CH92/105	39.75	42.58	41.16	34.87	36.24	35.56
LCN8010	40.40	43.60	42.00	34.01	46.68	40.35
30786	40.55	47.68	44.11	32.54	44.29	38.42
83350	40.95	38.15	39.55	34.72	52.05	43.38
TME1	41.30	45.35	43.33	27.62	43.82	35.72
81/00015	40.05	43.75	41.90	39.33	47.30	43.31
CH92/108	39.83	44.73	42.28	34.06	33.18	33.62
MK95/054	39.00	44.90	41.95	29.26	43.72	36.49
Mbundumali	46.68	46.48	46.58	33.36	40.95	37.16
Gomani	43.10	43.05	43.08	34.11	45.86	39.99
Mkondezi	39.65	46.28	42.96	26.25	41.69	33.97
TMS60121	43.58	43.15	43.36	33.29	45.40	39.34
TMS84563	42.88	41.80	42.34	29.85	45.43	37.64
Maunjili	44.65	43.68	44.16	37.71	40.11	38.91
TMS60142A	44.68	45.40	45.54	38.39	42.24	40.31
Mean	41.44	43.69	42.57	34.06	43.43	38.74
CV (%)	8.73	4.83	6.97	15.16	10.51	12.58
LSD for genotype	NS	7.54	6.97	NS	NS	NS
LSD for location	-	-	2.21	-	-	3.62

TABLE 2. Analysis of variance for root dry matter and starch yield

Source of variation	df	Dry matter (%)		Starch yield (%)	
		Sum of squares (SS)	Contribution to SS (%)	Sum of squares (SS)	Contribution to SS (%)
Total	79	970	-	4470	-
Location (L)	1	77 **	7.94	1759 ***	39.35
Rep (location)	2	56	5.77	314	7.02
Genotype (G)	19	344 *	35.46	839	18.77
G x L	19	158	16.29	656	14.68
Error	38	335	34.54	902	20.18

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

Ltd., 2001). In Malawi, different industries have set different maximum protein content in starch, all lower than 1.0%.

Whiteness of starch. There were significant ($P<0.05$) differences among genotypes for Chitedze and Makoka. Most of the cassava genotypes starch was similar to cornstarch used by the industries (Table 3). There were significant differences in the main effects, locations and genotypes (Table 3), but the interaction of genotype by location was not significant. Genotype contributed most to the variation (72.4%). Although GxE interaction was not significant, it still contributed much higher variation than location (Table 4). The whitest starch was the cornstarch, but there were no significant differences with the starch from Gomani and Sauti (Table 3). Generally, Chitedze produced whiter starch than Makoka.

Starch colour is very important where the colour of the final product matters. From this study, cassava can be grown anywhere and any genotype can be used to produce white starch which may be acceptable to industries.

Starch pH. There were highly significant ($P<0.01$) differences among the genotypes at both locations. The genotypes that produced starch with the highest pH at Chitedze were CH92/108, Silira, CH92/082 and TME1, while the lowest pH was detected in cornstarch (Table 3). At Makoka CH92/108, Silira Gomani and MK95/054 had the highest pH, while cornstarch had the lowest pH. The pH for native starch ranged from 4.7 to 5.8 at both sites, which was within the recommended industry range of 4.5 and 7.0. There were highly significant ($P<0.01$) differences in the main effects (locations and genotypes) and their interaction. The genotypes contributed 74.8 % of variation (Table 4). Cultivars CH92/108, Silira MK95/054, Gomani and CH92/082 had a high pH values. Makoka gave a higher pH of 5.4 for starch than Chitedze (pH 5.0, Table 3), though both sites had pH values that were within the industrial range of 4.5 and 7.0 (African Products Limited, 2001; National starch and chemical company, 2002).

Since the GxE interaction was highly significant for starch pH, it was difficult to single out superior genotypes using main effects only; therefore stability analyses was done. According to the cultivar performance measure (P_i), 83350, CH92/108, TMS4(2)1425, LCN8010, TME1 and CH92/112 were the most stable (Table 5). According to Wi-ecovalence, the most stable genotypes were Silira, CH92/112, CH92/105, Maunjili, Mkondezi, TMS84563 and TMS60142A. In Table 5, Shukla's stability variance (σ^2_i) values, as well as the ranking order of the genotypes stability are presented. According to the stability variance, no covariate, Mkondezi, Maunjili Silira, CH92/112, CH92/105 TMS60121, TMS60142A and Sauti were stable. AMMI IPCA scores showed that the most stable genotypes were 81/00015, 30786, CH92/112, LCN6010 and CH92/108 (Table 5).

The overall ranking of the genotypes for stability using the four stability parameters showed that CH92/112, 81/00015, LCN8010, CH92/105, CH92/108 and Silira were stable (Table 5). Spearman's coefficient of rank correlation was determined for traits with significant GxE interaction (Table 6). On this basis Wi-ecovalence was significantly and positively correlated with stability variance (no covariate). The other stability parameters were not correlated. The overall rank was not correlatedwith cultivar superiority measure, but there were significant correlations with Wi-ecovalence, stability variance and AMMI. The stability parameter that was closest to the overall rank was Wi-ecovalence, followed by AMMI and the stability variance came third (Table 6).

Genotypes that were stable could be presumed universal, thus their pH was not dependent on environment. On the other hand, those that were unstable were specifically adapted to certain environments. The AMMI analysis showed that MK95/054 and TMS84563 were unstable and were best suited to Makoka. Sauti and 83350 were also unstable and were best suited to Chitedze.

Any one of Wi-ecovalence, stability variance or AMMI can be used for stability analysis, but AMMI is recommended since it provides additional information on the allocation of unstable genotypes into their appropriate environments.

Moisture content in starch. There were highly significant ($P<0.05$) differences among cassava genotypes at Chitedze, and Makoka (Table 3). Cornstarch had the lowest moisture content. The

TABLE 3. Whiteness, pH, moisture and ash content in starch for cassava genotypes evaluated in two locations in Malawi

Cassava genotype	Whiteness of starch			pH of starch			Starch moisture content (%)			Starch ash content (%)		
	Chitedze	Makoka	Mean	Chitedze	Makoka	Mean	Chitedze	Makoka	Mean	Chitedze	Makoka	Mean
Silira	94.75	94.75	94.75	5.5	5.5	5.5	13.10	14.20	13.65	0.13	0.11	0.12
Sauti	96.02	96.02	96.02	5.2	5.1	5.2	12.60	13.70	13.15	0.09	0.11	0.10
CH92/082	94.94	94.94	94.94	5.4	5.5	5.5	12.20	14.30	13.25	0.09	0.15	0.12
TMS4(2)1425	95.36	95.36	95.36	5.0	5.3	5.2	11.20	14.20	12.70	0.22	0.13	0.17
CH92/112	93.49	93.49	93.49	5.1	5.5	5.3	10.30	13.70	12.00	0.15	0.13	0.14
CH92/105	94.56	94.56	94.56	4.8	5.5	5.2	11.40	12.30	11.85	0.13	0.13	0.13
LCN8010	94.63	94.63	94.63	5.1	5.7	5.4	11.80	13.40	12.60	0.20	0.14	0.15
30786	94.94	94.94	94.94	5.2	5.6	5.4	11.80	13.50	12.45	0.10	0.16	0.13
83350	96.11	96.11	96.11	5.2	5.1	5.2	12.50	12.90	12.70	0.25	0.15	0.20
TME1	94.51	94.51	94.51	5.3	5.3	5.3	11.60	13.70	12.65	0.20	0.11	0.15
81/00015	94.84	94.84	94.84	5.1	5.6	5.4	11.80	14.00	12.90	0.13	0.11	0.12
CH92/108	95.42	95.42	95.42	5.5	6.2	5.9	12.20	14.00	13.10	0.22	0.13	0.17
MK95/054	93.77	93.77	93.77	5.0	6.0	5.5	12.70	12.90	12.80	0.11	0.16	0.13
Mbundumali	96.28	96.28	96.28	4.8	5.7	5.3	12.60	13.10	12.85	0.12	0.19	0.15
Gomani	96.33	96.33	96.33	5.1	5.9	5.5	12.80	12.60	12.70	0.09	0.19	0.14
Mkondezi	94.81	94.81	94.81	4.9	5.7	5.3	12.60	13.20	12.90	0.12	0.09	0.11
TMS60121	95.38	95.38	95.38	5.0	5.8	5.4	12.00	13.70	12.85	0.18	0.09	0.13
TMS84563	95.22	95.22	95.22	4.7	5.8	5.3	12.10	12.00	12.05	0.12	0.13	0.12
Maunjili	95.48	95.48	95.48	4.9	5.1	5.0	12.80	13.90	13.35	0.13	0.10	0.11
TMS60142A	95.64	95.64	95.64	4.9	5.7	5.3	14.00	12.70	13.35	0.14	0.09	0.11
Nzeru corn starch	95.20	95.20	95.20	4.7	4.7	4.7	11.20	11.20	11.20	0.15	0.14	0.14
PIM corn starch	96.46	96.46	96.46	5.1	5.0	5.0	11.80	11.80	11.80	0.18	0.13	0.15
MPL corn starch	97.28	97.28	97.28	4.1	4.1	4.1	9.90	9.90	9.90	0.11	0.14	0.12
Corn flour	94.20	94.20	94.20	3.4	3.4	3.4	10.60	10.60	10.60	0.86	0.70	0.78
Mean	95.33	95.33	95.33	5.0	5.4	5.2	11.97	12.98	12.47	0.17	0.15	0.16
CV (%)	0.83	0.83	0.83	0.19	0.15	0.17	5.96	4.54	5.25	11.40	9.36	12.04
LSD for genotype	1.97	1.97	1.97	0.02	0.02	0.02	1.78	1.47	1.12	0.05	0.04	0.03
LSD for location	-	-	-	-	-	0.01	-	-	0.32	-	-	0.01

G=genotype; L=location; MPL=Malawi pharmacies limited; PIM= Packaging industries Malawi limited; Nzeru=Nzeru radio company range of moisture content at both sites ranged from 10.3 to 14.3%, which was below the industrial maximum of 15%.

There were highly significant (P<0.05) differences in the main effects (locations and genotypes) and their interaction. The locations contributed 16.6% to the variation; the genotypes 49.6%, and GxE contributed 20.1% (Table 4).

Silira, Maunjili, TMS60142A, CH92/082, Sauti and CH92/108 had high mean moisture contents (Table 3). Cornstarch from Malawi Pharmacies Limited (MPL) gave the lowest moisture content. The moisture content was below the industry recommended maximum of 15%.

Makoka had a higher moisture content of 12.5% than Chitedze (12%, Table 3), but both sites had starch moisture content that was below the industrial maximum values of 14-12% (National starch and chemical company, 2002).

According to cultivar performance measure (P_i), Silira, Maunjili, Sauti, TMS60142A and Mkondezi were the most stable (Table 7).

TABLE 4. Analysis of variance for whiteness, pH, moisture and ash content for 20 Malawi cassava genotypes evaluated at Chitedze and Makoka in Malawi

Source of variation	df	Whiteness		pH of starch		Moisture content (%)		Ash content (%)	
		Sum of squares (SS)	Contribution to SS (%)	Sum of squares (SS)	Contribution to SS (%)	Sum of squares (SS)	Contribution to SS (%)	Sum of squares (SS)	Contribution to SS (%)
Total	95	120.7	-	30.227	-	147.85	-	1.752	-
Location (L)	1	2.6 *	2.15	4.084 ***	13.51	24.60 ***	16.64	0.011 ***	0.61
Rep (location)	2	7.5	6.21	0.001	0.00	0.52	0.35	0.014	0.79
Genotype (G)	23	72.4 ***	58.88	22.615 ***	74.82	73.32 ***	49.59	1.617 ***	92.29
G x L	23	12.5	10.36	3.523 ***	11.66	29.71 ***	20.10	0.093 ***	5.30
Error	46	25.8	21.30	0.004	0.01	19.70	13.32	0.018	1.01

*** $P \leq 0.001$ * $P \leq 0.05$

TABLE 5. Summary of stability statistics for pH in starch from 20 Malawi cassava genotypes tested at Chitedze and Makoka in Malawi

Cassava genotypes	Cultivar superiority		Wi-Ecovalence		Stability variance -no covariate		AMMI		Overall rank
	Pi GxE Stat.	Rank	Wi GxE Stat.	Rank	σ^2_i GxE	Stat.	Rank	IPCA scores	Rank
Silira	0.0051	9	0.0000	1	-0.0001	2	-0.3806	13	5
Sauti	0.0082	17	0.0013	6	0.0008	5	-0.4566	16	13
CH92/082	0.0068	16	0.0058	10	0.0042	9	-0.3162	11	14
TMS(2)1425	0.0011	2	0.0058	10	0.0042	9	-0.1601	6	6
CH92/112	0.0035	5	0.0000	1	-0.0001	2	-0.0821	3	1
CH92/105	0.0044	8	0.0003	3	0.0001	2	0.1617	7	3
LCN8010	0.0013	3	0.0019	7	0.0013	6	0.0954	4	3
30786	0.0058	13	0.0058	10	0.0042	9	-0.0743	2	9
83350	0.0004	1	0.0070	11	0.0051	10	-0.4508	15	11
TME1	0.0022	4	0.0058	10	0.0042	9	-0.3806	13	10
81/00015	0.0052	10	0.0000	1	-0.0001	2	0.0096	1	2
CH92/108	0.0011	2	0.0051	9	0.0036	8	0.1461	5	4
MK95/054	0.0053	11	0.0047	8	0.0034	7	0.3938	14	12
Mbundumali	0.0042	7	0.0070	11	0.0051	10	0.3216	12	12
Gomani	0.0064	14	0.0129	12	0.0094	11	0.2300	9	14
Mkondezi	0.0066	15	0.0002	2	0.0000	1	0.2378	10	7
TMS60121	0.0037	6	0.0058	10	0.0042	9	0.2300	9	9
TMS84563	0.0052	10	0.0008	4	0.0005	3	0.4660	17	9
Maunjili	0.0058	13	0.0002	2	0.0000	1	-0.2284	8	4
TMS60142A	0.0055	12	0.0010	5	0.0006	4	0.2378	10	8

G = genotype; E = environment

TABLE 6. Spearman's coefficients of rank correlation for four GxE stability analysis procedures conducted for (1) pH, (2) moisture content and (3) ash content of starch from 20 cassava genotypes evaluated over two locations in Malawi

Stability parameter	Cultivar superiority measure (Pi)	Wi-Ecovalence	Stability variance – no covariate	AMMI
Wi-Ecovalence	(1)-0.2275 (2) 0.4999* (3) 0.3125			
Stability variance – no covariate	(1)-0.2700 (2) 0.3586 (3) 0.1313	(1) 0.9866*** (2) 0.7892*** (3) 0.8804***		
AMMI	(1) 0.1975 (2) 0.4118 (3)-0.2004	(1) 0.1640 (2) 0.7995*** (3) 0.1603	(1) 0.1149 (2) 0.996** (3) 0.0664	
Overall Rank	(1) 0.3990 (2) 0.6477** (3) 0.5495*	(1) 0.6795** (2) 0.9101*** (3) 0.8396***	(1) 0.6469** (2) 0.9050*** (3) 0.7214***	(1) 0.6600** (2) 0.9176*** (3) 0.3825

* $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

TABLE 7. Summary of stability statistics for moisture content of starch from 20 Malawi cassava genotypes, tested at Chitedze and Makoka in Malawi

Genotype	Cultivar superiority		Wi-Ecovalence		Stability variance -no Covariate		AMMI		Overall rank
	Pi GxE Stat.	Rank	Wi GxE Stat.	Rank	σ^2_i GxE Stat.	Rank	IPCA scores	Rank	
Silira	0.2050	1	0.0066	1	-0.0385	2	0.0515	1	1
Sauti	0.5800	3	0.0066	1	-0.0385	2	0.0515	1	3
CH92/082	0.8100	6	0.3916	11	0.5319	9	-0.3966	9	8
TMS4(2)1425	1.9625	16	1.5931	16	2.3119	14	-0.8000	14	16
CH92/112	3.5125	19	2.3871	10	3.4881	15	-0.9793	15	15
CH92/105	2.6900	18	0.0496	2	0.0252	1	0.1412	2	5
LCN8010	1.4125	13	0.0741	3	0.0615	3	-0.1725	3	4
30786	1.8500	15	0.3916	11	0.5319	9	-0.3966	9	12
83350	1.0525	10	0.3321	9	0.4437	8	0.3653	8	9
TME1	1.5300	14	0.3916	11	0.5319	9	-0.3966	9	11
81/00015	1.2325	12	0.4851	12	0.6704	10	-0.4415	10	12
CH92/108	0.8325	7	0.1711	6	0.2052	5	-0.2622	5	5
MK95/054	0.9125	9	0.5151	13	0.7148	11	0.4549	11	12
Mbundumali	0.8500	8	0.2556	8	0.3304	7	0.3204	7	7
Gomani	1.0825	10	1.0011	15	1.4348	13	0.6342	13	13
Mkondezi	0.7925	5	0.1891	7	0.2319	6	0.2756	6	6
TMS60121	1.0900	11	0.1176	4	0.1259	4	-0.2174	4	5
TMS84563	2.2250	17	0.8646	14	1.2326	12	0.5894	12	14
Maunjili	0.4000	2	0.0066	1	-0.0385	2	0.0515	1	2
TMS60142A	0.6400	4	3.1626	5	4.6370	16	1.1272	16	10

According to Wi-ecovalence, the most stable genotypes were Silira, Sauti, CH92/105, LCN8010, TMS60121 and TMS60142A. According to the stability variance (no covariate), the stable cassava genotypes were Maunjili, Silira, CH92/105, LCN8010, TMS60121, CH92/108 and Sauti. Using AMMI IPCA scores, the most stable genotypes were Silira, Sauti, Maunjili, CH92/105, LCN6010, TMS60121 and CH92/108 (Table 7). Using all four stability parameters, the most stable genotypes were Silira, Maunjili, Sauti, LCN8010, CH92/105 and TMS60121. The Spearman's coefficient of rank correlation showed that Wi-ecovalence was significantly and positively correlated to stability variance – no covariate, and AMMI. AMMI was also significantly and positively correlated with stability variance – no covariate. Cultivar superiority measure was only correlated to Wi-ecovalence (P<0.05) (Table 6).

The overall rank was highly significantly correlated with all the stability parameters, hence, any one of them could be used to test the stability of the genotypes for moisture content (Table 6), but AMMI is recommended since it also allocates unstable genotypes to respective areas of their best performance. The AMMI analysis showed that TMS4(2)1425 and CH92/112 were best suited to Makoka, while TMS60142A, TMS84563 and Gomani were best suited to Chitedze. Therefore, for starch moisture content any one of the four stability parameters can be used.

Ash content in starch. There were highly significant (P<0.05) differences among the genotypes at both locations (Table 3). The range of ash content at both sites was 0.09 to 0.25% that was much lower than the industrial maximum of 0.5% for the industry (National Starch and Chemical Company, 2002). There were highly significant differences in the main effects (locations and genotypes) and their interactions. Genotypes contributed 92.3% of the variation (Table 4). Genotypes 83350, CH92/108, TMS4(2)1425, TME1 and Mbundumali had the highest ash content (Table 3), while MPL cornstarch, 81/00015, TMS60142A, Maunjili, Mkondezi and Sauti the lowest. Ash content of

TABLE 8. Summary of stability statistics for ash content in starch from 20 Malawi cassava genotypes, which were tested at Chitedze and Makoka in Malawi

Genotype	Cultivar superiority		Wi-Ecovalence		Stability variance -no Covariate		AMMI		Overall rank
	Pi GxE Stat.	Rank	Wi GxE Stat.	Rank	σ^2_i GxE Stat.	Rank	IPCA scores	Rank	
Silira	0.1200	7	0.2379	13	0.1710	14	0.0072	1	5
Sauti	0.3222	19	0.3425	16	0.2485	16	-0.0701	8	16
CH92/082	0.1254	8	0.1642	11	0.1164	12	-0.1474	12	11
TMS4(2)1425	0.2616	17	0.0421	6	0.0260	7	0.1474	12	10
CH92/112	0.1599	12	0.0111	3	0.0030	2	0.0073	2	2
CH92/105	0.2451	16	0.0430	7	0.0266	8	-0.0314	5	6
LCN8010	0.1018	4	0.0150	4	0.0058	4	0.0846	9	3
30786	0.1152	6	0.0091	2	0.0015	1	-0.1474	12	3
83350	0.3182	18	0.3338	15	0.2420	6	0.1619	13	13
TME1	0.2110	15	0.2379	13	0.1710	14	0.1474	12	15
81/00015	0.1313	9	0.0002	1	-0.0051	3	0.0121	3	1
CH92/108	0.0000	1	0.0351	5	0.0207	5	0.1377	11	4
MK95/054	0.0770	3	0.2548	14	0.1835	15	-0.1329	10	10
Mbundumali	0.1893	13	0.1700	12	0.1206	13	-0.1619	13	12
Gomani	0.0640	2	0.0869	9	0.0591	10	-0.2199	14	5
Mkondezi	0.1537	10	0.0929	10	0.0635	11	0.0266	4	5
TMS60121	0.1044	5	0.0869	9	0.0591	10	0.1474	12	6
TMS84563	0.2040	14	0.3567	16	0.2590	17	-0.0556	6	14
Maunjili	0.3901	20	0.0857	8	0.0582	6	0.0266	4	7
TMS60142A	0.1578	11	0.0929	10	0.0635	11	0.0604	7	8

starch from cassava genotypes was not different from the cornstarch obtained from various industries.

Chitedze gave higher mean ash content of 0.17% for starch than Makoka (0.15%, Table 3), but both sites gave starch ash content which was lower than the industrial maximum of 0.5% (National Starch and Chemical Company, 2002).

According to the cultivar performance measure (P_i) CH92/108, Gomani, MK95/054, LCN8010 and TMS60121 were the most stable (Table 7). According to Wi-ecovalence, the most stable genotypes were 81/00015, CH92/112, 30786, LCN8010 and CH92/108. According to the stability variance – no covariate, the stable genotypes were 30786, CH92/112, 81/00015, LCN8010 and CH92/108 . Using AMMI IPCA scores, the most stable genotypes were Silira, 81/00015, CH92/112, Mkondezi, Maunjili and CH92/105. The overall ranking of the genotypes for stability on the basis of starch ash content using the four stability parameters 81/00015, CH92/112, LCN8010, 30786, CH92/108, Silira, Gomani and Mkondezi (Table 7). Spearman's coefficient of rank correlation (Table 6) showed that Wi-ecovalence was significantly and positively correlated to stability variance – no covariate. The other stability parameters were not correlated, hence, each one was unique and could not displace the other.

The overall rank was not correlated with cultivar superiority but was significantly correlated with Wi-ecovalence and stability variance – no covariate. With respect to ash content, AMMI was not correlated with the overall rank stability. The stability parameter that was closest to the overall rank was Wi-ecovalence, followed by stability variance – covariate (Table 7).

The genotypes that were stable suggest that their starch ash content was not dependent on environment. The AMMI analysis showed that Gomani, Mbundumali, 30786, CH92/082 and MK95/054 were best suited to Makoka, while 83350, CH92/108, TME1, TMS4(2)1425 and TMS60121 were best suited to Chitedze. The results show that either Wi-ecovalence or stability variance – no covariate can be used for stability analysis for ash content in starch.

INDUSTRIAL TESTS OF NATIVE CASSAVA STARCH IN MALAWI

Nzeru Radio Company Limited. Starch is an important component in the manufacturing of batteries (dry cells). The starch quality requirements include low iron levels, a maximum protein content of 0.50 %; a maximum ash content of 0.50 %; maximum moisture content of 15 %; maximum acid insolubles of 0.10 %; and should have a pH within the range of between 4.5 and 6.0. Then native cassava starch was brought. The paste made using native cassava starch passed the tests for pH, viscosity and specific gravity. Then batteries were successfully made on 30th January 2002. No problem was experienced in the course of making the batteries, and the paste was just like cornstarch in terms of fluidity and viscosity. The batteries were tested after one, six, 10 and 12 months after making, the cells that were made using cassava starch were still fine and the Zinc canes (the negative part of the battery) were intact, that is, not eaten away or corroded.

Malawi Pharmacies Limited (MPL). Native cassava starch was brought to MPL for trial. It passed all the tests and tablet making was successful. The compression for making the tablets was similar to the ones made from cornstarch. The disintegration of the tablets was also tested. Normally, tablets need to disintegrate within 4-15 minutes and they did pass even after one month of making. The tablets also passed the friability test, where 10 tablets are put in a machine and the machine is run for five minutes. The loss in weight was far less than 2%. From these results, it was concluded that use of cassava starch in tablet making was possible.

CONCLUSIONS

Genotypic influence on root dry matter is much greater than for the environment. The cassava genotypes evaluated produce starch that has no protein. Their ash and moisture contents are much lower than the industrial maximum requirement. The whiteness and pH of cassava starch too are within the recommended range. It is clear that native cassava starch is suitable for use in the major industries in Malawi but strict quality control need to be instituted to avoid cheating.

REFERENCES

African Products (Pty) Limited. 2001. Technical certificate for yellow IPS corn starch. Export MYRAL 030221. Quality Control Department, Randvaal, South Africa.

Agrobase. 2000. Agrobase 20 for Windows. Agromix Software, Inc. Winnipeg, Manitoba, Canada.

Anonymous. 1999. CRA Standard Analytical Methods B-44, C-44, E-48Joint FAO/WHO Expert Committee on Food Additives (JECFA) Monographs and Evaluations. Rome, Italy.

Becker, H.C. and Léon, J. 1988. Stability analysis in plant breeding. *Plant Breeding* 101:1-23.

CIAT, 1995. Annual Report. International Center of Tropical Agriculture. Cali, Colombia.

Crossa, J., H.G. Gauch and Zobel, R.W. 1990. Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. *Crop Science* 30:493-500.

De Vries, C.A. 1978. New developments in the production and utilization of cassava. *Abstracts on Tropical Agriculture, Special issue.*

FAO. 2000. FAO statistical Database.FAO, Rome, Italy.

Fungulani, T. and Maseko, E. 2001. Utilization of cassava starch in textile industry. In: *Cassava commercialisation for economic development in Malawi.* Mahungu, N.M., Banda, J. W. and Mataya, C. (Eds.), pp 98-99. Proceedings of the Symposium held at Kwacha International Conference Centre, Blantyre, Malawi, 21–23 May 2001.

Gauch, H.G. 1988. Model selection and validation for yield trials with interaction. *Biometrics* 44:05-715.

Hallack, H. 2001. Cassava. Scientific Name: *Manihot esculenta* Family: Euphorbiaceae, Spurge Duration: Short-lived shrubby perennial. www.wam.umd.edu/~mathewsc/Cassava.html.

IITA. 2001. Cassava. International Institute for Tropical Agriculture/Crops. Web: http://www.iita.org/crop/cassava.htm.

ISI, 2002a. ISI 02-1e determination of ash in starch and syrup. International Starch Institute (ISI) Science Park Aarhus, Denmark. http://home3.inet.tele.dk/starch/isi/methods/02ash.htm.

ISI, 2002b. ISI 05-1e Determination of dry matter in starch and syrup. International Starch Institute (ISI) Science Park Aarhus, Denmark. http://home3.inet.tele.dk/starch/isi/methods/05dm.htm.

ISI, 2002c. ISI 26-4e Determination of pH in Starch and Syrup. International Starch Institute Science Park Aarhus, Denmark. http://home3.inet.tele.dk/starch/isi/methods/26ph.htm.

ISO, 1997a. International standard: ISO 3593.

ISO, 1997b. International standard: ISO 1741.

Itaye, S., 2001. The use of starch in the production of corrugated cartons. In: *Cassava Commercialisation for Economic Development in Malawi.* Mahungu, N.M., Banda, J. W. and Mataya, C. (Eds.), pp 105-107. Proceedings of the Symposium held at Kwacha International Conference Centre, Blantyre, Malawi, 21–23 May 2001.

Lin, C.S. and Binn, M.R. 1988. A superiority measure of cultivar performance for cultivar x location data. *Can J Plant Sci* 68:193-198 (1988).

Moyo, C.C., Benesi, I.R.M. and Sandifolo,V.S. 1998. Current status of cassava and sweetpotato production and utilisation in Malawi. In: *Food Secvrity and Crop Diversification in SADC Countries: the Role of Cassava and Sweetpotato.* Akoroda, M.O. and Teri, J.M. (Eds.), pp 51-68. Proceedings of the scientific workshop of the Southern Africa Root Crops Research Network (SARRNET), 17-19 August 1998, Lusaka, Zambia.

National starch and chemical company, 2002. Standards for corn starch. National @ 78-1551 pregelatinised corn starch NF. National starch and chemical*excipients*products. A member of ICI Group. http://excipients.com/products.asp.

Numfor, F.A. and Walter, W.M. 1996. Cohesiveness of native cassava starch pastes: effect of fermentation. *African Journal of Root and Tuber Crops* 1:29-32.

Pérez, J.C., Morante, N. López, J., Lenis, J.I. , Jaramillo, G., Ceballos, H. and Calle, F. 2001. Advantages of the New Cassava Breeding Scheme at CIAT. In: Taylor, N.J., F. Ogbe and C.M. Fauquet (eds.). Abstract book for the Fifth International Scientific Meeting of the Cassava Biotechnology Network, 4 - 9 November 2001. Donald Danforth plant Science Center, St. Louis, Missouri, USA.

Shukla, G.K. 1972. Some statistical aspects of partitioning genotype-environmental components of variability. *Heredity* 29:237-245.

Silvestre, P. 1989. Cassava. McMillan, London.

Steel, R.G. and J.H. Torrie, 1980. *Principles and Procedures of Statistics*. McGraw-Hill, New York.

Wricke, G., 1962. Über eine methode zur erffassung der ökologischen Streubreite in feldversuchen. *Z Pflanzenzücht* 47: 92-96.

Zobel, R.W. 1988. Wright, M.J and Gauch, H.G., Statistical analysis of a yield trial. *Agronomy Journal* 80:388-393.