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Genotype by enviroment interaction (GXE) for native cassava (*Manihot esculenta* Crantz) starch quality and its 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 an average of 285 calories per person per day. Cassava is an important food and cash crop, and it is increasingly becoming important industrial crop in Malawi. Various cassava intermediate products are used but industries hesitate to use cassava starch because powder sold by some suppliers in the name of cassava starch failed. This study therefore was initiated to look into native cassava starch qualities from different Malawi cassava genotypes, determine the appropriate stability parameter to deal with genotype by environment interaction (GxE) for starch quality traits, and also find out the possibility of use of cassava starch by the main industries in Malawi. Trials were conducted in Malawi in 2000/01 season. Apart from starch quality parameters, root dry mater and starch extraction evaluation were also included. Various stability measures were used to deal with the problem of genotype by environment interaction. Feasibility of use of cassava starch in Malawian industries was also conducted. The results show that all the cassava genotypes produced starch with no protein just like the one used in the pharmaceutical industry. 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) was strongly correlated with other stability parameters like Wi-ecovalence and stability variance–no covariate. AMMI is therefore recommended for use in the stability analysis of starch quality parameters since it provides additional information on appropriate environments for unstable genotypes. This study suggests that genotype has a greater influence on root dry matter than the environment. This study showed that native cassava starch can be used in the pharmaceutical, battery and packaging material making and textile industries in Malawi, however strict quality control for cassava starch is required.

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 a wide variety of 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; Hallack, 2001; IITA, 2001, Moyo *et al.*, 1998; Silvestre, 1989).

Cassava starch is used directly in different ways or as a raw material for further processing (FAO, 2000) of various products such as food, textile, paper, adhesives, chemicals, glucose, soap, detergent, laundry, ethanol, cosmetic powders, sausage making, pharmaceuticals and insecticides. The unique properties of cassava starch suggest its use for speciality markets such as baby foods and non-allergenic products. Industries that use starch in Malawi have a negative attitude towards the use of cassava starch, because some industries have been buying local products in the name of cassava starch which were not as efficient as the 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 that are grown in Malawi. In addition, industries were to be supplied with proper native cassava starch so that they test its effectiveness in their production process.

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

Genotype by environment interaction (GxE) is an important issue facing plant breeders and agronomists in Malawi with a wide range of agroecologies and variable climate. Breeders constantly strive to develop improved genotypes that are superior in a number of agronomic and quality traits, over a relatively 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 on methods to measure and improve yield stability. These GxE interactions can be partly understood as a result of differential reactions to environmental stresses, such as drought, diseases and other factors (Becker and Léon, 1988). The function of experimental design and statistical analyses of multilocation trials is thus to eliminate and discard as much of unexplainable noise as possible (Crossa *et al.*, 1990).

Industries in Malawi have had a negative attitude towards the use of cassava starch. This has been so because some industries bought local products in the name of cassava starch which were either not as efficient as the corn starch which is normally used or in some industries led to a total failure (Fungulani and Maseko, 2001; Itaye, 2001). This scenario has been worrisome as far as cassava commercialisation is concerned. Cassava production is increasing, hence there is need to find markets for cassava so that it should not only be taken as a food security crop but also a cash crop. This is because most of the cassava products are multipurpose, thus, used as food and also have commercial value. This can only be achieved if cassava products can be used in various industries especially starch which has various uses in various specialised industries.

The objectives of this study therefore were: (i) to evaluate the elite Malawi cassava genotypes for dry matter content; (ii) to evaluate the native starch extraction rate for elite Malawi cassava genotypes; (iii) to evaluate the elite Malawi cassava genotypes for quality of the native starch extracted from them; (iv) to assess GxE interaction of the starch quality traits included in this study, (v) To determine the appropriate stability measure for dealing with GxE interactions, and (vi) to 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 2000/01 season. A randomised complete block design was used with four replicates. The plot sizes were four ridges, each with 12 plants (gross) and a net of two inner ridges each with 10 middle plants. The plants were planted on ridges at a spacing of 0.9 m by 0.9 m apart. The lengths of the stakes were 25 cm and they were planted in a slanting position at about 45^{o}.

About five undamaged roots were randomly selected for use in determination of dry matter. Medial sections of the tubers were shredded into thin slices, mixed thoroughly and a duplicate of 200 g samples for each genotype were weighed and put in containers. The samples were dried at 65^{o}C for 72 hours, and weighed immediately after removal from the oven. These steps were carried out within 24 hours after harvest to avoid post harvest changes through physiological deterioration or moisture loss of the root. Dry matter content was calculated based on the weight loss.

Native starch extraction was done using a the method of Numfor and Walter (1996). Ash content of starch was determined using a the method of CRA standard analytical method (1999), ISO (1997a) and ISI (2002a). 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^{o}C for 72 hours, and then cooled in a desiccator for 1 hour. 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^{o}/0^{o} at the Southern African Grain Laboratory, in South Africa. 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, approximately as the eye would evaluate it.

Industrial use of cassava products was reviewed by Fungulani and Maseko (2001), Itaye (2001) and Mataya (2001). The review also included previous visits to the industries by various stakeholders, and previous studies that were done by different players like the University of Malawi in collaboration with Packaging Industries Malawi Limited (PIM). In addition, industrial uses of native cassava starch was sought from various industries in Malawi by visiting them and holding discussions with the relevant authorities and departments. Trials were also set up with various industries using cassava starch, that is: 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.

Data analysis. An analysis of variance was performed on all measured 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. Genotypes with low ecovalence have smaller fluctuations from the mean across different environments and are therefore more stable. AMMI 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). 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 differences among the genotypes at Makoka, and the highest root dry matter content was for 30786, Silira, Mbundumali and Mkondezi (Table 1), and their dry matter were significantly higher than for CH92/112 and 83350. There were no significant differences between the genotypes at Chitedze. Mbundumali and Silira had the highest dry matter while CH92/112 had the lowest dry matter at both locations (Table 1). There were significant differences in the main effects for root dry matter content for locations, and for the genotypes, but there was no significant GxE interaction (Tables 2).

Although the locations gave highly significant differences in root dry matter content in cassava 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 found that dry matter content in roots of cassava 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

Table 1: Mean root dry matter and starch extraction for 20 Malawi cassava genotypes evaluated at Chitedze and Makoka in 2000/01

Genotype	Root dry matter			Starch extraction rate		
	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 G	NS	7.54	6.97	NS	NS	NS
LSD for L	-	-	2.21	-	-	3.62

CV=coefficient of variation; SED=standard error deviation; Sign.=probability level of significance; G=genotype; L=location

Table 2: Analysis of variance for root dry matter and starch extraction rate

Source of Variation	df	Dry matter (%)		Starch extraction rate (%)	
		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

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

strongly depend on edaphic-climatic and agronomic conditions.

Starch extraction from cassava roots. There were no significant differences in starch extraction among the genotypes at both locations (Table 1), but there were highly significant differences between the locations, with Makoka having a higher starch extraction rate. This agrees with observations made that the cassava roots at Makoka were very mealy as compared to the same genotypes at Chitedze. These differences could be attributed to the differences in the distribution of the rainfall at these two locations. Extended dry weather might have forced the plants at Chitedze to use their food reserves by breaking down some of the starch into sugars for survival during the dry season. The locations made the largest contribution to variation (Table 2). This suggests that one needs to consider where cassava should be grown and when should it be harvested to maximise starch extraction from the storage roots. There was no significant GxE interaction (Tables 2) in starch extraction, therefore the performance of the cassava genotypes for starch extractions were not influenced by locality.

Protein content in cassava starch. All the cassava genotypes produced starch without any protein just like the corn starch used in various industries. The lower the protein content, the higher the quality of that starch. Different industries have set different maximum protein content in starch but all are lower than 1.0 %.

Whiteness of starch. There were significant differences among the genotypes for Chitedze and Makoka. Most of the cassava genotypes were statistically similar to cornstarch used by the industries (Table 3). There were significant differences in the main effects between the locations, and among the genotypes (Table 3), but the interaction of genotype by location was not significant. The genotype contributed the most to variation (72.40 %). Although the GxE interaction was not significant, it still contributed a much higher amount of 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. The colour of starch is very important where the colour of the final product matters. This study therefore showed that cassava can be grown anywhere and any genotype can be used to produce white starch acceptable to all industries.

pH of starch. There were highly significant 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

Table 3: Whiteness, pH, moisture content and ash content for starch evaluated in 2000/01 season.

Genotype	Whiteness of starch (L)			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 G	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 L	-	-	-	-	-	0.01	-	-	0.32	-	-	0.01

G=genotype; L=location; MPL=Malawi pharmacies limited; PIM= Packaging industries Malawi limited; Nzeru=Nzeru radio company.

Table 4: Analysis of variance for whiteness, pH, moisture and ash content for 20 Malawi cassava genotypes evaluated at Chitedze and Makoka in 2000/01 season.

Source of Variation	df	Whiteness (L)		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

*** $p \leq 0.001$ * $p \leq 0.05$.

the lowest pH was detected in cornstarch (Table 3). At Makoka CH92/108, Silira Gomani and MK95/054 had the highest pH, while the 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 differences in the main effects (locations and genotypes) and their interaction. The genotypes contributed 74.82 % of variation (Tables 4). CH92/108, Silira MK95/054, Gomani and CH92/082 had a high pH. Makoka gave a higher mean pH value of 5.4 for starch than Chitedze (pH 5.0, Table 3), though both sites had pH values that were within the recommended range of between 4.5 and 7.0 (African Products (Pty) 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 effect means 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 ($ó^2_i$) values, as well as the ranking order of the genotypes' stability are given. 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). The results show that Wi-ecovalence was significantly and positively correlated to stability variance – no covariate. The other stability parameters were not correlated. The

Table 5: Summary of stability statistics for pH in starch from 20 Malawi cassava genotypes tested at Chitedze and Makoka in 2000/01 season.

Genotype	Cultivar superiority		Wi-Ecovalence		Stability variance-no covariate		AMMI		Overall Rank
	Pi Stat.	GxE Rank	Wi Stat.	GxE Rank	δ^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

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

* $p \leq 0.05$, ** $p \leq 0.01$, *** $p \leq 0.001$.

overall rank was not correlated to cultivar superiority measure, but there were significant correlations with Wi-ecovalence, stability variance – no covariate and AMMI. The stability parameter that was closest to the overall rank was Wi-ecovalence, followed by AMMI and the stability variance – no covariate, came third (Table 6).

The genotypes that were stable suggest that they were universal, thus their pH was not dependent on environment while 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, and 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 differences among the genotypes at Chitedze, and Makoka (Table 3). The cornstarch had the lowest moisture content. The range of moisture content at both sites ranged from 10.3 to 14.3 %, which was below the recommended maximum of 15 %. There were highly significant differences in the main effects (locations and genotypes) and for their interaction. The locations contributed 16.64 % to the variation, the genotypes 49.59 %, and GxE contributed 20.10 % (Table 4). Silira, Maunjili, TMS60142A, CH92/082, Sauti and CH92/108 had high mean moisture content (Table 3). Cornstarch from Malawi Pharmacies Limited (MPL) gave the lowest moisture content. The mean moisture content was below the industry recommended maximum of 15%. Makoka had a higher moisture content of 12.47 % than Chitedze (11.97 %, Table 3), but both sites had a starch moisture content that was below the recommended maximum values of 14-15 % (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). 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 cassava genotypes which were stable 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 at 5 % alpha level (Table 6).

The overall rank was highly significantly correlated to 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 their 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 moisture content of starch any one of the four stability parameters can be used.

Ash content in starch. There were highly significant differences among the genotypes at both locations (Table 3). The range of ash content at both sites ranged from 0.09 to 0.25 % that was much lower than the recommended maximum of 0.5 % for the industry. There were highly significant differences in the main effects (locations and genotypes) and their interaction. Genotypes contributed 92.29 % of the variation (Table 4). Genotypes 83350,

Table 7: Summary of stability statistics for moisture content of starch from 20 Malawi cassava genotypes, tested at Chitedze and Makoka in 2000/01 season.

Genotype	Cultivar superiority		Wi-Ecovalence		Stability variance-no Covariate		AMMI		Overall Rank
	Pi GxE Stat.	Rank	Wi GxE Stat.	Rank	d^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

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 had the lowest. The ash content of 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 recommended 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 cassava genotypes which were stable 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 using the four stability parameters showed that the overall most stable genotypes for ash content of starch were 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 stood on its own and could not displace the other.

The overall rank was not correlated to cultivar superiority measure but was significantly correlated with Wi-ecovalence and stability variance – no covariate. With respect to ash content, AMMI was not correlated to the overall rank stability. The stability parameter that was closest to the overall rank was Wi-ecovalence, followed by stability variance – covariate (Table 8). 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 use and regulation of native cassava starch in Malawi. David Whitehead and Sons Limited is a textile manufacturing company, which revealed that they normally use cornstarch, which is difficult and expensive to acquire. The company switched to a powder so called cassava starch obtained from local traders. The product was giving under-sized warp yarns and also caused clogging on the machines when weaving the cloth (Fungulani and Maseko, 2001). This study revealed that the powder was cassava flour and not cassava starch as the traders claimed. The use of native cassava starch, gave very good results (Fungulani and Maseko, 2001) in the sense that it produced the right size of warp yarns, no clogging was experienced on the machine, and the cloth was of high quality (it was smooth and pure white).

Packaging Industries (Malawi) Limited (PIM) is a company that produces a range of corrugated cartons used for packaging of different products for local distribution and

Table 8: Summary of stability statistics for ash content in starch from 20 Malawi cassava genotypes, which were tested at Chitedze and Makoka in 2000/01 season.

Genotype	Cultivar superiority		Wi-Ecovalence		Stability variance -no covariate		AMMI		Overall rank
	Pi GxE Stat.	Rank	Wi GxE Stat.	Rank	δ^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

exports. Major users of the cartons are soap, oil, confectionery, textile and garment manufacturing industries, and tobacco processing firms (Itaye, 2001). Cassava products in the name of starch has been used in the past but their use was discontinued in 1966 due to the fact that local producers of this type of starch were not able to consistently supply the company in accordance with its required quality standards (Itaye, 2001). Due to high landed cost of the imported cornstarch, PIM has been looking for alternative sources of supply. It is for this reason that PIM collaborated with the University of Malawi in 1997 to assess the possibility of use of cassava starch. When the properly extracted cassava starch was used, and the results were successful (Itaye, 2001; Peter Chingo and Yoweli Kawiya, personal communication).

Nzeru Radio Company Limited is a company that uses starch in 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) is a pharmaceutical company which manufacture drugs using both artificial and natural peoducts. 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.

Malawi Bureau of Standards (MBS) is a policing body for quality control of products and services in Malawi. It was found that MBS had neither the international nor national standards for starch. It was then agreed that they were going to source international standards and try to come up with national standards for starch. Hence, MBS needs to be committed in the quality control of cassava starch for it to be taken up by industries for use in their industries without hesitation.

Implications and Conclusions

This study is expected to enhance the harnessment of local markets for starch before thinking of export opportunities. The inclusion of industries in this study in a participatory manner cleared the doubt they had on cassava starch. As a result of this study industries are looking forward to getting suppliers for proper native cassava starch. The use of locally produced starch may entail in reduction of cost of production which may in turn lead to reduction of prices for products for consumers. The demand for local products like cassava starch is likely to push up the production of cassava in general in Malawi.

The genotypic influence on root dry matter is much greater than for the environment. This agrees with the hypothesis that one or a few major genes control root dry matter in cassava. Rainfall distribution affected the starch extraction from cassava roots. The more evenly the rain is distributed throughout the season, the wider the harvesting time for roots to achieve high starch extraction rate. All the cassava genotypes produced starch that had no protein, and their ash and moisture contents were much lower than the recommended maximum. Hence, cassava starch was of high quality in terms of protein, ash and moisture content. The whiteness and pH of cassava starch too were within the recommended range. The four stability parameters that were applied for starch moisture and ash content, and pH were compared using Spearman's coefficient of rank correlation. The AMMI was correlated to other measured stability parameters, and it also allocates unstable genotypes to their appropriate environments. AMMI is therefore recommended for use in stability analysis of starch quality parameters. It was also found that native cassava starch is suitable for use in the major industries which use cornstarch in Malawi but strict quality control need to be instituted to avoid cheating.

Way Forward

Further studies to isolate genes and markers responsible for root dry matter are required inorder to facilitate marker assisted selection. Further studies on determination appropriate period to harvest cassava for starch extraction in different agroecologies are needed. This will facilitate maximisation of starch extraction. There is need to organise farmers and link the producers/processors to industries which need the products in question like cassava starch.

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.

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

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

Crossa, J., H.G. Gauch and R.W. Zobel, 1990. Additive main effects and multiplicative interaction analysis of two international maize cultivar trials. *Crop Sci* 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.

Fungulani, T. and E. Maseko, 2001. Utilization of cassava starch in textile industry, in *Cassava commercialisation for economic development in Malawi: A book of abstracts for a symposium on the promotion of cassava commercialisation in Malawi*, Kwacha International Conference Centre, Blantyre, Malawi, 21–23. May. pp. 34.

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. IITA/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: A book of abstracts for a symposium on the promotion of cassava commercialisation in Malawi, Kwacha International Conference Centre, Blantyre, Malawi, 21–23 May. pp 26-28.

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

Mataya, C., 2001. A policy review of cassava processing, marketing and distribution in Malawi. In: Cassava commercialisation for economic development in Malawi: A book of abstracts for a symposium on the promotion of cassava commercialisation in Malawi, 21–23 May 2001. Kwacha International Conference Centre, Blantyre, Malawi: 8-11.

Moyo, C.C., I.R.M. Benesi and V.S. Sandifolo,1998. Current status of cassava and sweetpotato production and utilisation in Malawi, in *Food security and crop diversification in SADC countries: the role of cassava and sweetpotato*, Ed by Akoroda MO and JM Teri, Proceedings of the scientific workshop of the Southern Africa Root Crops Research Network (SARRNET), 17-19 August 1998, Lusaka, Zambia. pp 51-68.

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 W.M. Walter, 1996. Cohesiveness of native cassava starch pastes: effect of fermentation. *African Journal of Root and Tuber Crops* 1(2): 29-32.

Pérez, J.C., N. Morante, J. López, J.I. Lenis, G. Jaramillo, H. Ceballos and F. Calle, 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 MJ and Gauch HG, Statistical analysis of a yield trial. *Agron J* 80: 388-393.