The physico-chemical properties of cassava starch in relation to the texture of the cooked root

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ABSTRACT

The proximate composition, pasting cycle, swelling power and solubility of six cassava varieties harvested at 13 months and nine varieties harvested at 6 months were determined and compared with the mealiness of the cooked root and the elasticity and smoothness of the pounded paste. Differences were established between the varieties in their cooking quality especially in the mealiness rankings. The age at harvest affected the cooking quality of some varieties. The varieties also differed in their proximate composition and this was also affected by the age at harvest. None of the components on its own could explain all the differences in cooking quality between the varieties. The pasting cycle of the starch showed large variations between varieties harvested at the same age, between the two harvesting ages and between the starch and flour of the same variety. These differences were explained on the basis of the variation in the rate of swelling of the starch granules and the fragility of the swollen granules. However, it was not possible to establish any direct relationship between the cooking quality parameters and specific points on the amylograph. The varieties again differed in swelling power and solubility of starch determined at 85°C, which confirmed the results of the amylograph studies that the varieties differed in the strength of the binding forces between the granules. The swelling power and solubility of starch of three varieties with contrasting cooking qualities determined over 60-95°C showed that a variety with good cooking quality is one in which the starch granules neither swell too rapidly nor too slowly on heating.

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RÉSUMÉ

SAFO-KANTANKA, O. & ACQUISTUCCI, RITA: *Les propriétés physico-chemiques de fécule de manioc par rapport à la texture de la racine cuite.* La constitution immédiate, le cycle de la raclée, le pouvoir de gonflement et la solubilité de six variétés de manioc récoltées à 13 mois et de neuf varietés récoltées à 6 mois, étaient déterminées et comparées avec l'aspect farineux de la racine cuite ainsi que l'élasticité et l' aspect lisse de la pâte pilonnée. Des différences étaient établies entre les variétés dans leurs qualités de cuisson surtout dans les classsments de leur nature farineuse. L' âge pendant la récolte affectait la qualité de cuisson de certaines variétés. Les variétés se sont distinguées dans leur composition immédiate et ceci était également influencé par l' âge pendant la récolte. Aucun des composants pourrait en lui même expliquer toutes les différences en qualité de cuisson entre les variétés. Le cycle de la raclée de fécule montrait des grandes différences entre les variétés récoltées au même âge, entre les deux âges de récolte et entre la fécule et la farine de la même variétés. Ces différences étaient expliquées en fonction de la proportion de variation de gonflement de granulés de fécule et la fragilité des granulés gonflés. Cependant, il n'etait pas possible d'etablir aucum rapport direct entre les paramètres de la qualité de cuisson et des points spécifiques sur l' amylographe. Encore, les variété se sont distinguées en pouvoir de gonflement et en solubilité de fécule déterminée à 85 °C, qui confirmait les résultats des études amylographes que les variétés se distinguaient à l' égard de la puissance des forces de cohésion entrte les granulés. Le pouvoir de gonflement et la solubilité de fécule de trois variétés ayant contraste en qualitiés de cuisson déterminées par-dessus de 60-95 °C montraient qu' une variété avec une bonne qualité de cuisson est celle sur laquelle les granulés de fécule ne se gonflent ni trop rapidement ni trop lentement au chaufage.

Introduction

Cassava (*Manihot esculenta*, Crantz) is an important staple in most parts of Africa and other tropical areas. In Ghana, it is used in many food preparations including *ampesi*, *fufu*, *kokonte*, *gari*, *yakayake* and *agbeli-krakro*. The preparation of the last three products involves some kind of fermentation and so the cooking quality of the fresh root is not important. Ampesi is the boiled or roasted root eaten with a vegetable sauce, and it is important that the cooked root be mealy. Fufu which is the boiled root pounded into a paste and eaten with soup must be elastic and free of lumps (referred to as smoothness) in order to be acceptable. These fufu-eating qualities also apply to kokonte, which is the flour cooked and stirred into a paste and eaten with soup. The changes in elasticity that take place in the fufu and kokonte if consumption is delayed are also important to the consumer.

In spite of these many uses, there is little information on which the plant breeder can depend to select different genotypes that are suited for particular uses. There is a tendency, therefore, for farmers to reject a disease-resistant and high-yielding variety, if it is found to be unsuitable for their particular food preparations.

According to Howard (1974), the Potato Quality Research Working Party of the European Association for Potato Research distinguishes between four types of potato based on what they are used for. There are types used for salad and boiling; multipurpose types used for chips, mashing, baking and salad and boiling; multipurpose types used for chips, mashing, baking and salad; mealy types used for mashing and baking and very mealy types used for mashing. These are grouped into categories A, B, C and D respectively.

The classification is based on the texture, colour, discolouration and flavour of the cooked tuber and of these factors, texture is the most important. Linehan & Huges (1969) concluded from their review that variations in the texture of the cooked potato can be only partly explained by variations in the starch content of the tuber. Bettelheim & Sterling (1955) found no relationship between the texture of the cooked potato and amylose content.

The ability of the starch granule to sell and yield a viscous paste is considered by Rasper (1982) to be among the most important practical properties of starch, since it affects its rheological properties. Mazurs, Schoch & Kite (1957) were the first to interpret the various points on the amylograph in terms of the practical rheological properties of the starch paste. Another important characteristic of the starch granule which also affects its rheological properties is the nature and strength of the associative forces between the granules. The differences in swelling and solubilization patterns of various starches can, therefore, also be explained on the basis of the differences in the character and strength of the micellar network within the granule (Rasper, 1969).

In cassava, very little information is available on the factors that influence the cooking quality and other uses of the root. The objective of this work, therefore, was to study the proximate composition, pasting cycle, swelling power and solubility of the starches of a number of cassava varieties and to find out the relationships that exist between these starch properties and the sensory evaluation of their cooking quality. Such knowledge will assist the plant breeder in developing selection techniques, and in breeding cassava varieties suited for specific uses.

Materials and methods

Segregates of cassava varieties developed at the International Institute of Tropical Agriculture (IITA) in Nigeria and some local Ghanaian varieties were used in these experiments. The first group (Set A) consisted of six varieties and was harvested at 13 months while the second group (Set B) was made up of nine varieties harvested at 6 months. The cooking quality parameters considered at harvest were the mealiness of the cooked root and the elasticity and smoothness of the pounded paste. The method of Safo-Kantanka & Owusu-Nipah (1992) was followed in determining the cooking quality. This involved the use of a six-member "trained" panel made up of regular cassava consumers, to score the cooked root for mealiness and the pounded paste for its elasticity and presence or absence of lumps (smoothness). The rest of the harvested root was peeled and cut into thin slices and dried at 60 °C in the oven for 48 h. The bulk of the dried chips was taken to the National Nutrition Institute in Rome, Italy, where the rest of the analysis was carried out. The dry chips were milled into flour using a pin mill (Buhler Niag-NLJ202, Milan, Italy). Starch was extracted from the flour by washing liberally with distilled water. The starch was dried at room temperature, pulverized and stored for subsequent use. The flour used in the analyses was finely milled in a cyclotec mill (Cyclotec 1033 Tecator, Hoganas, Sweden).

Proximate composition

The AOAC (1984, 1990) methods of analysis were used in determining the fat, protein, ash and fibre contents of the samples. The starch content was determined following the acid hydrolysis method as described by Rickard & Behn (1987) and amylose content was determined by the iodine colorimetric method as described by McCready & Hassid (1943). It was not possible to carry out the fat and protein analyses for varieties in Set B. In all cases, at least duplicate samples per variety were analyzed.

Hot-paste viscosity

The standard Brabender amylograph procedure was followed (Brabender Ohg Duisburg, 1989). A starch suspension (70 gl^{-1}, 500 ml) was placed in the cup of the standard Brabender (Duisburg, Germany) amylograph and heated until a base temperature of 50 °C was attained. Heating continued from 50 °C to 95 °C and held for one hour then cooled to 50 °C and held for an hour. The heating rate was 1.5 °C min^{-1} and the bowl speed was 75 rev min^{-1} using a 700 cm g^{-1} measuring cartridge. The flour was run at two concentrations of 70 and 100 gl^{-1}.

Swelling power and solubility

The method of Schoch (1964) was adapted using 1 g starch (db) suspended in 50 ml of distilled water in 75 ml centrifuge bottles and heating at 85°C in a water bath for 30 min while stirring slowly. The solubility and swelling power of the starches of the three varieties Ankra, 91934 and 30474 which showed distinct differences in their amylograms were determined over the temperature range of 60-95°C at 5°C intervals. All measurements were made in triplicate.

Results and discussion

Analysis of Variance (ANOVA) and correlation analysis were carried out on the data to establish differences between the varieties and relationships between the sensory evaluation and the physico-chemical properties of the starch and flour.

Cooking quality

TABLE 1

Cooking Quality Ranking of Cassava Varieties Harvested at 13 Months (Set A)

Variety	*Mealiness of cooked tuber*	*Elasticity of pounded paste*	*Smoothness of pounded paste*
Ankra*	4.0	4.0	4.0
91934	1.5	3.0	2.5
Isunikaniyan-W (ISU-W)	3.1	4.0	4.0
30001-W	3.5	4.0	3.5
30474	2.1	4.0	2.9
60142	2.9	4.0	3.6
Variety Harvested at 6 Months (Set B)			
Ankra*	4.0	4.0	4.0
Akosua-Tumtum	3.2	4.0	3.5
Atra*	3.0	3.8	4.0
60142	2.8	3.2	2.7
ISU-W	2.3	3.8	2.7
518-DB	2.7	3.2	3.0
30001-W	2.7	3.7	2.5
ISU-DB	3.0	3.2	2.2
1425-DB	2.0	3.2	2.2

+ The rankings are the mean score of 6 panelists.

* Local varieties.

Description of ranking

Scale	*Mealiness*	*Elasticity*	*Smoothness*
1	Poor	Not elastic	Not smooth or lumpy
2	Fair	Fair	Fair
3	Good	Good	Good
4	Very Good	Very Good	Very Good

There was a great deal of variation in the cooking quality rankings of the varieties (Table 1). The local varieties were generally better cooking types than the IITA segregants. There was greater variation in the mealiness of the cooked root and the smoothness of the pounded paste than in the elasticity of the paste. This shows that even though a root may be non-mealy when cooked, an elastic paste may be produced when pounded, but the paste may not necessarily be smooth. The varieties harvested at 6 months received lower cooking quality rankings than those harvested at 13 months. The only exception was Ankra in which the rankings in both maturity groups were the same. This shows that the age at harvest may affect the cooking quality of some varieties.

Proximate composition of root and starch

TABLE 2

Proximate Composition of the Root and Starch of Root Cassava Harvested at 13 Months

Varieties	*Starch (gkg^{-1})*	*Fat (gkg^{-1})*	*Protein (gkg^{-1})*	*Ash (gkg^{-1})*	*Fibre (gkg^{-1})*
Ankra	713	16.6	9.9	17.0	56.8
91934	692	15.8	9.3	12.7	61.2
ISU-W	699	18.7	7.4	16.0	54.4
30001-W	706	22.3	7.9	17.2	60.0
30474	689	17.8	8.0	11.9	83.7
60142	702	21.5	6.1	12.1	74.2
LSD at 5%	22.2	1.3	3.7	0.5	3.6
LSD at 1%	29.6	1.7	4.9	0.7	4.8
CV per cent	1.57	4.23	22.7	1.85	2.76

Starch

Varieties	*Amylose (gkg^{-1})*	*Fat (gkg^{-1})*	*Protein (gkg^{-1})*	*Ash (gkg^{-1})*
Ankra	19.2	2.7	3.5	3.2
91934	16.4	2.5	1.8	1.4
ISU-W	19.8	1.8	4.2	3.0
30001-W	15.3	1.9	4.0	3.6
30474	18.8	2.2	3.7	2.9
60142	18.4	2.4	2.8	2.4
LSD at 5%	1.03	0.8	1.0	0.4
LSD at 1%	1.37	1.1	1.3	0.6
CV %	2.83	18.6	14.9	9.63

TABLE 3

Proximate Composition of 6-month-old Cassava Root (Set B)

Variety	*Starch (gkg^{-1})*	*Amylose (%)*	*Ash (gkg^{-1})*	*Fibre (gkg^{-1})*
Ankra	684	20.9	12.2	42.9
Akosua-Tuntum	662	22.6	16.5	39.3
60142	680	18.6	16.9	40.6
ISU-W	662	22.0	13.6	45.6
Atra	665	20.8	21.1	61.2
518-DB	677	21.8	13.5	54.5
30001-W	668	20.9	16.7	51.5
ISU-DB	668	20.3	17.7	55.6
1425-DB	660	20.1	15.8	55.9
LSD at 5 %	9.49	1.53	0.8	5.9
LSD at 1%	12.7	2.04	1.1	7.9
CV %	0.70	3.63	2.61	6.04

Tables 2 and 3 give the proximate composition of the root and starch of the varieties. There were no statistically significant differences in starch content between the varieties harvested at 13 months, but statistically significant differences existed between varieties harvested at 6 months. This would suggest that some of the varieties had not attained their maximum starch content at six months. Ketibu & Oyenuga (1972) also reported that peak starch content in cassava is reached at 8 months while Obigbesan & Agboola (1973) reported that maximum starch content is not attained until 15 months. The amylose content of the starch, however, differed among the varieties, especially those harvested at 13 months. The apparently higher levels of amylose in the 6 month old material was not statistically tested.

The varieties in both maturity groups differed in the ash content of the root, but the average amount of ash in the root was not greatly influenced by the age of harvesting. Significant differences were established in the fibre and fat contents but not protein content of the root of the varieties in Set A. The components of the starch studied were fat, protein and ash for varieties in Set A. These represented very small proportions of the starches, and yet statistically significant differences were established between the varieties.

Proximate composition of root and cooking quality

The product-moment correlation coefficients between the cooking quality parameters and proximate composition are shown in Table 4. Many of the correlation coefficients were not statistically significant, even though some of them were relatively high. This situation may be due to the small number of varieties used in the experiments rather than the complete absence of any relationship. With error degrees of freedom of 4 and 7 in the correlation analysis for Sets A and B respectively, the value of the correlation coefficient (r) must be equal to or greater than 0.811 and 0.666 respectively before statistical significance could be established (Steel & Torrie, 1960). The correlations are, therefore, discussed in terms of their relative values instead of their statistical significance.

TABLE 4

Correlation Between Cooking Quality and Proximate Composition

Set A	*Mealiness*	*Elasticity*	*Smoothness*
Ash content of starch	0.80 *	0.85 *	0.68 ^{ns}
Ash content of root	0.38 ^{ns}	0.55 ^{ns}	0.30 ^{ns}
Fat content of starch	-0.06 ^{ns}	-0.36 ^{ns}	-0.18 ^{ns}
Fat content of root	0.30 ^{ns}	-0.43 ^{ns}	-0.14 ^{ns}
Protein content of starch	0.64^{ns}	0.83*	0.68 ^{ns}
Protein content of root	0.81*	0.35^{ns}	0.71^{ns}
Starch content of root	0.64 ^{ns}	0.33 ^{ns}	0.36 ^{ns}
Amylose content of starch	0.22 ^{ns}	0.45 ^{ns}	0.51 ^{ns}
Fibre content of root	-0.45 ^{ns}	0.17 ^{ns}	-0.49 ^{ns}
Set B			
Starch content	0.61 ^{ns}	-0.10 ^{ns}	0.30 ^{ns}
Amylose content	0.09 ^{ns}	0.58 ^{ns}	0.33 ^{ns}
Ash content of root	-0.12 ^{ns}	-0.09 ^{ns}	0.03 ^{ns}

ns = Not significant

* = 5 per cent level of significance.

In both Sets A and B, the correlation between starch content and mealiness were relatively higher than those between starch content and elasticity or smoothness of the pounded paste. On the other hand, the correlation between amylose content and smoothness or elasticity was relatively higher than that between amylose content and mealiness. Olorunda, Awoth & Numfor (1981) reported that mealiness was related to amylose content. But their finding and that in the present study are in contrast to Asaoka, Blanshard & Rickard (1991) who did not find any relationship between the differences in eating quality and amylose content. The ash content of the starch was highly and significantly correlated to mealiness and elasticity and the correlation to smoothness, though not statistically significant, was high (r=0.68).

The correlation coefficients between the cooking quality parameters and the protein content of the root and starch were relatively high and statistically significant in some cases. The fat content of the root and starch had no relationship with any of the cooking quality parameters. The correlation between fibre content and mealiness and smoothness were relatively high and negative, implying that varieties with very high fibre contents produce roots with unacceptable cooking qualities.

It may be concluded then, that even though differences exist in the proximate composition of cassava varieties, none of the components studied sufficiently explains all the observed differences in cooking quality. In spite of the lack of statistical significance in some cases, the magnitude of the correlation coefficients were high enough, in certain cases, to suggest the following:

1. Mealiness of the cooked root depends largely on the total starch content of the root, while the elasticity and smoothness of the pounded paste depends largely on the amylose content of the starch.
2. Varieties with high fibre contents may produce roots with unacceptable cooking qualities.
3. Of the minor components of cassava root and

starch, the ash and protein contents were the only ones which were related to cooking quality, but the relationships were not very conclusive and calls for more investigation, so that we can better understand how chemical fertilization of cassava is likely to affect its cooking quality.

Hot paste viscosity

The results of the hot-paste viscosity studies using the Brabender Amylograph are presented in Tables 5 and 6, and discussed below.

TABLE 5

Viscosity of Starch and Flour During Gelatinization (Set A)

				Brabender viscosity units (BU)							
Varieties	*Pasting temperature °C*	*Temperature of peak viscosity °C*	ΔT	*Peak visc.*	*Visc. at 95 °C*	$\Delta P1$	*Visc. after 95 °C hold*	$\Delta P2$	*Visc. at 50 °C*	$\Delta P3$	*Visc. after 50 °C hold*
Cassava starch (70gl^{-1})											
Ankra	74	82	8	560	460	100	260	43	480	85	420
91934	74	77	3	500	380	120	145	62	280	95	240
60142	69	77	8	440	390	50	200	49	430	115	360
30474	71	85	14	340	290	50	140	52	280	100	260
ISU-W	75	83	8	300	260	40	160	39	260	63	230
30001-W	68	83	15	400	360	40	240	33	420	75	360
Cassava flour (70gl^{-1})											
Ankra	68	76	8	490	320	170	150	53	280	87	250
91934	68	72.5	4.5	380	40	340	0	100	0	-	0
60142	69.5	74	4.5	300	210	90	80	62	140	75	130
30474	71	78.5	7.5	90	60	30	30	50	50	67	50
ISU-W	69.5	76.3	6.8	300	210	90	80	62	140	75	120
30001-W	68	78.5	10.5	300	200	100	60	70	120	100	110
Cassava flour (70gl^{-1})											
Ankra	68	77	9	1100	780	320	300	62	600	100	600
91934	67.3	71	3.7	880	70	810	10	86	20	100	20
60142	69.5	75.5	6	980	500	480	120	76	320	167	320
30474	69.5	74	4.5	380	120	260	50	58	120	140	120
ISU-W	68	75.5	7.5	950	460	490	140	70	300	114	300
30001-W	68	74	6	940	60	480	110	76	260	136	260

ΔT = Temperature of peak viscosity - Pasting temperature

$\Delta P1$ = Peak viscosity - viscosity at 95 °C

$$\Delta P2 = 100 \times \frac{\text{Viscosity at 95 °C - Viscosity 95 °C hold}}{\text{Viscosity at 95 °C}}$$

$$\Delta\ P3 = \frac{\text{Visc. at 50 °C - Visc. after 95 °C hold}}{\text{Visc. after 95 °C Hold}} \times 100$$

Pasting temperature. There were differences among the varieties in the pasting temperature, which agrees with an observation by Moorthy (1985). The lowest temperature at which pasting occurred was 66.5 °C and the highest was 75 °C. In Set A, the pasting temperature of the starch was higher than that of the flour. The gelatinization range was estimated as the difference between the temperature of peak viscosity and the pasting temperature, shown as T in Tables 5 and 6. There was a lot of variation in this parameter between the varieties, except in the flour of Set B, where T values were more uniform. Rosenthal *et al.* (1974) and Synder (1984) also established varietal differences in the gelatinization range.

Peak viscosity. An examination of varieties which appeared in both Sets A and B shows that,

TABLE 6

Viscosity Changes of Starch and Flour During Gelatinization (Set B)

Varieties	*Pasting temperature °C*	*Temperature of peak visc.°C*	ΔT	*Peak visc.*	*Visc. at 95 °C*	$\Delta P1$	*Visc. after 95 °C hold*	$\Delta P2$	*Visc. at 50 °C*	$\Delta P3(\%)$	*Visc. after 50 °C hold*
				Brabender viscosity units (BU)							
Cassava starch $(70 gl^{-1})$											
Ankra Akosua	71	80	9	420	400	20	220	45	400	82	360
Tuntum (AK-T)	72.5	80	7.5	360	290	70	150	48	280	87	270
Atra	69.5	74.5	5	540	360	180	200	44	380	90	340
518-DB	68	80	12	310	290	20	180	38	320	78	290
1425-DB	66.5	77	10.5	400	320	80	180	44	320	78	290
ISU-W	69.5	72.5	3.0	510	390	120	250	36	420	68	360
ISU-DB	66.5	72.5	6.0	460	390	70	300	23	500	67	420
30001-W	71	80	9.0	380	320	60	220	31	380	73	340
60142	69.5	75.5	6.0	400	220	80	120	45	240	100	240
Cassava flour $(70 gl^{-1})$											
Ankra Akosua	69.5	75.5	6	260	140	120	70	50	120	71	120
Tuntum (AK-T)	66.5	72	4.5	390	220	170	80	64	140	75	120
Atra	69.5	74	4.5	280	150	130	60	60	120	100	100
518-DB	69.5	74	4.5	200	80	120	40	50	60	50	60
1425-DB	69.5	74	4.5	440	270	170	100	63	180	80	160
ISU-W	68.8	73.3	4.5	400	220	180	80	64	150	88	140
ISU-DB	66.5	71	4.5	390	210	180	60	71	100	67	100
30001-W	69.5	74	4.5	260	100	160	60	40	100	67	100
60142	69.5	74.8	5.3	250	60	190	30	50	50	67	50

ΔT = Temperature of peak viscosity - Pasting temperature.

$\Delta P1$ = Peak Viscosity - Viscosity at 95 °C

$$\Delta P2 = 100 \times \frac{\text{Viscosity at 95 °C - Viscosity 95 °C hold}}{\text{Viscosity at 95 °C}}$$

$$\Delta\ P3 = \frac{\text{Visc. at 50 °C - Visc. after 95 °C hold}}{\text{Visc. after 95 °C hold}} \times 100$$

with the exception of ISU-W, the peak viscosity of the 13-month old materials was higher than the 6-month old materials, thus showing that age at harvest has an effect on the extent of swelling of the granules. There was a similar trend with the flour. The viscosity of the flour was generally lower than that of the starch at the same concentration, but the differences in some varieties were remarkably large. Moorthy, Richard & Blanshard (1994) found a similar difference between the viscosity of the cassava starch and flour and attributed this to the higher fibre content of the flour.

Viscosity at 95°C. According to Tipples (1982), the viscosity at 95 °C in relation to the peak viscosity reflects the fragility of the swollen granules. This change in viscosity is shown as Δ P1 in Tables 5 and 6. The results again showed a great deal of variation between the varieties and P1 was larger in the flour than in the starch. The change in viscosity, P1, in the flour of the varieties 91934 and 30474 was outstanding. In 91934, there was a drop from 380 to 40 BU, but 30474 had a peak viscosity of 90 BU and dropped by only 30 units. A similar observation was made with the $100 gl^{-1}$ flour samples. Among the varieties studied, therefore, the granules of 91934 swelled most readily while 30474 granules had the least ability to swell. The starch of the 6-month old varieties also showed much variation in P1 and these differed from those in Set A.

Viscosity after the 95 °C hold. According to Tipples (1982), the viscosity after cooking at 95 °C shows the stability or breakdown of the paste during cooking, especially when compared to the peak viscosity or the viscosity at the beginning of the hold. P2 in Tables 5 and 6 gives the percentage drop in viscosity at the end of the hold as compared to the viscosity at the beginning of the hold. This shows that in both Sets A and B, the proportional breakdown of the paste in the flour was higher than in the starch. Again, the two varieties 91934 and 30474 showed the opposite extremes. After cooking for one hour at 95 °C, the starch of 91934 had the greatest proportional break down, and the 70 gl^{-1} flour sample was no longer a viscous paste while the 100 gl^{-1} flour sample which had a peak viscosity of 880 BU had now dropped to 10 BU. This again shows the high degree of fragility of the swollen granules of 91934. The 70 and 100 gl^{-1} flour samples of 30474 underwent the least change in viscosity which may be due to the fact that there was very little swelling of its granules.

Viscosity at 50 °C. The extent of the increase in viscosity on cooling to 50 °C reflects the retrogradation tendency of the starch product (Tipples, 1982). P3 in Tables 5 and 6 represents the percentage increase in viscosity when the paste is cooled from 95 °C to 50 °C. There was a great deal of variation among the varieties in both Sets A and B. For the varieties in Set A, retrogradation was highest in the 100 gl^{-1} flour sample, but retrogradation of the pure starch at 70 gl^{-1} was higher than that of the flour at the same concentration. The variety 60142 showed the greatest retrogradation tendency among the starches of both maturity groups.

According to Tipples (1982), the viscosity

TABLE 7

Correlation Between Cooking Quality and Pasting Cycle

	Viscosity changes during gelatinization				
Cooking quality parameters	*Peak viscosity*	*Viscosity at 95 °C*	*Viscosity after 95 °C hold*	*Viscosity at 50 °C*	*Viscosity after 50 °C hold*
Set A Starch (70 gl^{-1})					
Mealiness	0.16	0.35	0.88	0.74	0.76
Elasticity	-0.39	-0.16	0.44	0.40	0.45
Smoothness	-0.07	0.09	0.63	0.48	0.49
Set A Flour (70 gl^{-1})					
Mealiness	0.45	0.96**	0.91*	0.92**	0.92**
Elasticity	-0.26	0.62	0.64	0.62	0.64
Smoothness	0.37	0.93**	0.89*	0.88*	0.87*
Set B Starch (70 gl^{-1})					
Mealiness	-0.02	0.25	0.06	0.15	0.22
Elasticity	0.28	0.40	0.06	0.11	0.19
Smoothness	0.18	0.18	-0.23	-0.12	-0.06
Set B Flour (70 gl^{-1})					
Mealiness	-0.36	-0.34	-0.23	-0.25	-0.22
Elasticity	0.12	0.18	0.35	0.38	0.37
Smoothness	-0.18	-0.29	-0.07	-0.01	-0.07

* 5 per cent of significance

** 1 per cent of significance

changes during the hold at 50 °C indicate the stability of the cooked paste as it might be used. There were only slight changes in viscosity during this period.

Relationship of viscosity changes to cooking quality

From the product-moment correlation coefficients between the cooking quality rankings and the various points on the amylograph (Table 7), it is difficult to predict the cooking quality from any specific point on the amylograph. However, it was possible to make the following distinctions between the varieties from the amylographs. A good cooking variety might be expected to have granules which swell to a great extent (peak viscosity); these swollen granules should not break down easily (viscosity at 95 °C and after 95 °C hold); and the paste should not harden to a large extent when cooled (retrogradation tendency). A deficiency at any of these points will not produce a good cooking variety. Once again, taking the variety 91934 as an example, we can see that it had one of the highest peak viscosities which was reached within the shortest temperature range-gelatinization range. However, it had the most fragile swollen granules especially in the flour, and at the end of the 95 °C hold, it was no longer a viscous paste. It is not a good cooking variety. The variety 30474 illustrated the opposite extreme. The 70 gl^{-1} flour sample had the lowest peak viscosity while the starch sample also showed one of the lowest values. The gelatinization range was relatively high. This suggests that the granules of 30474 do not swell easily and that may be due to strong bonding forces between the granules. Compared to the peak viscosity value, there was a 50 per cent drop in viscosity at the 95 °C hold and it also showed a relatively high retrogradation tendency. The poor cooking quality of 30474 may, therefore be largely due to the strong forces between the granules. Ankra which was the best cooking variety had the highest peak viscosity, and at 95 °C it still produced the most viscous paste and had a retrogradation tendency not too different from the other varieties. The other varieties were intermediate.

TABLE 8

Swelling Power and Solubility at 85 °C

Variety	*Swelling power*	*Solubility (per cent)*
Set A		
Ankra	33.60	22.46
91934	47.79	31.12
ISU-W	25.96	19.31
30001-W	22.48	21.12
30474	21.71	19.96
60142	27.11	17.96
LSD (5%)	9.93	1.08
LSD (1%)	13.36	1.45
Set B		
Ankra	24.63	16.33
Ak-T	34.96	25.23
Atra	32.13	20.84
60142	27.21	22.57
ISU-W	38.44	20.49
518-DB	33.31	25.58
30001-W	31.94	27.02
ISU-DB	35.94	19.39
1425-DB	34.51	25.15
LSD (5%)	1.46	0.75
LSD (1%)	1.96	1.00

Swelling power and solubility

The results of the swelling power (SWP) and solubility determined at 85 °C are presented in Table 8. Statistically significant differences for both parameters were established between the varieties. Moorthy & Ramanujam (1986) also found differences in SWP and solubility between cassava cultivars in India. The swelling power of an aqueous suspension of starch is an indication of the strength of the hydrogen bonding between the granules. The results, therefore, show that the bonding forces between the granules vary between the varieties and confirm the observations made in the amylograph studies.

The correlation coefficients between SWP and solubility and the cooking quality parameters are presented in Table 9. The only coefficients that were statistically significant were those between

TABLE 9

Correlation between Cooking Quality, Swelling Power and Solubility

Variety	*Swelling power*	*Solubility*
Set A		
Mealiness	0.43	-0.54
Elasticity	0.87*	-0.94**
Smoothness	0.56	-0.63
Set B		
Mealiness	0.64	-0.64
Elasticity	0.12	-0.17
Smoothness	0.47	-0.42

* 5 per cent significance
** 1 per cent significance

SWP and solubility and elasticity in Set A, but there were no significant correlations in Set B. In all cases, the correlations were negative, indicating that the higher the SWP or the weaker the binding forces between the granules, the less desirable the cooked or pounded product. There were exceptions such as 30474 which had very strong binding forces but had poor cooking quality.

The differences in the strength of the bonding forces between the granules of the different varieties became more apparent when the SWP and solubility of the three varieties Ankra, 91934 and 30474 were studied over the temperature range of 60-95 °C. The three were chosen because they showed very distinct differences in their amylograph behaviour and also differed in their cooking qualities. The results are presented graphically in Fig. 1 and 2.

The SWP and solubility curves show that the starches of the three varieties differed in the rate of swelling of their granules. The variety 91934 showed a very rapid rate of swelling which suggests that its granules have relatively weak bonding forces. This would explain why in the amylograph studies, 91934 lost its viscosity in the flour after stirring at 95 °C for one hour. The variety 30474 had the slowest rate of swelling of the three varieties, and this would agree with its amylograph behaviour

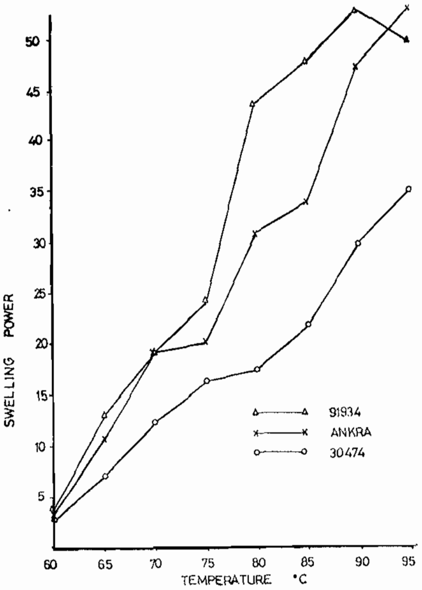

Fig.1. The effect of temperature on the swelling power of three cassava varieties

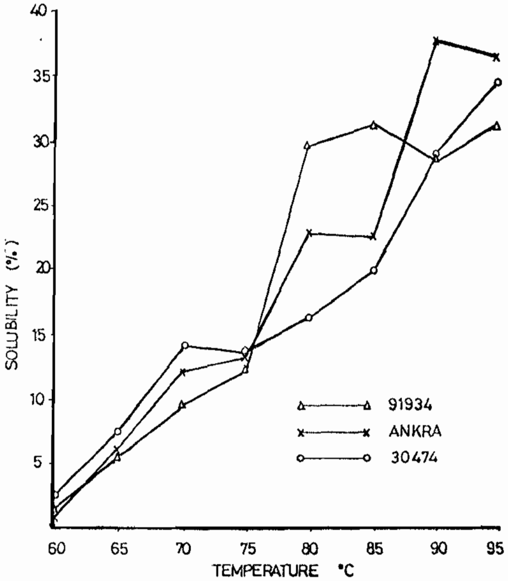

Fig. 2. The effect of temperature on the solubility of three cassava varieties

which showed very low hot-paste viscosity values. The rate of swelling of Ankra was intermediate between the other two varieties.

The two varieties 91934 and 30474 had the poorest cooking quality in terms of mealiness and smoothness of the pounded paste. Ankra gave the best results. The three varieties, therefore, show that for good cooking quality, a gradual swelling as occurred in Ankra is desirable. Too rapid swelling indicating very weak bonding forces as occurred in 91934, results in poor cooking quality. Similarly, too strong bonding forces as occurred in 30474, results in poor cooking quality.

It may be concluded that the chemical and rheological analyses undertaken in this study help to explain the differences in cooking quality between cassava varieties but none seems to provide a simple method of objective assessment which could be used by the plant breeder as selection criterion.

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