CHARACTERIZATION OF WATER YAM (*DIOSCOREA ALATA*) FOR EXISTING AND POTENTIAL FOOD PRODUCTS

BY

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CERTIFICATION

This is to certify that this thesis is the candidate's own account of her research

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Abstract

The yam species, *Dioscorea alata* has an advantage for sustainable cultivation due to its comparatively good agronomic characteristics. This research was aimed at identifying the major chemical and physical characteristics of *D. alata* tubers that affect food and industrial processing qualities. Tubers from 20 varieties of *D. alata* were compared to a reference variety, *D. rotundata*. The tubers were processed into flour for the determination of quality characteristics. Pounded yam, boiled yam and *amala* products were also prepared for sensory assessment against the reference. The influences of tuber maturity and length of storage on the quality characteristics were also evaluated, as well as the tuber tissue microstructure. On the average, most of the characteristics evaluated were relatively higher in *D. alata* varieties as compared to *D. rotundata*: moisture (72.2%), sugar (5.7%), protein (6.0%) and total dietary fibre (6.9%) contents; higher water binding capacity (163.3%), solubility (11.0%), and amylose (29.4%); breakdown (198.7 RVU), peak time (6.3 min) and pasting temperature (84.2 ^{o}C). However, dry matter (27.8%) and starch contents (68.4%), peak, setback, and final viscosities (215.7, 57.3 and 256.0 RVU respectively) were comparatively lower. *D. alata* varieties equally had appreciable contents of minerals. Based on the physicochemical and chemical properties, *D. alata* could be processed to flour for use in bakery products and diet formulations. The measured physicochemical properties in conjunction with pasting properties of the *D. alata* varieties suggest the presence of strong bonding forces within their starch granules. The relatively higher pasting temperatures required, and the lower pasting viscosities make *D. alata* suitable for producing weaning foods and other products that require low viscosity. Pasting properties of *D. alata* revealed relatively higher thermal and mechanical stability which will make it a good ingredient for processed foods, especially those that require thermal sterilization. The sensory analyses showed that *D. alata* varieties have comparative advantage over *D. rotundata* for *amala* production. However, specific promising varieties (TDa 98-159, TDa 291, TDa 297 and TDa 93-36) would need further genetic improvement to render them suitable for boiled yam and pounded yam dishes. Microstructural studies of the cooked cells in majority of the *D. alata* varieties (71%) showed incomplete disruption of the cells and consequently reducing exudation of starch contents. This feature partly accounts for less suitability of *D. alata* for sticky and doughy yam products in production areas. Moisture content of *D. alata* tubers decreased significantly from 5 to 9 months after planting (MAP) (74.53 to 71.76%) and throughout the 5 months storage period (71.76 to 68.06%) as a result of dehydration. Sugar and starch contents increased from the 5MAP to 9MAP (4.54 to 4.70%; 65.92% to 72.01% respectively), however, starch content decreased at the end of 5 months storage period (72.01 to 66.55%) with concomitant increase in sugar content (4.70-6.83%). The observations are due to photosynthetic materials accumulation during growth period and breakdown of starch to sugars as a result of respiration during storage.

Amylose content generally decreased with the storage period but swelling power increased (6.26-9.02%). Pasting viscosities increased throughout the growth period to the end of storage. The increases in dry matter and sugar contents, swelling power and pasting viscosities of stored *D. alata* tubers would have significant improvement in their organoleptic and textural properties.

Contribution to Science

From this study, the following have been established and therefore add onto the scientific knowledge on *D. alata* yam species:

1. *D. alata* varieties had higher total dietary fibre than what is reported for brown rice (5%) (Best, 2005) with a few varieties having comparable values to whole wheat flour. The specific varieties with high TDF will be useful in diet formulation because of its health benefits
2. *D. alata* flour (*elubo*) is very good for *amala* product. This product should be promoted in Ghana due to the high flour storability and ease of preparation.
3. Significant mineral variations were observed among *D. alata* varieties which suggest the potential for improvement through breeding programmes.

Publications and Paper Presentations from Work

1. **Baah, F. D.**, B. Maziya-Dixon, R. Asiedu, I. Oduro and W. O. Ellis (2009). Physicochemical and pasting characterisation of water yam (*Dioscorea* spp.) and relationship with eating quality of pounded yam. *Journal of Food, Agriculture and Environment*. Vol. **7**(2):107-112.
2. **Baah, F. D**., B. Maziya-Dixon, R. Asiedu, I. Oduro and W. O. Ellis (2009) Nutritional and biochemical composition of *D. alata* (*Dioscorea* spp) tubers. *Journal of Food, Agriculture and Environment*. Vol. **7**(2):373-378.
3. **Baah, F. D**., Maziya-Dixon, B., Asiedu, R., Oduro, I. and Ellis, W. O. (2007). Organoleptic quality assessment of major traditional yam products from greater yam (*Dioscorea alata*). A paper presented at the Tenth Triennial Symposium of the International Society for Tropical Root Crops-African Branch (ISTRC-AB), Mozambique.
4. **Baah, F. D.**, Maziya-Dixon, B., Asiedu, R., Oduro, I. and Ellis, W. O. (2007). Evaluation of *Dioscorea alata* varieties for making pounded yam. A paper presented at the 1st International Chester Food Science and Technology Conference.
5. **Baah, F. D.,** Maziya-Dixon, B., Asiedu, R., Ellis, W. O. and Oduro, I. (2006). Suitability of *Dioscorea alata* Genotypes for Making Traditional Food Products in West Africa. 14th Triennial Symposium of the International Society for Tropical Root Crops (ISTRC) - Book of Abstract p. 36.
6. Akin-Idowu, P., Asiedu, R., Maziya-Dixon, B. and **Baah, F. D**. Nutritional Enhancement of Yam: A paper co presented at the Annual Conference and Scientific Meeting of Nutrition Society of Nigeria (NSN) held at Abeokuta, Nigeria, 8-10 December 2006.

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DEDICATION

To the Glory of God and

To my Cherished Husband and Sons;

Kwabena, Kwame and Kwasi Wireko-Manu

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

APPENDIX

Appendix 1: Physicochemical characteristics (%) of yam varieties from Ghana

Serial no.	Species/variety	Amylose	Amylopectin	Swelling Power	Solubility	WBC*
	D. alata					
1	Apu	25.58	74.42	7.29	12.23	208.09
2	TDa 291	28.19	71.81	6.78	10.26	158.69
3	TDa 297	23.63	76.37	8.87	16.15	232.04
4	TDa 98/01168	24.11	75.89	7.07	9.80	215.48
5	TDa 98/01174	25.54	74.46	7.39	9.19	179.50
6	TDa 98/01176	21.69	78.31	7.36	10.47	192.32
7	TDa 99/00022	24.66	75.34	8.30	14.60	197.83
8	TDa 99/00048	25.78	74.22	8.27	9.03	194.22
9	TDa 98/00049	26.65	73.35	7.96	10.12	214.53
10	TDa 99/00199	27.84	72.16	7.88	13.06	189.41
11	TDa 99/00214	26.49	73.51	9.75	16.38	182.63
12	TDa 99/00395	23.33	76.67	6.23	8.81	228.96
13	TDa 99/00446	24.23	75.77	6.27	7.93	167.43
14	TDa 99/00528	27.79	72.21	6.47	9.54	211.08
15	TDa 99/01169	28.17	71.83	8.22	19.98	181.38
16	KM 1999	31.56	68.44	7.39	9.22	152.68
17	WM 2001	31.14	68.86	7.55	7.18	127.40
18	WM 2003	28.95	71.05	7.88	9.44	188.05
	Min	21.69	68.44	6.23	7.18	127.40
	Max	31.56	78.31	9.75	19.98	232.04
	Mean	26.41	73.59	7.60	11.30	190.09
	SE	0.63	0.63	0.21	0.81	6.37
	LSD	1.25	1.25	1.24	2.33	19.40
	D. rotundata					
	Pona	27.36	72.64	12.05	8.94	149.63

*WBC: Water binding capacity

Appendix 2: Pasting characteristics of yam varieties from Ghana

Serial no.	Species/Variety	Peak Visc. † (RVU)	Trough (RVU)	B. Down‡ (RVU)	Final Visc. (RVU)	Setback (RVU)	Peak time (Min)	Pasting temp. (^{o}c)
	D. alata							
1	Apu	78.2	71.1	85.5	116.5	45.4	7.0	87.2
2	TDa 291	190.1	175.1	179.5	210.7	35.6	5.3	83.6
3	TDa 297	146.7	143.3	41.0	178.8	35.6	7.0	87.2
4	TDa 98/01168	74.8	66.9	95.0	112.3	45.4	7.0	90.1
5	TDa 98/01174	177.4	174.0	40.5	210.0	36.0	7.0	86.9
6	TDa 98/01176	165.9	163.9	23.0	222.4	58.5	6.7	84.1
7	TDa 99/00022	89.9	88.3	19.5	115.8	27.5	5.7	85.3
8	TDa 99/00048	201.3	196.9	52.5	249.2	52.3	5.8	85.3
9	TDa 98/00049	170.7	165.2	66.5	213.3	48.2	5.5	84.4
10	TDa 99/00199	284.6	258.7	311.5	317.2	58.6	6.4	88.2
11	TDa 99/00214	148.3	129.1	230.0	163.7	34.7	5.2	86.1
12	TDa 99/00395	93.2	88.6	55.0	131.3	42.7	7.0	85.5
13	TDa 99/00446	117.6	113.9	44.5	152.5	38.6	7.0	84.0
14	TDa 99/00528	167.9	160.3	92.0	208.5	48.2	7.0	87.4
15	TDa 99/01169	217.2	212.0	63.0	261.1	49.2	7.0	83.7
16	KM 1999	147.2	131.7	186.5	194.3	62.6	7.0	88.9
17	WM 2001	217.2	212.0	63.0	261.1	308.1	7.0	83.7
18	WM 2003	150.0	147.9	25.5	193.2	45.4	6.8	84.8
	Min	74.80	66.85	19.50	112.25	27.45	5.15	83.60
	Max	284.60	258.65	311.50	317.20	308.10	7.00	90.10
	Mean	157.66	149.91	93.00	195.08	59.56	6.49	85.89
	SE	12.88	12.30	19.05	13.38	14.79	0.16	0.46
	LSD	18.12	17.25	24.85	23.04	180.01	0.15	1.36
	D. rotundata							
	Pona	291.17	186.17	105.00	422.75	236.58	4.73	79.88

† visc. = viscosity; ‡ B. Down=breakdown

Appendix 3: Chemical composition (%) of varieties from Ghana

		Fresh Tuber		Flour			
Serial no	Specie/variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
	D. alata						
1	Apu	69.27	30.73	9.05	4.40	3.56	71.34
2	TDa 291	70.16	29.85	5.87	2.57	2.86	64.01
3	TDa 297	79.31	20.70	7.88	4.32	6.91	63.76
4	TDa 98/01168	74.30	25.70	7.72	3.52	4.09	69.74
5	TDa 98/01174	69.93	30.07	6.04	3.66	3.31	70.52
6	TDa 98/01176	56.47	43.53	5.07	4.54	3.18	77.56
7	TDa 99/00022	67.72	32.28	7.57	3.32	4.83	71.42
8	TDa 99/00048	65.45	34.55	7.21	3.62	4.62	70.70
9	TDa 98/00049	72.89	27.12	6.19	4.09	4.36	60.42
10	TDa 99/00199	66.86	33.14	5.94	3.55	4.28	61.01
11	TDa 99/00214	69.18	30.83	5.95	2.66	4.38	62.28
12	TDa 99/00395	69.07	30.94	6.18	3.36	5.31	65.58
13	TDa 99/00446	66.84	33.16	6.71	3.82	2.43	62.81
14	TDa 99/00528	71.44	28.56	6.51	3.95	5.52	63.68
15	TDa 99/01169	64.27	35.73	5.77	1.74	5.00	68.55
16	KM 1999	71.08	28.93	7.10	3.52	5.47	74.51
17	WM 2001	69.68	30.33	5.26	3.50	2.44	67.83
18	WM 2003	69.43	30.57	5.16	3.36	4.47	63.83
	Min	56.47	20.70	5.07	1.74	2.43	60.42
	Max	79.31	43.53	9.05	4.54	6.91	77.56
	Mean	69.07	30.93	6.51	3.53	4.28	67.20
	SE	1.09	1.09	0.25	0.16	0.28	1.15
	LSD	4.81	4.81	0.30	0.84	4.13	0.22
	D. rotundata						
	Pona	56.99	43.01	3.46	2.05	4.60	70.26

Appendix 4: Summary of the influence of maturity of *D. alata* tuber on chemical Properties

Appendix 4.1: Chemical properties of tubers (5 months maturity)

S.No.	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	75.57	24.43	3.21	2.1	4.9	61.61
2	TDa 01/00041	73.21	26.79	7.57	3.13	5.47	67.83
3	TDa 01/00081	78.43	21.57	6.33	2.36	4.95	67.37
4	TDa 92-2	75.39	24.61	4.86	2.3	6.21	70.34
5	TDa 95-310	72.65	27.35	6.14	2.65	3.24	63.68
6	TDa 98/01174	76.42	23.58	4.86	2.15	4.3	64.11
7	TDa 98-159	68.82	31.18	9.15	2.72	2.08	72.63
8	TDa 99/00332	75.53	24.47	7.77	1.81	5.17	61.01
9	TDa 99/00395	78.92	21.08	9.27	2.68	6.52	61.3
10	TDa 291	73.35	26.65	6.49	2.01	2.25	62.39
11	TDa 297	68.61	31.39	7.42	1.93	5	69.63
12	TDa 93-36	77.44	22.56	8.46	2.24	4.37	69.12

Appendix 4.2: Chemical properties of tubers (7 months maturity)

S.No.	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	73.33	26.67	6.92	3.5	6.67	77.74
2	TDa 01/00041	75.18	24.83	7.46	3.64	7.89	73.29
3	TDa 01/00081	78.14	21.87	5.36	2.56	8.47	73.78
4	TDa 92-2	75.58	24.43	6.31	2.72	8.52	62.51
5	TDa 95-310	66.41	33.59	7.54	4.16	2.87	66.72
6	TDa 98/01174	70.33	29.67	3.95	2.45	6.99	61.09
7	TDa 98-159	66.69	33.32	7.53	2.62	7.21	70.94
8	TDa 99/00332	75.16	24.84	6.04	5.84	6.95	73.38
9	TDa 99/00395	69.28	30.73	7.98	3.32	6.34	71.4
10	TDa 291	69.69	30.32	4.91	2.09	5.79	72.98
11	TDa 297	69.56	30.45	5.08	2.28	4.68	71.94
12	TDa 93-36	77.07	22.93	7.69	3.36	7.19	80.17

Appendix 4.3: Chemical properties of tubers (9 months maturity)

S.No.	Variety	9MAH	9MAH	9MAH	9MAH	9MAH	9MAH
1	TDa 00/00103	70.82	29.18	6.01	2.93	6.61	68.62
2	TDa 01/00041	76.19	23.81	7.49	2.65	4.16	68.4
3	TDa 01/00081	78.87	21.13	7.67	2.74	4.72	65.21
4	TDa 92-2	74.52	25.48	7.14	2.58	7.83	72.84
5	TDa 95-310	69.17	30.83	5.82	2.57	1.92	76.06
6	TDa 98/01174	75.02	24.98	5.69	1.86	6.11	78.46
7	TDa 98-159	66.04	33.96	7.44	2.52	1.76	77.76
8	TDa 99/00332	65.6	34.4	6.57	2.73	6.09	65.6
9	TDa 99/00395	71.21	28.79	7.27	2.57	4.65	72.9
10	TDa 291	72.89	27.11	5.7	3.19	4.04	72.27
11	TDa 297	65.6	34.4	7.78	2.8	4	66.02
12	TDa 93-36	75.18	24.82	7.67	2.42	4.54	80.02

Appendix 5: Summary of the influence of maturity of *D. alata* tuber on physicochemical properties

Appendix 5.1: Physicochemical properties of tubers (5 months maturity)

S. no.	VTY†	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	27.9	72.1	11.04	14.13	129.92
2	TDa 01/00041	27.26	72.74	10.79	15.61	161.97
3	TDa 01/00081	27.9	72.1	13.17	15.67	139.64
4	TDa 92-2	27.84	72.16	10.47	13.89	210.19
5	TDa 95-310	26.25	73.76	8.25	10.72	224.23
6	TDa 98/01174	23.35	76.66	10.6	13.24	179.07
7	TDa 98-159	25.96	74.04	10.76	9.4	189.25
8	TDa 99/00332	24.68	75.32	9.43	12.31	162.85
9	TDa 99/00395	22.27	77.73	10.62	16.72	195.22
10	TDa 291	23.81	76.19	9.51	10.93	134.25
11	TDa 297	23.58	76.42	10.9	11.31	168.03
12	TDa 93-36	22.33	77.67	8.83	11.69	158.66

Appendix 5.2: Physicochemical properties of tubers (7 months maturity)

S. no.	VTY†	Amylose	Amylopectin	Swellingpower	Solubility	WBC
1	TDa 00/00103	22.46	77.54	6.73	9.06	188.54
2	TDa 01/00041	26.42	73.58	6.67	13.5	205.42
3	TDa 01/00081	31.06	68.94	5.97	11.39	158.31
4	TDa 92-2	24.48	75.52	6.69	10.97	193.66
5	TDa 95-310	30.27	69.73	6.69	7.56	197.47
6	TDa 98/01174	27.9	72.1	6.36	7.63	207.99
7	TDa 98-159	27.72	72.29	7.28	9.09	226.62
8	TDa 99/00332	30.35	69.66	6.14	9.31	184.57
9	TDa 99/00395	21.85	78.16	6.64	10.26	197.82
10	TDa 291	22.14	77.87	5.36	8.54	131.77
11	TDa 297	28.29	71.71	6.12	7.46	143.72
12	TDa 93-36	22.25	77.76	7.08	10.48	197.05

Appendix 5.3: Physicochemical properties of tubers (9 months maturity)

S. no.	VTY†	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	24.47	75.54	5.52	10.04	176.44
2	TDa 01/00041	30.79	69.22	6.37	8.92	162.53
3	TDa 01/00081	26.56	73.44	6.31	10.22	156.57
4	TDa 92-2	27.83	72.17	5.31	11.76	148.26
5	TDa 95-310	29.93	70.08	5.94	7.48	164.94
6	TDa 98/01174	33.8	66.2	6.68	10.28	164.49
7	TDa 98-159	31.06	68.95	5.83	8.8	140.16
8	TDa 99/00332	34.28	65.72	6.05	10.63	152.44
9	TDa 99/00395	29.52	70.49	5.93	9.53	176.7
10	TDa 291	31.43	68.57	6.57	8.92	131.67
11	TDa 297	27.18	72.82	5.98	7.76	128.3
12	TDa 93-36	29.75	70.25	6.33	9.1	162.84

Appendix 6: Summary of the influence of maturity of *D. alata* tuber on pasting properties

Appendix 6.1: Pasting properties of tubers (5 months maturity)

S. no.	VTY†	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
1	TDa 00/00103	131.6	121.6	10	183.7	62	7	87.2
2	TDa 01/00041	208.8	191	17.8	249.6	58.7	5.7	82.4
3	TDa 01/00081	197.1	163.5	33.6	198.2	34.6	5	82
4	TDa 92-2	274	236.4	37.6	297.7	61.3	5.6	85.2
5	TDa 95-310	84.7	67.2	17.5	131	63.9	7	88.5
6	TDa 98/01174	71.3	55.2	16.1	114.2	59	7	88.9
7	TDa 98-159	233.2	223.7	9.5	301.3	77.6	7	87.7
8	TDa 99/00332	58.3	40	18.3	99.7	59.7	7	94.5
9	TDa 99/00395	94.2	82	12.2	152.3	70.3	7	88.9
10	TDa 291	258.1	250.6	7.5	304.4	53.8	6.6	83.9
11	TDa 297	297.8	271.3	26.5	315.6	44.3	5.7	83.9
12	TDa 93-36	146.7	136.2	10.5	175.4	39.3	7	87.2

Appendix 6.2: Pasting properties of tubers (7 months maturity)

S. no.	VTY†	Peak	Trough	Breakdown	Finalvisc	Setback	Peaktime	Pastingtemp
1	TDa 00/00103	264.71	251.79	12.92	301.25	49.46	4.97	88.08
2	TDa 01/00041	100.88	73.88	27	92.67	18.79	4.7	86.85
3	TDa 01/00081	204	164	40	198.84	34.84	4.44	84.88
4	TDa 92-2	194.84	174.5	20.34	207.25	32.75	5.3	89.35
5	TDa 95-310	279.46	253.67	25.79	349.5	95.84	4.9	86.13
6	TDa 98/01174	300.54	276.38	24.17	352.42	76.04	5.33	86.88
7	TDa 98-159	190.96	167.96	23	201.17	33.21	5.17	88.95
8	TDa 99/00332	224.46	190.5	33.96	222.83	32.34	5.04	87.45
9	TDa 99/00395	186.21	181.83	4.38	227.21	45.38	7	88.98
10	TDa 291	286.04	282.46	3.58	339.5	57.05	6.67	94.85
11	TDa 297	330.75	248	82.75	328.25	80.25	5.07	89.3
12	TDa 93-36	185	171.04	13.96	226.75	55.71	7	85.53

Appendix 6.3: Pasting properties of tubers (9 months maturity)

S. no.	VTY†	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
1	TDa 00/00103	245	233.5	11.5	286.1	52.6	5	87.7
2	TDa 01/00041	243.2	223.8	19.3	293.2	69.4	4.8	84.9
3	TDa 01/00081	205.1	192.3	12.9	255.7	63.4	7	86.6
4	TDa 92-2	227.1	226.1	1	275	48.9	6	86
5	TDa 95-310	288	263.3	24.6	368.3	104.9	4.5	83.7
6	TDa 98/01174	206.3	202.3	4	247.6	45.3	6	87.8
7	TDa 98-159	305.2	274.1	31.1	366.1	92	5.4	90.6
8	TDa 99/00332	219.6	175	44.7	209.7	34.8	5.1	88.1
9	TDa 99/00395	196	190.4	5.6	253.8	63.4	7	88.1
10	TDa 291	256.3	248.6	7.7	305.5	56.8	5.5	84.1
11	TDa 297	292	219.2	72.8	279	59.8	5	87.8
12	TDa 93-36	226.5	217.3	9.1	283.8	66.4	7	85.5

Appendix 7: Summary of the influence of storage of *D. alata* tuber on chemical properties

Appendix 7.1: Chemical properties of freshly harvested tubers (0 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	70.82	29.18	6.01	2.93	6.61	68.62
2	TDa 01/00041	76.19	23.81	7.49	2.65	4.16	68.40
3	TDa 01/00081	78.87	21.13	7.67	2.74	4.72	65.21
4	TDa 92-2	74.52	25.48	7.14	2.58	7.83	72.84
5	TDa 95-310	69.17	30.83	5.82	2.57	1.92	76.06
6	TDa 98/01174	75.02	24.98	5.69	1.86	6.11	78.46
7	TDa 98-159	66.04	33.96	7.44	2.52	1.76	77.76
8	TDa 99/00332	65.60	34.40	6.57	2.73	6.09	65.60
9	TDa 99/00395	71.21	28.79	7.27	2.57	4.65	72.90
10	TDa 291	72.89	27.11	5.70	3.19	4.04	72.27
11	TDa 297	65.60	34.40	7.78	2.80	4.00	66.02
12	TDa 93-36	75.18	24.82	7.67	2.42	4.54	80.02

Appendix 7.2: Chemical properties of tubers (1 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	74.18	25.83	9.37	3.01	10.22	65.79
2	TDa 01/00041	73.53	26.48	7.01	3.02	7.03	73.33
3	TDa 01/00081	77.40	22.60	5.61	3.00	8.86	73.79
4	TDa 92-2	63.04	36.97	10.36	3.64	14.71	56.03
5	TDa 95-310	69.29	30.71	6.76	2.42	5.72	73.41
6	TDa 98/01174	73.98	26.03	5.70	2.93	11.12	67.93
7	TDa 98-159	64.85	35.16	8.87	3.26	4.36	71.28
8	TDa 99/00332	72.42	27.59	6.39	2.71	7.89	72.26
9	TDa 99/00395	69.76	30.24	6.84	2.90	9.36	73.40
10	TDa 291	71.95	28.05	5.97	2.76	8.87	67.45
11	TDa 297	68.45	31.56	8.15	2.46	5.47	65.66
12	TDa 93-36	71.56	28.44	5.10	2.31	5.89	57.01

Appendix 7.3: Chemical properties of tubers (2 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	75.23	24.77	6.58	3.27	3.87	77.99
2	TDa 01/00041	73.56	26.44	8.76	3.68	3.98	70.95
3	TDa 01/00081	74.03	25.97	5.53	3.14	8.15	72.37
4	TDa 92-2	75.66	24.34	6.48	2.89	7.2	73.56
5	TDa 95-310	70.53	29.48	6.04	2.85	4.55	77.08
6	TDa 98/01174	73.79	26.22	7.09	3.04	6.25	72.71
7	TDa 98-159	65.92	34.09	5.17	2.61	4.48	72.04
8	TDa 99/00332	71.69	28.32	5.52	2.81	8.85	69.98
9	TDa 99/00395	71.89	28.11	5.88	3.22	8.49	67.11
10	TDa 291	67.17	32.84	4.39	2.02	6.78	56.71
11	TDa 297	68.56	31.44	9.02	2.18	5.05	68.52
12	TDa 93-36	79.58	20.43	7.1	3.12	6.86	70.2

Appendix 7.4: Chemical properties of tubers (3 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	69.83	30.17	6.66	3.06	4.12	69.71
2	TDa 01/00041	67.32	32.68	8.23	3.23	3.53	75.77
3	TDa 01/00081	68.35	31.66	7.71	3.29	4.36	75.71
4	TDa 92-2	72.37	27.63	7.19	3.17	7.26	78.58
5	TDa 95-310	66.53	33.48	7.45	3.81	3.88	66.27
6	TDa 98/01174	71.18	28.83	5.34	2.54	4.81	67.10
7	TDa 98-159	65.39	34.61	8.31	3.19	2.99	75.07
8	TDa 99/00332	69.65	30.36	5.70	3.13	6.92	79.92
9	TDa 99/00395	74.86	25.14	6.93	3.39	5.26	74.39
10	TDa 291	68.85	31.16	5.86	1.99	4.81	77.74
11	TDa 297	67.68	32.33	6.40	2.58	3.80	83.43
12	TDa 93-36	77.19	22.81	7.73	2.72	4.34	76.79

Appendix 7. 5: Chemical properties of tubers (4 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	72.81	27.19	5.44	3.05	6.25	62.69
2	TDa 01/00041	64.76	35.24	8.41	3.52	5.66	64.21
3	TDa 01/00081	67.16	32.85	6.22	2.30	5.44	68.19
4	TDa 92-2	71.72	28.29	7.62	2.85	8.85	53.16
5	TDa 95-310	66.01	34.00	6.83	3.56	4.91	63.69
6	TDa 98/01174	66.69	33.31	6.74	2.91	3.82	69.93
7	TDa 98-159	62.16	37.85	5.95	2.90	5.30	62.79
8	TDa 99/00332	60.23	39.77	6.40	2.11	6.79	59.68
9	TDa 99/00395	70.52	29.49	8.05	3.12	6.12	67.05
10	TDa 291	62.21	37.80	6.13	2.26	5.20	69.01
11	TDa 297	68.71	31.29	7.54	2.43	4.70	54.54
12	TDa 93-36	66.57	33.43	6.90	2.66	6.20	63.00

Appendix 7.6: Chemical properties of tubers (5 month of storage)

S. No	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
1	TDa 00/00103	71.89	28.11	8.04	3.53	7.37	62.2
2	TDa 01/00041	67.84	32.16	9.52	4.29	4.54	67.27
3	TDa 01/00081	66.76	33.24	4.21	3.19	5.89	68.13
4	TDa 92-2	70.37	29.63	5.42	2.99	9.56	67.66
5	TDa 95-310	67.87	32.13	4.12	4.04	6.72	75.66
6	TDa 98/01174	66.98	33.02	5.15	2.73	5.11	62.91
7	TDa 98-159	61.43	38.57	7.18	4.13	4.91	64.13
8	TDa 99/00332	70.03	29.97	5.87	3.26	8.79	68.01
9	TDa 99/00395	61.36	38.64	9.28	3.5	8.05	61.52
10	TDa 291	69.43	30.57	6.65	2.6	7.61	70.21
11	TDa 297	65.78	34.22	7.36	2.65	5.23	62.92
12	TDa 93-36	65.2	34.8	6.93	2.95	8.14	67.99

Appendix 8: Summary of the influence of storage of *D. alata* tuber on physicochemical properties

Appendix **8**.1: Physicochemical properties of freshly harvested tubers (0 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	24.47	75.54	5.52	10.04	176.40
2	TDa 01/00041	30.79	69.22	6.37	8.92	162.50
3	TDa 01/00081	26.56	73.44	6.31	10.22	156.60
4	TDa 92-2	27.83	72.17	5.31	11.76	148.30
5	TDa 95-310	29.93	70.08	5.94	7.48	164.90
6	TDa 98/01174	33.80	66.20	6.68	10.28	164.50
7	TDa 98-159	31.06	68.95	5.83	8.80	140.20
8	TDa 99/00332	34.28	65.72	6.05	10.63	152.40
9	TDa 99/00395	29.52	70.49	5.93	9.53	176.70
10	TDa 291	31.43	68.57	6.57	8.92	131.70
11	TDa 297	27.18	72.82	5.98	7.76	128.30
12	TDa 93-36	29.75	70.25	6.33	9.10	162.80

Appendix 8.2: Physicochemical properties of tubers (1 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	26.28	73.73	6.43	10.75	150.21
2	TDa 01/00041	24.15	75.85	6.68	10.62	126.96
3	TDa 01/00081	25.52	74.48	6.35	11.21	133.22
4	TDa 92-2	20.56	79.44	6.71	16.83	155.12
5	TDa 95-310	24.80	75.21	5.65	8.41	129.81
6	TDa 98/01174	22.44	77.57	6.57	12.51	156.63
7	TDa 98-159	25.97	74.03	6.25	7.19	144.22
8	TDa 99/00332	28.08	71.93	5.99	10.20	144.14
9	TDa 99/00395	24.20	75.80	6.34	10.35	140.94
10	TDa 291	26.25	73.75	6.08	11.65	114.22
11	TDa 297	28.58	71.42	6.13	8.06	138.24
12	TDa 93-36	26.25	73.75	5.99	9.33	124.56

Appendix 8.3: Physicochemical properties of tubers (2 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	24.74	75.27	7.63	6.10	155.68
2	TDa 01/00041	26.56	73.44	7.37	10.70	135.64
3	TDa 01/00081	26.22	73.78	7.26	11.13	134.12
4	TDa 92-2	25.20	74.81	7.39	11.25	149.30
5	TDa 95-310	26.21	73.79	8.18	7.98	190.37
6	TDa 98/01174	27.57	72.44	7.54	9.53	184.97
7	TDa 98-159	26.93	73.07	7.50	9.80	126.62
8	TDa 99/00332	25.49	74.51	8.36	11.01	145.81
9	TDa 99/00395	27.71	72.29	8.80	17.51	156.48
10	TDa 291	24.00	76.00	8.17	9.07	134.85
11	TDa 297	26.17	73.84	7.69	9.45	143.03
12	TDa 93-36	26.11	73.89	7.77	11.05	148.01

Appendix 8.4: Physicochemical properties of tubers (3 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	25.35	74.65	6.93	7.43	151.04
2	TDa 01/00041	25.28	74.73	8.21	8.27	146.15
3	TDa 01/00081	23.51	76.50	8.07	9.97	158.52
4	TDa 92-2	22.44	77.57	7.56	10.87	150.94
5	TDa 95-310	29.02	70.99	7.49	8.33	159.02
6	TDa 98/01174	26.13	73.87	8.13	6.80	151.06
7	TDa 98-159	25.25	74.76	8.74	6.43	162.89
8	TDa 99/00332	26.13	73.87	7.43	11.23	167.92
9	TDa 99/00395	24.13	75.87	6.79	9.39	126.97
10	TDa 291	27.61	72.39	8.04	6.67	133.07
11	TDa 297	24.03	75.98	8.53	6.91	130.57
12	TDa 93-36	25.74	74.26	7.67	8.81	126.55

Appendix 8.5: Physicochemical properties of tubers (4 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	21.09	78.91	7.32	11.49	149.44
2	TDa 01/00041	25.35	74.65	6.59	12.22	166.25
3	TDa 01/00081	23.90	76.11	9.62	8.65	135.64
4	TDa 92-2	25.14	74.86	8.89	14.77	143.12
5	TDa 95-310	24.26	75.74	7.53	10.34	137.52
6	TDa 98/01174	21.84	78.16	9.14	8.70	155.77
7	TDa 98-159	27.09	72.91	9.50	10.11	129.10
8	TDa 99/00332	21.01	79.00	8.57	9.63	153.08
9	TDa 99/00395	19.09	80.92	8.16	11.13	134.87
10	TDa 291	27.20	72.81	9.25	8.53	129.21
11	TDa 297	25.67	74.34	7.05	7.98	149.56
12	TDa 93-36	27.15	72.86	7.34	9.88	134.65

Appendix 8.6: Physicochemical properties of tubers (5 month of storage)

S. No	Variety	Amylose	Amylopectin	Swelling	Solubility	WBC
1	TDa 00/00103	24.00	76.00	8.17	10.94	172.90
2	TDa 01/00041	22.57	77.43	8.59	9.93	180.60
3	TDa 01/00081	25.61	74.39	10.01	8.10	155.80
4	TDa 92-2	21.68	78.32	9.40	10.48	142.10
5	TDa 95-310	27.12	72.88	8.98	9.35	167.40
6	TDa 98/01174	21.32	78.68	10.52	8.26	175.40
7	TDa 98-159	24.60	75.40	9.57	8.48	154.90
8	TDa 99/00332	21.68	78.32	9.29	10.37	147.50
9	TDa 99/00395	23.43	76.57	6.83	8.46	148.50
10	TDa 291	26.42	73.59	8.91	9.47	144.00
11	TDa 297	25.40	74.60	9.58	7.45	156.00
12	TDa 93-36	25.97	74.03	8.47	9.33	143.60

Appendix 9: Summary of the influence of storage of *D. alata* tuber on pasting properties

Appendix **9**.1: Pastingl properties of freshly harvested tubers (0 month of storage)

Variety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	245.0	233.5	11.5	286.1	52.6	5.0	87.7
TDa 01/00041	243.2	223.8	19.3	293.2	69.4	4.8	84.9
TDa 01/00081	205.1	192.3	12.9	255.7	63.4	7.0	86.6
TDa 92-2	227.1	226.1	1.0	275.0	48.9	6.0	86.0
TDa 95-310	288.0	263.3	24.6	368.3	104.9	4.5	83.7
TDa 98/01174	206.3	202.3	4.0	247.6	45.3	6.0	87.8
TDa 98-159	305.2	274.1	31.1	366.1	92.0	5.4	90.6
TDa 99/00332	219.6	175.0	44.7	209.7	34.8	5.1	88.1
TDa 99/00395	196.0	190.4	5.6	253.8	63.4	7.0	88.1
TDa 291	256.3	248.6	7.7	305.5	56.8	5.5	84.1
TDa 297	292.0	219.2	72.8	279.0	59.8	5.0	87.8
TDa 93-36	226.5	217.3	9.1	283.8	66.4	7.0	85.5

Appendix 9.2: Pasting properties of tubers (1 month of storage)

Variety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	204.8	199.0	5.8	268.0	68.9	6.6	85.2
TDa 01/00041	260.5	189.0	71.5	248.3	59.3	4.8	84.1
TDa 01/00081	186.5	126.1	60.5	155.5	29.4	4.6	84.6
TDa 92-2	70.2	65.7	4.5	112.4	46.7	7.0	85.0
TDa 95-310	284.3	158.9	125.3	207.6	48.7	4.8	86.2
TDa 98/01174	122.3	115.8	6.5	173.8	58.0	7.0	83.8
TDa 98-159	335.3	273.0	62.3	358.7	85.7	5.2	89.4
TDa 99/00332	200.9	144.3	56.6	179.0	34.7	4.9	86.6
TDa 99/00395	189.2	172.4	16.8	215.1	42.6	5.2	87.0
TDa 291	129.7	115.6	14.1	141.0	25.4	5.4	83.2
TDa 297	231.8	165.9	65.8	216.6	50.7	5.1	90.1
TDa 93-36	294.4	282.1	12.3	345.8	63.7	5.7	94.6

Appendix 9.3: Pasting properties of tubers (2 month of storage)

ariety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	294.4	285.6	8.8	347.8	62.2	5.9	86.6
TDa 01/00041	287.2	168.2	119.0	220.8	52.5	4.6	83.7
TDa 01/00081	223.3	159.1	64.2	202.5	43.4	4.8	84.1
TDa 92-2	166.7	136.9	29.8	169.4	32.5	5.1	88.2
TDa 95-310	288.9	253.9	35.0	324.8	70.9	5.4	85.7
TDa 98/01174	229.3	211.3	18.1	241.7	30.5	5.5	87.3
TDa 98-159	309.0	244.0	65.0	340.4	96.5	5.1	88.6
TDa 99/00332	203.8	123.2	80.6	153.8	30.6	4.6	84.8
TDa 99/00395	217.2	169.0	48.2	215.8	46.7	4.8	85.4
TDa 291	166.5	114.7	51.8	141.5	26.8	4.7	82.9
TDa 297	169.1	95.1	73.9	112.8	17.7	5.1	88.3
TDa 93-36	188.4	177.4	11.0	204.9	27.5	5.7	83.1

Appendix 9.4: Pasting properties of tubers (3 month of storage)

Variety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	244.2	238.3	5.9	300.1	61.8	6.5	87.8
TDa 01/00041	193.0	187.4	5.6	230.4	43.0	6.8	87.4
TDa 01/00081	70.9	60.3	10.6	99.6	39.3	7.0	84.5
TDa 92-2	93.0	85.8	7.3	124.9	39.2	7.0	87.2
TDa 95-310	226.4	218.7	7.8	292.0	73.4	5.9	84.9
TDa 98/01174	219.9	200.0	19.9	246.6	46.6	6.1	89.0
TDa 98-159	237.9	213.1	24.8	250.0	36.9	5.7	89.7
TDa 99/00332	155.1	148.2	7.0	176.5	28.3	5.5	87.9
TDa 99/00395	138.1	128.3	9.8	190.3	62.0	7.0	85.6
TDa 291	208.8	202.1	6.7	248.7	46.6	6.5	85.2
TDa 297	269.2	228.3	40.9	300.5	72.2	5.1	86.2
TDa 93-36	172.7	163.4	9.3	206.0	42.7	7.0	87.0

Appendix 9.5: Pasting properties of tubers (4 month of storage)

Variety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	215.8	208.1	7.8	295.0	87.0	7.0	86.5
TDa 01/00041	294.0	246.5	47.5	307.9	61.4	5.3	85.4
TDa 01/00081	255.9	242.4	13.6	322.7	80.3	5.8	85.4
TDa 92-2	177.7	170.0	7.7	225.6	55.7	6.8	85.8
TDa 95-310	235.1	231.9	3.2	314.0	82.1	6.5	86.6
TDa 98/01174	153.7	147.3	6.3	198.0	50.7	6.7	86.2
TDa 98-159	251.1	233.4	17.7	299.9	66.5	6.0	85.3
TDa 99/00332	185.5	178.9	6.7	237.1	58.2	6.6	84.4
TDa 99/00395	163.2	152.6	10.6	233.1	80.5	7.0	84.6
TDa 291	245.1	237.3	7.8	298.8	61.5	6.2	86.6
TDa 297	305.5	171.5	134.1	239.4	68.0	4.9	86.6
TDa 93-36	319.8	250.1	69.7	304.6	54.5	5.4	85.7

Appendix 9.6: Pasting properties of tubers (5 month of storage)

Variety	Peak	Trough	Breakdown	Final viscosity	Setback	Peak time	Pasting temp.
TDa 00/00103	233.2	214.8	18.4	305.7	90.9	5.9	86.5
TDa 01/00041	151.9	138.6	13.4	218.4	79.9	5.9	84.8
TDa 01/00081	306.5	292.7	13.8	388.3	95.6	5.7	79.9
TDa 92-2	205.9	198.5	7.5	279.9	81.5	7.0	85.3
TDa 95-310	323.4	258.9	64.5	398.8	139.9	4.9	80.8
TDa 98/01174	307.0	242.7	64.3	337.5	94.8	5.1	82.8
TDa 98-159	284.9	239.5	45.3	312.8	73.3	5.3	85.6
TDa 99/00332	265.9	253.0	12.9	342.3	89.3	6.3	85.3
TDa 99/00395	141.6	135.0	6.6	216.7	81.7	7.0	85.2
TDa 291	226.5	213.5	13.0	267.9	54.4	6.3	82.4
TDa 297	367.9	261.9	106.0	417.5	155.6	4.9	82.5
TDa 93-36	275.0	254.5	20.5	309.1	54.5	5.7	84.8

Appendix 10A: Multiple paired comparison sensory evaluation questionnaires used for pounded yam

Test Product: **Pounded yam** Name:

Date:

You are presented with coded samples of **Pounded yam**. Please assess each at a time in comparison with a reference **'R'** and score the degree of difference as you have been trained using the scale below

Scale

Very much worse	1
Very poor	2
Moderately poor	3
Slightly poor	4
No difference	5
Slightly better	6
Moderately better	7
Much better	8
Very much better	9

Sample difference from R

Sample Code / **Attributes**				
Color				
Smoothness				
Stickiness				
Consistency				
Elasticity				
Hardness				

Appendix 10B: Multiple paired comparison sensory evaluation questionnaires used for boiled yam

Test Product: **Boiled yam** Name:

Date:

You are presented with coded samples of **Boiled yam**. Please assess each at a time in comparison with a reference **'R'** and score the degree of difference as you have been trained using the scale below

Scale

Very much worse	1
Very poor	2
Moderately poor	3
Slightly poor	4
No difference	5
Slightly better	6
Moderately better	7
Much better	8
Very much better	9

Sample difference from R

Sample Code / **Attributes**				
Color				
Wetness				
Taste				
Hardness				
Mealiness				

Appendix 10C: Multiple paired comparison sensory evaluation questionnaires used for *amala* product

Test Product: '**Amala'** Name:

Date:

You are presented with coded samples of *amala*. Please assess each at a time in comparison with a reference **'R'** and score the degree of difference as you have been trained using the scale below

Scale

Very much worse	1
Very poor	2
Moderately poor	3
Slightly poor	4
No difference	5
Slightly better	6
Moderately better	7
Much better	8
Very much better	9

Sample difference from R

Sample Code / **Attributes**				
Color				
Smoothness				
Stickiness				
Consistency				
Elasticity				
Hardness				

Appendix 11: Pictures in the Thesis

Appendix 11A: Sample of *D. alata* tubers used

Appendix 11B: Yam pounder used to cook and pound yam

Appendix 11C: Panelists evaluating product samples in partitioned booths in a sensory evaluation room

Appendix 11D: Rapid Visco- Analyser being used to determine pasting properties of flour samples

Appendix 11E Compound microscope being used to observe slides of starch granules and take pictures

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CHAPTER ONE

1.0 Introduction

Yam (*Dioscorea* spp.) is a multi-species crop that originated principally from Africa and Asia before spreading to other parts of the world (Hahn *et al*., 1987). It belongs to the family Dioscoreaceae within the genus *Dioscorea* (Coursey, 1983; Ayensu, 1972) and serves as a staple crop in West Africa (Asiedu *et al.*, 1992). The yam tuber, which is the most important part of the plant, can be stored longer than other root and tuber crops, ensuring food security even at times of general scarcity. It is the third most important tropical root and tuber crop after cassava and sweetpotato (Fu *et al*., 2005). The crop is of major importance in the diet and economic life of people in West Africa, the Caribbean islands, parts of Asia, and Oceania (Ravindran and Wanasundera, 1992; Girardin *et al*., 1998). Yam is an elite crop, preferred over other root and tuber crops in West Africa and a choice during ceremonies and festivities (Coursey, 1967; Hahn *et al.*, 1987). Resource poor people, especially women, derive a good income from its production, processing, and marketing. It also has ritual and socio-cultural significance in West and Central Africa.

West Africa is the leading producer of yam and grows over 90% of the worldwide production (40 tones fresh tubers/year), followed by the West Indies where Jamaica is the leading producer (Dipeolu *et al*., 2002; FAOSTAT, 2004). The third most important region of yam production is East Africa where Tanzania and Sudan are the major producers. Yam is also produced in Japan, Papua New Guinea, the Philippines, and Panama. Nigeria is the world's largest producer of yams followed by Ghana, Ivory Coast and Togo (FAO, 2003). Both fresh tubers and yam flour are now exported from Ghana and Nigeria to developed countries such as United Kingdom and United States of America. These are mainly patronised by emigrants from growing regions. According to the Nigerian Export Promotion Council (NEPC), Nigeria realized N56 billion from yam export in 2008 as against N37 billion in 2007 (Osibo, 2009). However, Ghana exports the largest quantity of yams (about 12 000 t) annually and average yam consumption per capita per day is highest in Bénin (364 kcal) followed by Côte d'Ivoire (342 kcal), Ghana (296 kcal), and Nigeria (258 kcal). (IITA, 2009).

Sustainable production and utilization of yam are important steps in enhancing food security and alleviating poverty, particularly in West Africa where it is estimated to provide more than 200 dietary calories each day for over 60 million people (Nweke *et al*., 1991; FAO, 2002).

Yam tubers have been used as traditional food in the home with little industrial use; however the traditional uses are diverse and the crop has more utilization potentials. Yam is consumed in different forms, mainly boiled, fried, or baked. Tubers are often dried and milled into flour for various products. Boiled yam could also be pounded and eaten with sauce. Yam can be fried or roasted as snacks. Another processed product is pottage which is usually prepared with other ingredients such as onions, pepper, a protein source, oil, etc. Boiled yam, pounded yam and *amala* are the forms of yam most consumed in West Africa, especially in Nigeria and Benin (Akissoe *et al*., 2001). A few yam species are also grown and used as health food and for medicinal purposes (Farombi *et al*., 1997; Albrecht and McCarthy, 2006).

Yam production faces many constraints, among which are high production cost (mainly planting material and labor cost), post-harvest losses and low yields. The Asiatic *D. alata* Linn, introduced to West Africa some hundred years ago, is fairly widely grown (Mignouna *et al*., 2003). It possesses a higher multiplication ratio and tuber yield as well as better storability than the preferred indigenous species, such as *D. rotundata*. *D. alata* has been estimated to have a potential yield of between 60 and 75t/ha year (Zinsou, 1998). However, very few varieties of the species are used for major food products in West Africa, or further processed because of its perceived unimpressive food quality traits such as its less suitability for the preferred cohesive and elastic dough in *fufu* or pounded yam. Even though *D. alata* is also eaten as boiled, it is less preferred to *D. rotundata* varieties. Breeders are therefore keen to improve the food quality of the species as it has good agronomic characteristics. However, in order to exploit *D. alata* for diverse uses, the inherent/intrinsic tuber properties that influence its usage should be well investigated.

Stored yam tubers do respire at reduced levels in the dormant state i. e. after harvesting. Consequently, several physiological and biochemical changes are known to occur which may negate or enhance the food quality of tubers (Mozie, 1988; Onayemi and Idowu, 1988; Treche and Agbor-Egbe, 1996; Girardin *et al*., 1998; Tschannen *et al*., 2003). In the case of *D. alata*, there is a general perception that the organoleptic properties of the tubers improve upon storage (Personal communication). However, the optimum storage time to improve and maintain its food value has not been well investigated.

1.1 Justification

Yam, in particular *D. alata*, has been less studied, compared to other root and tuber crops (Hoover, 2001). *D. alata* has the potential to enhance food security and create wealth in West Africa, where food production cannot keep pace with population growth. It is the most widely distributed species, having comparatively better agronomic characteristics such as ease of propagation and yields, higher nutritive value, and a longer storage life and thus plays a very significant role when other food crops are in short supply. The quantity and type of yam cultivated by farmers depend partly on what consumers regard as being of acceptable food quality. Sensory/organoleptic properties such as texture, appearance and flavour/taste are the main acceptability factors used by consumers to evaluate the quality of yam tuber (Bourne, 1990). These sensory factors are primarily influenced by the chemical, physicochemical and pasting characteristics of the tuber starch, a predominant chemical component of yam. Broad and detailed knowledge of these properties of *D. alata* and how they are related to product organoleptic properties is necessary to facilitate food quality improvement programmes and use in diverse food products. It will also enhance value addition through processing, as is currently possible for wheat-, maize- and cassava-based products. This will eventually increase its market demand and hence increase production/utilization, leading to poverty reduction for producers and processors.

1.2 Objective

The overall objective is to identify inherent/intrinsic characteristics of *D. alata* tubers that affect food and industrial processing qualities. Specifically the study intends to:

1. Characterize different varieties of *D. alata* yam tubers in terms of chemical, physicochemical and pasting properties.
2. Evaluate the quality of three most consumed yam products (*amala*, pounded yam and boiled yam) in West Africa made from *D. alata* varieties in comparison with a reference variety from *D. rotundata* (the preferred species for the products).
3. Establish a relationship between chemical, physicochemical and pasting properties of *D. alata* tubers and the organoleptic properties of three local food products prepared from them
4. Study the microstructure of yam tuber and evaluate the influence of cooking on it.
5. Evaluate the influences of maturity and storage on chemical, physicochemical and pasting properties of *D. alata*.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Root and tuber crops

Tropical root and tuber crops including cassava, sweetpotato, yam and aroids are enjoyed as vegetables, used as raw materials for small-scale industries, and consumed as staple foods especially in the less developed countries (Ravi *et al*., 1996). They were critical components in the diet during the early evolution of mankind and were the most important food crops of very ancient origin in the tropics and subtropic, associated with human existence, survival and socio-economic history (Asha and Nair, 2002). Their production, with the exception of sweetpotato, is limited to the warmer regions because of lack of tolerance to freezing temperatures (O'Hair, 1990). Apart from providing basic food security and a source of income and diversity in diet, they also serve as proteins for the less affluent and as additional source of essential vitamins and minerals. Root and tuber crops are found in a wide variety of production systems and do well under various levels of management from low to high input systems. This is a distinctive feature which makes them important for improving the productivity and richness of agro-systems. Even though their agronomic properties have been well documented, their food and industrial quality characteristics have not been studied extensively. The full potential of these staples is being realized in growing regions and they would continue to contribute to energy and nutrient requirements for the increasing population.

2.2 Yam

2.2.1 Origin and distribution of yams

Yams (*Dioscorea* species) are annual or perennial tuber-bearing and climbing plants belonging to the family of Dioscoreaceae. Some species of yam originated from Africa before spreading to other parts of the world while some originated from Asia and have spread to Africa (Hahn *et al*., 1987). Today, yams are grown widely throughout the tropics and they have a large biological diversity including more than 600 species worldwide (Burkill, 1960; Coursey, 1967) but only six are widely cultivated in West and Central Africa. These cultivated species are *D. alata*, *D. bulbifera*, *D. dumetorum* (Pax), *D. esculenta* (Lour), *D. cayenensis* Lamk and *D. rotundata* (Poir). Wild types of yam also exist and may be used as food after undergoing processing during the hunger seasons (Tetteh and Saakwa, 1994). A few yam species are also grown and used as health food and for medicinal purposes (Farombi *et al*., 1997; Albrecht and McCarthy, 2006). In the West African yam zone, which is the principal producer on a global basis, *D. rotundata*, *D. cayenensis* and *D. alata* are commonly grown.

2.2.2 Water yam **(***Dioscorea. alata* L*)*

D. alata is also referred to as greater yam, Asian greater yam and ten-month yam (Martin, 1976). It is more important as food in West Africa and the Caribbean than in Asia and the Americas where it originated, and has been competing with the most important native species, *D. rotundata* Poir. It was introduced to Africa some hundred years ago from Malaysia through agriculturists and by Portuguese and Spanish seafarers (Martin, 1976).

It is next to *D. rotundata* in terms of volume of production and extent of utilization. *D. alata* species is the highest yielding among the yam species and can store relatively longer than other species (5-6 months) after harvest. *D. alata* is also known for its high nutritional content, with crude protein content of 7.4%, starch content of 75-84%, and vitamin C content ranging from 13.0 to 24.7 mg/100 g (Osagie, 1992).

D. alata tubers have variable shapes, the majority being cylindrical. Its tubers vary in number, from one to five. The flesh of the tuber ranges in colour from white to purplish (FAO, 1994). The texture of its flesh is usually not as firm as that of white yam and less suitable than other species for the preparation of the most popular food products from yam (*fufu* and pounded yam especially) in the West Africa region. However, it is reported that *D. alata* is a major staple food in Côte d'Ivoire, where it constitutes about 65% of the yam grown in the country (Orkwor, 1998). In the West Indies, Papua New Guinea and New Caledonia, *D. alata* is the major food yam grown and consumed by the people (Orkwor, 1998). It is eaten as mashed yam in Trinidad and Tobago and in Barbados.

2.3 Agronomic characteristics

Yam is a plant of the tropical climates and does not tolerate frosty conditions (Coursey, 1967). Temperatures below 20 °C impede the growth of the plant which needs temperatures between 25 and 30 °C to develop normally. Light intensity is known to affect growth and tuber formation. Short days between 10 to 11 hr promote tuber formation, while days longer than 12 hr promote vine growth. This is usually the reason why yam vines are staked to ensure maximum interception of light by the leaves to promote yield (Coursey, 1982; Okezie, 1987). An annual rainfall of about 1000 mm spread over five to six months and deep, fertile, friable, and well-drained soils are ideal for yam cultivation (IITA, 2009). Most food yams give the highest yields in areas where long rainy seasons prevail. Yam is also able to survive long dry periods, though yields are reduced considerably.

Traditionally, yams are propagated vegetatively from whole tubers (seed yams), large tuber pieces (sets) or from minisetts (Otoo *et al.*, 1985). The growth of yam starts with a sprout from the post dormant tuber (Passam, 1977; Onwueme, 1984). According to Craufurd *et al.* (2001) and Sobulo (1972) yams exhibit a sigmoidal growth pattern common to most annual plants. A period of slow growth during establishment is followed by a phase of rapid exponential growth as the canopy reaches maximum area and, finally, growth rates decline as the canopy senesces. Maturity has not been well defined in yam even though it is traditionally measured by the dryness of vines (Okoli, 1980). Osagie and Opute (1981) also reported that the physiological status of yam tuber at harvest may influence its storage period and food quality characteristics.

2.4 Economic and social importance of yam

Yam naturally has a dormancy period, unlike most tropical crops, which gives the advantage of a longer storage period, ensuring a food supply even at times of general scarcity. Yam can be stored for up to 6 months or even longer depending on the means of storage. Stored yam is stored wealth and can be sold when prices are higher.

Yam is second to cassava as the most important tropical root crop but from a nutritional point of view, it is better than cassava on account of its higher vitamin C (40-120 mg/g edible portion) and crude protein content (40-140 g/kg dry matter) (Opara, 1999). Information on the nutritive value of yam has been highlighted by several authors in their work on yam (Bradbury and Holloway, 1988; Opara, 1999; Alves, 2000; Afoakwa and Sefa-Dedeh, 2001). In the South Pacific, yam is a significant food crop, accounting for over 20%, 8.1%, and 4.6% of the total dietary calorie intake in the Kingdom of Tonga, Solomon Islands, and Papua New Guinea, respectively (Opara, 1999).

Processed yam products have a very high market price internationally if well produced. For instance, international market research conducted by a team of International Export Consultants (IEC) revealed that in early 1999, the international price of processed yam flour and yam chips/pellets ranged between $120,560 per tonne and $152,362. These prices were even higher than those of cassava starch and cassava chips/pellets, which sold at between $90,000 and $105,000 for cassava chips/pellets and from $120,000 to $135,000 for cassava starch. Until recently yams were mainly subsistence crops in Africa, but are now grown as cash crop for both local and export. Report from a survey in Nigeria revealed that when purchasing power improved at all expenditure levels, there was a corresponding increase in household yam consumption (Nweke *et al.*, 1992). This means that yam will continue to have a high market potential in Nigeria.

Yam also has ritual, medicinal and socio-cultural significance. It is the choice during ceremonies and festivities (Coursey, 1967; Hahn *et al.*, 1987). In some parts of Southeastern Nigeria, the meals offered to gods and ancestors consist principally of mashed yam. Some traditional ceremonies are celebrated with yam as the major food item such as the New Yam Festival in parts of West Africa. In parts of Igboland in

Southeastern Nigeria, it is customary for the parents of a bride to offer her seed yams for planting as a resource to assist her in raising a family.

2.5 Production and storage

Food yams are grown extensively in Africa especially in West Africa with over 90% of the world's production coming from the areas called "the yam zone of Africa" (FAO, 2002). According to FAO statistics, 48.7 million tonnes of yams were produced worldwide in 2005, and 97% of this was in sub-Saharan Africa. West and Central Africa account for about 94% of world production. Nigeria is the leading producer with 34 million tonnes followed by Côte d'Ivoire (5 million tonnes), Ghana (3.9 million), and Bénin (2.1 million tonnes) (IITA, 2009). Table 2.1 shows the current production and consumption of yam in Africa. Sub-Saharan Africa is expected to produce 98.1% of total world production of yam by 2020 (Scott *et al.*, 2000a). From 1995 to 2000, total world production increased from 32.7 million tonnes to 37.5 million Mt (Figure 2.1). During the period 1975 to 1990, the total area cultivated to yam increased by about 38.8% globally, with corresponding increase in the total production (45.8%). This increase in production was due to the increase in cultivated area but not improvement in per hectare yields. West Indies, the second most important yam-producing region, is reported to produce over 250,000 tonnes of yam; approximately 5% is exported, resulting in an annual export earning of over $15 million (Mitchell *et al.*, 1989; Wheatley, 2000).

Table 2.1: Yam area cultivated, yield, production and consumption in various regions

	Africa			Asia	Pacific	Caribbean	Latin America
	WCA	ESA	All Africa				
Area ('000 ha)	4,136	81	4,273	15	22	65	68
Yield (t/ha)	8.0	4.3	7.9	13.8	14.0	8.6	9.6
Production ('000 tonnes)	37,584	347	38,069	204	343	557	682
Consumption (kcal/capita/day	108.0	4.5	82.0	2.0	70.0	33.0	7.8

Source: FAOSTAT (2005)

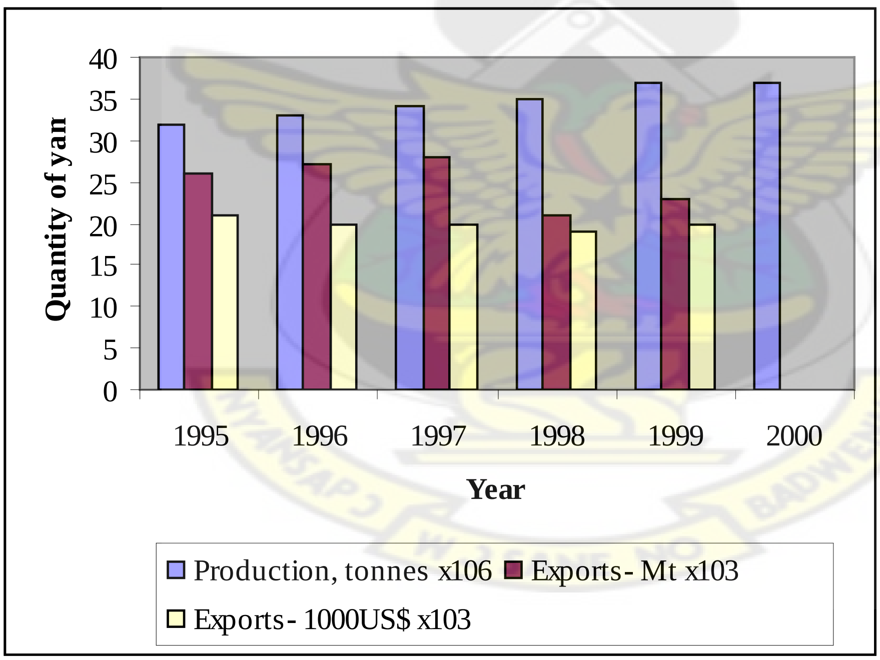


Figure 2.1: World production and trade in yam

Source: (FAO/STAT, 2000)

2.5.1 Storage of yams

Yam is a seasonal crop and most available during its harvesting period, but scarce and expensive during its planting and growing seasons (Ajayi and Madueke, 1990). Harvested tubers of yam are mostly stored to preserve parts for vegetative propagation, for consumption at the household level or preserved for the market when prices are higher. The storage life of yams is, however, limited to their dormancy period after which they begin to sprout and quickly lose their dietary value. The tubers are stored under different conditions at the various growing areas. In principle, they must be stored in an accessible, adequately ventilated area protected against direct sunlight (Scott *et al*., 2000b). The length of storage varies, depending on factors such as type of species, dormancy period and market demand, but it is generally from two to four months (Onwueme, 1978). Storage of yam for up to 9 months has been reported in Niger State (Alabadan, 2002).

Stored yam tubers continue to respire at reduced levels after harvesting in the dormant state. Consequently, they undergo several physiological and biochemical changes (such as loss of tuber weight, sprouting, breakdown of starch to sugars, changes in protein and other tuber constituents) which have been observed to affect food quality. A number of studies (Ikediobi and Oti, 1983; Ravindran and Wanasundera, 1992; Hariprakash and Nambisan, 1996; Treche and Agbor-Egbe, 1996; Afoakwa and Sefa-Dedeh; 2002 and Tschannen *et al.*, 2003) have reported on yam storage and associated physiological and biochemical changes.

2.5.2 Storage losses

Yam, like other root and tuber crops such as cassava and taro, suffers considerable post-harvest losses which can be as high as 60% (Asiedu, 1986; Coursey and Booth, 1997; Wheatley, 2000; Alabadan, 2002). These losses could be caused by external agents, such as insects, rodents, fungi and bacteria, or physiological processes, such as sprouting. Others include damage during harvesting and transportation of the crop and the high water content of the tuber (70-80%) that makes it vulnerable to spoilage. When sprouting begins, tubers can no longer be stored effectively because it increases susceptibility of tubers to pathogens and causes a rapid loss of stored carbohydrate (Passam and Noon, 1977; Girardin *et al*., 1998). Improved post-harvest technologies, such as desprouting and the application of gibberellic acid which is known to prolong tuber dormancy are valuable for storing yam tubers (Tschannen *et al.*, 2003). Passam and Noon (1977) reported that healthy tubers can be kept for as long as they can be prevented from sprouting.

2.5.3 Method of Storage

Good storage should maintain tubers in their most edible and marketable conditions by preventing large moisture losses, spoilage by pathogens, attack by insects and animals, sprouting and protection from direct rain (Scott *et al.*, 2000b).

2.5.4 Traditional storage

Traditionally, farmers store yam tubers in small quantities using simple storage techniques. The type of storage structure is influenced by climatic conditions, the purpose of the yam tubers in storage, type of building materials available and the resources of the farms (FAO, 1990). The principle involves keeping uninjured tubers in barns, usually on a raised platform, or tying the tubers singly to live poles to provide shade and allow good ventilation. Some are also stored in pits, barns and warehouses (Alabadan, 2002). Free air circulation and a low temperature are essential for good storage. There are also underground and storage housing structures, sheds, huts, silos and cribs (Ravi *et al.*, 1996). Tubers may also be left underground for several weeks as a storage method.

2.5.5 Modern storage

Various modern methods, such as the use of chemicals, irradiation and low temperature or controlled atmospheric conditions, to delay or suppress sprouting of yams for longer storage, have been reported (Tschannen *et al.*, 2003; Swannell *et al.*, 2003). Even though most of these modern methods are capable of achieving long- term storage, they are expensive to maintain and not feasible in the yam producing areas due to lack of funds for required equipment and frequent interruption of electricity supply.

5.5.6 Production and storage constraints

The cycle of yam production to the final consumption presents a number of constraints that hamper increased and sustainable production to satisfy the high rate of population increase in production areas. The principal problems in yam production that have been identified are the high cost of seed yam, high labour requirement (labour cost during planting, weeding, staking, and harvesting), diseases and pests, as well as high post-harvest losses (Orkwor, 1998). Studies indicate that the cost of labour accounts for over 40% out of which 20% is spent on harvesting alone (Onwueme and Charles, 1994). The use of the edible mother tuber as planting materials (unlike the use of stem cuttings for cassava) contributes to the costs of production that are higher than for other staples. Farmers who cannot afford to buy seed yam or produce the seed yam by themselves, must set aside about 30% of their harvest for planting the next year. The multiplication rate is quite slow and tedious especially on the field. About 1:10 has been reported as compared to 1:300 for some cereals. Its propagules can also serve as sources of virus diseases, nematodes and fungi unless appropriate measures are taken.

Another major constraint to yam production is the limited processing technologies. About 30% of harvested yam tubers are lost as waste. The greater part of the world's yam production is kept in the tuber form, partly because limited technologies exist for the production of shelf-stable processed yam products (Osagie, 1992). The bulkiness of fresh yam tubers is associated with high transport and low market margins for both farmers and traders and is thus a matter of serious concern in the urban markets (Cooke *et al*., 1988). The absence of a loss-free, long-term storage method for yam has probably contributed to the delay in the large-scale commercialization of yam production and processing. Storage methods, structures and post-harvest handling as well as processing technologies are very important factors in maintaining quality throughout the year.

2.6 The yam tuber and its composition

Tuber size and shape are variable depending on the species and growing conditions and may range from 2-3 m in length and over 50 kg in weight. The tubers of most important cultivars are cylindrical in shape, with some root 'hairs'. Tannin cells and cells containing bundles of crystals (raphids) are also present, and these crystals are responsible for allergic reactions when yam tubers and some other root crops are eaten raw or placed in contact with the skin. The outer part of the tuber forms several layers of cork which constitute effective protection from lesions, water loss and penetration of pathogens from the soil or storage compartments. The inner part of the tuber is formed by parenchyma tissue which is interwoven with vascular channels. In the tissue is stored carbohydrate, mainly in the form of starch. Even though water and carbohydrate form the bulk of the tuber, it also contains non-carbohydrate components. Differences in growing environment, maturity stage, method of storage and species may also affect variation in the tuber composition (Asiedu, 1986).

2.6.1 Nutritional composition

Yam, apart from providing basic food security and income, is a source of nutrition for millions of people. It is a rich source of carbohydrate and also contributes to vitamins and minerals especially where it is consumed in large quantities. Generally the ash content of yam gives an indication of its mineral status (Osagie, 1992). Yam tubers have high contents of moisture, dry matter and starch. They are relatively good sources of some minerals. They contain appreciable amount of potassium, a mineral that helps to control blood pressure. Yam is therefore recommended for people with high blood pressure but is not suitable for people with renal failure (Osagie and Eka, 1998). Woolfe (1987) reported that yam flour had higher levels of fibre than potato flour, refined wheat flour, maize and rice. The complex carbohydrates and fibre slow down the rate at which sugars are released and absorbed into the bloodstream. Yam is also a good source of manganese, a trace mineral that helps with carbohydrate metabolism and also acts as a cofactor in a number of enzymes important in energy production and antioxidant defences. It also contains traces of vitamin B- complex (Barquar and Oke, 1977). An amount of 1.44 mg/100g of β-carotene, a precursor of vitamin A, has been reported in *Igangan* a cultivar of *D. cayenensis* (Osagie, 1992). About 0.8 mg/100 g of beta carotene and 5-10 mg/100 g vitamin C contents have also been reported in *D. alata* (Osagie, 1992). According to Bradbury and Singh (1986), total ascorbic acid content of yam tubers is about 50% greater than that of cassava; values ranging from 200-2100 μg/100g (fwb) has been reported for various species. Yam also contains the limiting essential amino acids, isoleucine and sulphur-containing amino acids.

The phosphorus content of most yam tubers exceed 200 mg/100g, but occur mostly as phytic acid. Moorthy and Nair (1989) reported phosphorus content between 0.011 and 0.015% for *D. rotundata* in India. Typical values for potato starch are in the range 0.04-0.13% (Galliard and Bowler, 1987). Yam starches are reported to contain 3 to 4 times as much phosphorus as those found in cassava and aroids (Moorthy, 1994). Peroni *et al.* (2006) reported higher amounts of phosphorus in yam (0.022%) compared to other tropical root and tuber crops such as cassava and sweetpotato. Asemota *et al*. (1992) found phosphorus content to be higher in *D. alata* than in *D. rotundata* and *D. cayenensis*. The amount of this minerals or nutrients in yams depends on the type of soil it was harvested from, moisture content and maturity of the crop. Most of the calcium in yam tubers occurs principally as raphide bundles - crystals that occupy whole cells as calcium oxalate. They are also present within starch grains where they serve storage functions and act as nuclei for deposition of starch (Okoli and Green, 1987).

Yams also contain a steroid sapogenin compound called diosgenin, which can be extracted and used as base for drugs such as cortisone and hormonal drugs (Albrecht and McCarthy, 2006). Some species contain alkaloids (e.g. dioscorine $C_{13}H_{19}O_2N$) and steroid derivatives, which render the tuber bitter and sometimes poisonous if consumed without proper processing (Purseglove, 1976). Brown yam flour is reported to have antioxidant activity (Farombi, 1998; Farombi *et al.*, 2000) which could be utilised to stabilise bulk oils, emulsions and biological membranes against lipid peroxidation. Table 2.2 shows the nutritional composition of yam from different authors.

2.6.2 Phenolic compounds and polyphenol oxidase in yam

Anthocyanins and carotenoids are pigments known to occur in yam to give characteristic colours to the flesh of the tuber. Xantophyll esters and and β- carotene in *D. cayenensis* is reported to be responsible for the yellow flesh of the species (Martin and Ruberte, 1976). Some *D. alata* cultivars have cream coloured or light yellow flesh, which may be because of carotene content. Varieties with higher anthocyanin content are often prone to polyphenolic oxidation. The anthocyanin pigment in *D. alata* and *D. trifida* cultivars may impart a pink or purplish-red colour to the tuber tissue, either the entire tuber tissue or just beneath the skin of the tuber. The anthocyanins consist of a mixture of cyanidin glucosides and can also occur in many intermediate forms. Rasper and Coursey (1967), reported the predominance of cyanidin-3: 5,di-glucosides in one West African cultivar of *D. alata* and ferullic acid cyanidin-3-gentiobioside ester in a West Indian cultivar of the same species.

Table 2.2: Nutrient contents of yam species (*Dioscorea* spp.) per 100 g fresh edible tuber portions

Nutrient (g/100g)	*D. alata*	*D. rotundata*	*D. cayenensis*	*D. esculenta*	*D. dumetorum*
% Moisture	65-78.6	50.0-80	60-84	67-81	67-79
% Carbohydrate	22-31	15-23	16	17-25	17-28
% Starch	16.7-28	26.8-30.2	16.0	25	18-25
% Free sugar	0.5-1.4	0.3-1	0.4	0.6	0.2
% Protein	1.1-3.1	1.1-2.3	1.1-1.5	1.3-1.9	2.8
% Crude fat	<0.1-0.6	0.05-0.1	0.06-0.2	0.04-0.3	0.3
% Fibre	1.4-3.8	1.0-1.7	0.4	0.2-1.5	0.3
% Ash	0.7-2.1	0.7-2.6	0.5	0.5-1.5	0.7
Phosphorous (mg)	28- 52	17	17	35-53	45
Calcium (mg)	28 -38	36	36	12-62	52
Vitamin C (mg/100g)	2.0-8.2	6.0-12.0			
Iron (mg)	5.5-11.6	5.2	5.2	0.8	
Food energy (kcal)	140	142	71	112	122
β-carotene (μg)	5-10				
Thiamine (mg)	0.05- 0.10			0.1	
Riboflavin (mg)	0.03- 0.04			0.01	
Niacin (mg)	0.5			0.8	

Sources: Coursey (1967); Eka (1985); Bradbury and Holloway (1988); Muzac-Tucker *et al*. (1993); Osagie (1992); Asiedu *et al*. (1997) and Opara (1999)

The major yam species are also reported to contain polyphenol oxidase enzyme whose activity varies even within a given species (Muzac- Tucker *et al*., 1993). Imbert and Seafort (1968) and Martin and Ruberte (1967) also identified the following polyphenols in yam: catechins, epicatechins, chlorogenic acids and leucoanthocyanidins.

It is known that polyphenolic compounds in yams undergo polyphenolic oxidase-catalysed reactions to form o-quinones, their primary oxidation products, which react with other components to form brown polymeric compounds (Ozo, 1985). These reactions are responsible for browning in yam when the tubers are cut or when processed (Farombi *et al*. 2000). Antioxidant activity in brown yam flour was evaluated and according to Farombi *et al.* (2000), brown yam flour contains natural antioxidant and as such may mediate in oxidative damage and diseases caused by environmental chemicals. Specific phenolics in yam are known to play a role in disease resistance of the tuber (Ikediobi 1983). The rate of browning in yam has been positively correlated with the amount of phenolic compounds and polyphenol oxidases in yam tuber (Asemota *et al*., 1992; Muzac-Tucker *et al*., 1993). Muzac-Tucker *et al*. (1993) reported of a range of 0.061-10.50 g/100g dry weight phenolics in *D. alata* varieties while 0.023-0.034 g/100g dry weight was obtained for *D. rotundata* varieties.

2.6.3 Carbohydrate component

The carbohydrate component of yam is made up of sugars, non-starch polysaccharides, and starch, the predominant component.

2.6.4 Sugars

Glucose and sucrose are the main free sugars reported in yam tubers (Kouassi *et al*., 1990; Mensah, 1995; Hariprakash and Nambisan, 1996). The presence of maltose and fructose were reported after tubers were stored for some days (Hariprakash and Nambisan, 1996). Other sugars found are pentose and mannose (Omijeh, 1986). These sugars are in lower quantities when the crop is harvested but during storage, starch is hydrolyzed to different sugars (especially when sprouting starts) such as maltose and fructose (Hariprakash and Nambisan, 1996). Thus elevating the level of sugars and decreasing starch content consequently. The organoleptic properties such as taste and mouthfeel are reported to improve during storage (Onayemi and Idowu, 1988) probably due to the increase in sugar content. Differences in species, variety and growth environment also influence the level of sugars in yam tubers (Mensah, 1995).

2.6.5 Non-starchy carbohydrates

The non-starchy components of yam comprise cellulose, lignin, hemicellulose and pectin. These are generally present in the cell wall and have been found to have numerous benefits for health and in food product and processing development. The cell wall is known to provide rigidity, strength and shape to the plant cell and the non-starchy component of it is partly responsible for the textural properties of the plant-based food (Brett and Waldron, 1996). Cellulose has been used as a bulking agent in food due to its water-absorbing ability and low solubility. Some of the early dietary fibre ingredient sources were based on cellulose powders or microcrystalline cellulose. Both soluble and insoluble hemicelluloses play important roles in food products, the former functioning as soluble fibre and the latter as insoluble fibre. They are characterized by their ability to bind water and hence serve as bulking agents. Pectin substances are of importance as a component of dietary fibre because of their ion-exchange properties, as a result of galacturonic acid units, and gelling (viscosity enhancing) properties (Bornet, 1994). Holloway *et al*. (1985) reported pectin contents of 2.6% (dry basis) in *D. alata* tubers. Hemicellullose, cellulose and lignin contents in *D. alata* were reported by the same author to be 3.4%, 1.6% and 1.1% (dry basis), respectively. The fibre components of yam cell walls were determined by Lund *et al.* (1983), who found cellulose contents of 0.57, 0.20, 0.63; hemicellulose contents of .0.18, 0.07, 0.21; and lignin contents of 0.11, 0.13, 0.10 (wet basis) for *D. alata, D. rotundata* and *D. esculenta*, respectively. Fibre in food products has been estimated by non-enzymatic gravimetric methods (crude fibre, acid detergent and neutral detergent methods). For most foods, these methods do not recover a significant portion of what is considered to be total dietary fibre. An enzymatic-gravimetric method has been developed in which the sum of the soluble and insoluble polysaccharides and lignin are measured as a unit and considered to be total dietary fibre (TDF) (AOAC, 1990). No literature on total dietary fibre has been reported in yam even though there is a general belief that it has an appreciable amount based on separately measured components. Cereal grains, particularly whole grains, are the most important sources of dietary fibre (Dongowski *et al.*, 2002). Whole-oat flour typically has 14% total dietary fibre, whole wheat flour 12% and whole brown rice 5%. Even at these low levels, the fibre contents of whole-grain flours would have a significant impact on performance (Best, 2005). Due to low digestibility, it is recommended that high levels of fibre be included in foods to reduce the caloric density.

2.6.6 Starch

Starch is the major storage energy in various plants in nature. Tuber crops such as yam are quite rich in starch, accounting for 60 to 89% of yam carbohydrates (Degras, 1986; Muthukumarasamy and Panneerselvam, 2000). Starch is a predominant determinant of yam's physical and chemical properties; hence it can be used to predict its use (Osagie, 1992).

Native starch exists as microscopic granules. It is deposited in multilayer grains that vary in size and shape. The size and shape of these granules are characteristic of the starch's botanical source, growing and harvest conditions. It is assumed that starches with a range of granular structures behave uniquely, thus providing a range of functional attributes. Starch granules could be classified as type A and type B, which differ in their chemical and physical properties and also have different end uses. In industrial processing, the range of starch granules and their gelatinization temperatures are economically important for good product formulation and equipment performance.

Rasper (1971) observed that particle size and distribution are among the characteristics that most markedly affect the behaviour of starch granules. Large-sized granule fractions were found to be more susceptible to chemical and enzymatic hydrolysis. The small-sized granule fraction of barley had lower amylose than the large fractions (Tang *et al*., 2001). A relationship has also been observed between the arrangement of starch granules in a molecule and its functionality (Lorenz and Collins, 1990). Moorthy (1994) reported that large variability in shape exists among yam starches, round, triangular, oval and elliptical. Granule size was reported to range from 20 to 140 μm and from 10 to 70 μm for *D. alata* and *D. rotundata/cayenensis* respectively (Moorthy, 2002). Sizes of starch granules from *D. alata* (varieties Florido and Bete bete) and *D. cayenensis-rotundata* (Krengle) varied from 13 to 52 μm and from 19 to 50 μm respectively (Brunnschweiler *et al.*, 2004). Moorthy and Nair (1989) reported bigger starch granules for *D. alata* (35 μm) and *D. rotundata* (33 μm) as against a smaller granule size for *D. esculenta* (2-15 μm). Table 2.3

also represent different species of yam and their starch granule characteristics. In general, granule size may vary from less than 1 μm to more than 100 μm. Starch composition, gelatinization and pasting properties, enzyme susceptibility, crystallinity, swelling and solubility are all affected by granule size (Lindeboom *et al.*, 2004)

Table 2.3: Starch granule characteristics from different yam species

species	Granule size (μ)	Gelatinization temperature (°C)	Starch characteristics
D. alata	5-50	69.0-78.5	Fairly large granules, oval or egg-shaped, elongated rounded squares, or mussel-shell-shaped, sometimes with one side flattened
D. rotundata	5-45	64.5-75.5	
D. opposita	3-25	65.5-75.5	
D. cayenensis	5-60	71.0-78.0	Many fairly large granules, of rounded triangular form, sometimes elongated, rarely trapezoidal form
D. bulbifera	5-45	72.0-80.0	
D. esculenta	1-15	69.5-80.5	All granules small, rounded or polyhedral, sometimes complex, as though built up from many smaller granules
D. hispida	1-5	75.5-83.0	
D. dumetorum	1-4	77.0-85.5	
D. trifida	10-65	-	

Source: (Siedmann, 1964; Coursey, 1967; Emiola and Delarosa, 1981).

2.6.6.1 Molecular structure of starch granules

Granules consist of starch molecules which are arranged radially and form a series of concentric layers that alternate as amorphous and semi-crystalline regions. Each starch molecule is a large polymer made up of glucose units linked together by glycosidic bonds into longer strands or polymers. There are two distinct polymer types, amylose and amylopectin. The structure and the relative amount of both play an important role in determining starch properties and also influence pasting and physicochemical properties such as gelatinization, viscosity, retrogradation, solubility, swelling power and water absorption (Moorthy, 1994; You and Izidorczyk, 2002; Gerard *et al.*, 2001; Lindeboom *et al.*, 2004).

Amylose is the smaller polymer and essentially of linear structure. It consists of (1-4) linked alpha-D-glucopyranosyl units (Karim *et al.*, 2000). However, some amylose molecules have about 0.3-0.5% alpha-1, 6 linkages (branches) (Takeda *et al.*, 1999). It imparts definite characteristics to starch (Moorthy, 1994). Amylose is easily leached out from swollen granules just above the gelatinization temperature. Leached out amylose has a high affinity for iodine and forms complexes with it to produce a dark blue colour compared to a red, violet or brown colour for amylopectin (Balagopalan *et al*., 1988). The colour is due to the formation of a complex in which the iodine ions fit into the helical structure assumed by amylose in solution and forms the basis for the determination of amylose content in starches. However, long chains of amylopectin can form a helical complex with iodine, thus amylose values could be overestimated if the starch contains long branch chains. The amylose content of yam starches is between 14 and 30% depending on yam species, with 21-30% amylose for *D. alata*, 21-25 % for *D. rotundata* and 21-25% for *D. cayenensis* (Moorthy, 2002). Higher values have also been reported for *D. alata* in literature (McPherson and Jane, 1999; Moorthy, 2001; Hoover, 2001; Peroni *et al.*, 2006).

Amylose content is one of the important factors affecting starch pasting and retrogradation behaviors (Zhenghong *et al*., 2003). According to Singh *et al.* (2006), the viscosity parameters during pasting are cooperatively controlled partly by the properties of the swollen granules and the soluble materials leached out (mainly amylose) from the granules. Collado and Corke (1997) reported that peak viscosity in sweetpotato was significantly negatively correlated with amylose content. High amylose starches are also reported to have high gelatinization temperatures (Richardson *et al*. 2000). In rice, amylose content has been customarily used as a principal criterion in making selection and cross linking aimed at developing rice cultivars for parboil-canning application (Juliano and Hicks, 1996).

Amylopectin is one of the largest molecules in nature. The molecular weight of amylopectin is 100 times higher than that of amylose. Unlike amylose polymer, amylopectin consists of much shorter chains of (1-4) alpha D-glucose residues connected by (1-6) alpha-D-glucopyranosyl units (Karim *et al*., 2000). Approximately after every 20-30 glucopyranose residues, a branch point occurs, where a chain of alpha-D- (1-4) glucopyranosyl unit is linked to the C-6 hydroxymethyl position of a glucose residue through an alpha-D-(1-6) glycosidic linkage. This makes amylopectin structure more complex compared to amylose. The very different structures of amylose and amylopectin account for their dissimilar properties and functions in food systems. The linear nature of amylose molecules causes them to line up and associate with each other very tightly, whereas amylopectin molecules tend to be less tightly bound because the branching keeps the molecules at a greater distance from each other. Jane and Chen (1992) reported synergistic effects between amylopectin chain length and amylose molecular size on the viscosity of starch paste. Whereas amylopectin contributes to granule swelling, amylose and lipid contents inhibit it. Table 2.4 gives a summary of the differences between amylose and amylopectin molecules.

Table 2.4: Differences between amylose and amylopectin characteristics

Property	Amylose	Amylopectin
Molecular structure [a]	Linear (α-1,4)	Branched (α-1,4; α-1,6)
Molecular weight [b]	~106 Daltons	~108 Daltons
Degree of polymerization [a]	1500-6000	3×105-3×106
Helical complex [b]	Strong	Weak
Iodine colour [a]	Blue	Red-purple
Dilute solutions [a]	Unstable	Stable
Retrogradation [b]	Rapidly	Slowly
Gel property [a]	Stiff, irreversible	Soft, reversible
Film property [b]	Strong	Weak and brittle

From a: Jane (2000) b: Zobel (1988)

2.6.6.2 Properties of starch

During food processing, starch undergoes changes such as gelatinization and pasting which influence the texture and stability of the food products. The basic starch qualities or functionally important properties of starch are gelatinization, pasting properties, swelling power and solubility, enzymatic digestibility and retrogradation (Leach, 1965;

Rickard *et al*., 1991). These properties control the sensory attributes and stability of processed starch products.

(A) Swelling and solubility

The starch granule is a well organized structure. Unmodified starch granules are generally insoluble in water below 50 ^{o}C and can hold up to about 30% of their dry weight in cold water. The subsequent changes in volume and moisture are reversible at this point. As the temperature of an aqueous suspension of starch is increased above a certain range, hydrogen bonds holding molecules together disrupt and expose the hydroxyl units. At this point, water molecules become attached to the liberated hydroxyl groups and the granules continue to imbibe water and swell to many times their original size. Granules swell over a range of temperatures, indicating their heterogeneity of behaviour. As a direct result of granule swelling, there is an increase in starch solubility (Singh *et al*., 2003). Amylose is reported to be the main component which leaches into the surrounding medium to increase solubility.

Swelling and solubility provide evidence of the magnitude of interaction between starch chains within the amorphous and crystalline domains or provide evidence of non-covalent bonding between molecules within the starch granules. The extent of this interaction is influenced by the amylose to amylopectin ratio in terms of molecular/weight distribution, degree and length of branching and conformation (Leach *et al*., 1959, Hoover, 2001; Singh *et al*., 2003). Starches with more phosphate groups, such as potato starch, are more prone to swelling (Hoover, 2001). Starch phosphate monoesters carry negative charges and repel one another, thereby reducing interchain associations. This increases the level of hydrated molecules. Formation of amylose-lipid complexes could also restrict swelling and solubilization. Yam species exhibit lower and single stage swelling curves unlike cassava which displays two. This is attributed to the more highly ordered internal arrangement in the granules of yam (Swinkels, 1985). Swelling power and solubility can be determined by heating a weighted gram of starch sample in excess water (Leach *et al*., 1959). Differences in swelling power and solubility between species and among cultivars could be due to differences in starch composition and granule organization (Singh *et al*., 2003).

(B) Gelatinization and pasting

As the temperature of starch/flour slurry increases further, the granules rupture and deform irreversibly in a process called gelatinization. Gelatinization is characterized by crystalline melting, loss of birefringence and starch solubilization. At this stage more soluble amylose leaches out into solution with subsequent increased viscosity. Gelatinization of starch takes place over a definite range of temperature known as the gelatinization temperature. The initial point of gelatinization and the range over which it occurs are governed by starch concentration, method of observation, granule type and heterogeneities within the granule population under observation (Atwel *et al*., 1988). This range is reflected in the steepness of the initial rise in viscosity in the pasting curve. Modification of starch such as annealing or cross-linking will usually reduce this range.

The temperature at the onset of the rise in viscosity is the pasting temperature. It provides an indication of the minimum temperature required to cook a given sample, and has implications for the stability of other components in a food formula. Pasting temperature is characterized by an initial change in viscosity, due to the swelling properties of the starch (Afoakwa and Sefa-Dedeh, 2002). When starch granules are extremely swollen, they are fragile and easily broken when stirred, causing a decrease in viscosity. The combined processes that follow gelatinization are referred to as pasting.

This series of events is of high importance in the food industry, since it affects the texture and digestibility of starchy foods. Varietal differences in the pasting properties of yam starches have been reported (Rasper and Coursey, 1967; Moorthy and Nair, 1989; Afoakwa and Sefa-Dedeh, 2002; Sahorè *et al.*, 2005; Otegbayo *et al.*, 2006; Riley *et al.*, 2006). An empirical rheological test of the gelatinization properties of starches is the measurement of the viscosity of starch dispersions in a temperature/time profile using the Brabender Visco–amylograph or Rapid Visco Analyser (RVA) which has been designed as a simple-to-use viscometer. The RVA is able to reasonably imitate the cooking of flour/starch and provides results that are closely correlated with the quality of the end product (Newport Scientific, 1998). The viscosity changes produced by heating and cooling starches in water generally provide a similar characteristic pasting curve as shown in figure 2.2. The RVA profile depicts six significant points: pasting temperature, peak viscosity, viscosity at 95 ^{o}C (trough or holding strength), viscosity at constant 95 ^{o}C (breakdown), viscosity at 50 ^{o}C (final viscosity) and viscosity at constant 50 ^{o}C (setback). The pasting behaviour of starches is very important for starch characterization and applications.

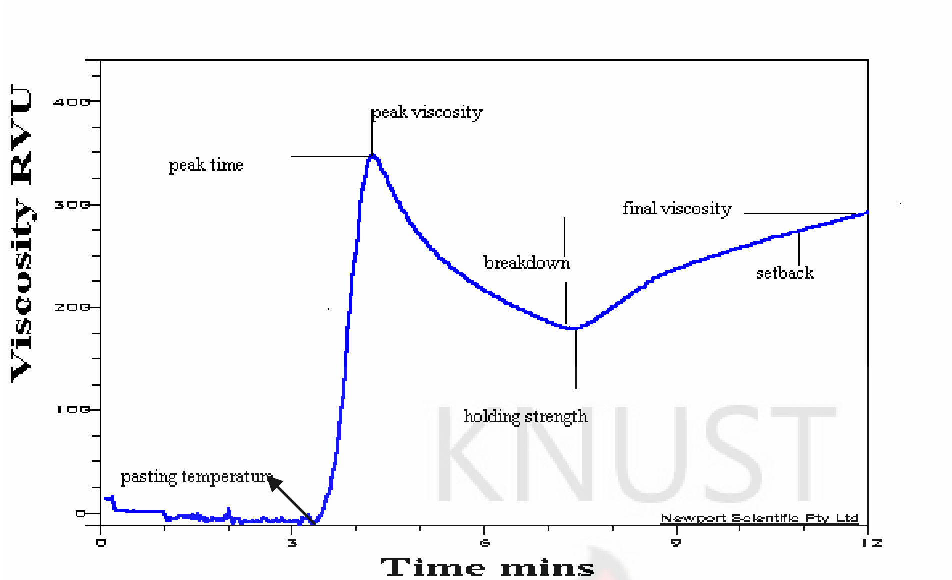


Figure 2.2: Typical RVA pasting profile showing the significant points during heating and cooling of flour/starch sample

Peak viscosity occurs at the equilibrium point between swelling, causing an increase in viscosity, and rupture and alignment, causing it to decrease. The rate and degree of swelling and breakdown are characteristic of the starch source, and are affected by the processing, presence of other components and modification. Peak viscosity is often correlated with final product quality, and also provides an indication of the viscous load likely to be encountered by a mixing cooker.

During the hold period of a typical pasting test, the sample is subjected to a period of constant temperature (95 ^{o}C) and mechanical shear stress. This further disrupts the granules and amylose molecules will generally leach out into solution, aligned in the direction of the shear. This period is commonly accompanied by a breakdown in viscosity, sometimes called shear thinning, holding strength, hot paste viscosity or trough. The rate of reduction depends on the temperature and degree of mixing, or shear applied to the mixture, and the nature of the material itself. The ability of a mixture to withstand this heating and shear stress is an important factor for many processes. Cross-linked starches are more resistant to breakdown.

Yam starches do not exhibit any distinct peak height as it is observed with wheat and a number of other cereal starches (Emiola and Delarosa, 1981) but show a stable rise in viscosity during the heating and holding process, suggesting the stability of the yam paste and the gradual crystalline disruption. Generally *D. rotundata* yam starches have higher viscosities than *D. alata* (Rasper, 1969; Farhat *et al*., 1999, Bokanga, 2000).

Changes in viscosity also accompany the formation of gels upon cooling of starch paste. Viscosity will usually increase to a final viscosity at this point. Final viscosity is the most commonly used parameter to define a particular sample's quality, as it indicates the stability of the material to form a viscous paste or gel after cooking and cooling. There is a progressive re-association of the starch molecules upon ageing or cooling which results in gel formation. The phase is referred to as setback and involves retrogradation which is the recrystallization or reassociation between starch molecules (Eliasson and Gudmundsson, 1996). Retrogradation is most rapid with amylose and much slower with amylopectin due to the short chain length branches of the former. In food products which are based on starch gels, retrogradation can lead to liquid being expressed from the gel, a phenomenon known as syneresis or weeping, which is generally an undesirable occurrence. High setback is associated with syneresis during freeze thaw. The rate at which viscosity increases in yam starches during cooling is dependent on the degree of starch-water binding (Ayernor, 1985). The crystallinity of retrograded amylopectin is lost following re-heating to approximately 70 °C, whereas temperatures above 145 °C are required to remove the crystallinity of retrograded amylose. This is a temperature well above the range used for the processing of starchy foods. This implies that retrograded amylose, once formed, will retain its crystallinity following re-heating of the food.

Retrogradation is, however, sometimes promoted to modify structural, mechanical, or organoleptic properties of certain starch-based products as practiced in the production of breakfast cereals and parboiled products. This is because retrogradation results in hardening and reduces stickiness (Colonna *et al.*, 1992). It is also applied in the production of mashed potatoes, to decrease the amount of soluble starch and to improve the consistency of the reconstituted product. The same technology is used in Japanese noodles and Chinese rice vermicelli to reduce stickiness and to obtain the characteristic chewiness (Watanabe, 1981; Seow and Teo, 1996).

Yam starches have been classified into three groups according to physicochemical and functional properties. The first group includes *D. alata* and *D. cayenensis-rotundata* varieties which are characterized by large starch granules, high amylose content, high intrinsic and apparent viscosities and low gelatinization enthalpies. A second class includes *D. esculenta* varieties that contain small granules, have low intrinsic and apparent viscosities and high gelatinization enthalpies. A third group consisting of *D. dumetorum* varieties is close to the second group but characterized by 100% A-type crystalline patterns (Rolland-Sabate *et al*., 2003). Gallant *et al.* (1992) reported that the starch of *D. alata*, *D. cayenensis* and *D. esculenta* showed a B-type crystallinity pattern while Brunnschweiler *et al.* (2004) f ound a mixture between A and B – type crystallinity pattern for the starch of *D. alata* and *D. cayenensis-rotundata*.

2.7 Microstructure of yam

Microstructure refers to the microscopic description of the individual constituents, (crystal structures, their size, composition, arrangements) of a material. It may include the study of their effect on the macroscopic behaviour in terms of physical properties, such as strength, toughness, and so on, which in turn govern the application of these materials in industry and manufacture

The outer part of the yam tuber forms several layers of cork and the inner part is formed by a tissue of parenchyma cells, which are interwoven with vascular channels. Starch is contained within the tissue in thin walled parenchymatous cells (Degras, 1986) and the non-carbohydrate components are mainly present in the cell wall. The thin cell wall imparts stability to individual cells while the cell walls of the major cells provide rigidity, strength and shape to the plant cell. Starch is the predominant determinant of yam's physicochemical and functional properties (Degras, 1986; Muthukumarasamy and Panneerselvam, 2000). However, the non-starchy component is partly responsible for the texture and mechanical properties of mature tissues and hence the textural properties of the plant-based food (Brett and Waldron, 1996). Many authors have used microstructure to describe or study the texture of various food products (Stanley and Tung, 1976; Brunnschweiler, 2004). A microstructural study is necessarily part of breeding activities that aim at altering the texture of plant-based materials such as *D. alata* for specific uses.

Part of this study looked at the microstructure of *D. alata* tubers (cell structure and starch granule morphology) and its implication for food uses.

2.8 Utilization of yam

Yam tubers have been diversely utilized and still have more utilization potentials. The main use of yam in producing countries is as food (Rasper and Coursey, 1967) with little industrial involvement.

2.8.1 Domestic uses

Consumer preference is highest for fresh yam, which can be fried, boiled, or roasted like potatoes (Ravindran and Wanasundera, 1992). After cassava and cereals, the highest source of dietary energy in Nigeria's food basket is yam (Oguntona, 1994). Yam is prepared differently in different places. Processing of yam for consumption is done differently at the various production areas as follows:

2.8.1.1 Pounded yam

This is usually made from the preferred yam species, *Dioscorea rotundata* in West Africa. Pounded yam is a very popular and important food in Nigeria and other countries such as Benin. It is one of the most important prepared forms of yam. It is prepared by cooking peeled and sliced tubers, and pounding with a mortar and pestle to form consistent and smooth dough (Coursey, 1967; Osagie, 1992; Onwueme and Charles, 1994). Pounded yam is eaten with soup containing meat or fish or both, which acts as a source of proteins, vitamins and minerals, making pounded yam intake a complete balanced diet.

2.8.1.2 Fufu

This is a product similar to pounded yam which is eaten mostly in Ghana. *Fufu* is prepared from cassava in combination with plantain or cocoyam but in yam producing zones or during a scarcity of plantain and cocoyam, *fufu* is prepared from boiled yam tuber and cassava. Cooked tuber pieces are pounded in a mortar with a pestle until an elastic dough is obtained. *Fufu* is eaten with soup.

2.8.1.3 Amala

In Benin and western parts of Nigeria, yam tubers are processed into slightly fermented flour called *elubo* for a product called *amala*. To prepare *elubo*, yam tubers are peeled, sliced, and parboiled in water at about 63 ± 3 °C. The slices are left in the water, well covered, for about 24 hr to ferment slightly. They are drained and dried for market throughout the year. Dried tuber slices are usually purchased on the market, crushed or pounded in a traditional mortar with pestle and milled into flour. *Elubo* is usually mixed with four parts of boiling water to give a smooth thick paste called *amala* (Akissoe *et al.*, 2001) which is eaten with soup. *Amala* is a delicacy for the Yoruba of western Nigerian (Osagie, 1992; Onwueme and Charles, 1994; Orkwor, 1998). The same product is popular in Benin where it is called *telibo*.

2.8.1.4 Boiled yam

Boiled yam is also a popular and easy to prepare food in the production areas. The tubers are first peeled, sliced and cooked in a pot with water until done. Salt is usually added to give the desired taste. Boiled yam is taken with vegetable or tomato stew, beans and soup.

2.8.1.5 Roasted yam

Tubers of yam are first washed and cut into chunks or roasted whole in their skin over firewood, hot coals or baked in a hot earth oven**.** Roasted yam used to be eaten mostly on the farmers' field but it has now become a popular street food or fast food in most urban centres of the growing regions (Orkwor, 1998). In Ghana, it is usually eaten with a piece of salted roast fish. In Eastern Nigeria, it is eaten with red palm oil.

2.8.1.6 Ikokore or ikpankwukwo

This product is made from *D. alata* and is a classic traditional food eaten in Nigeria. It is pottage made from grated fresh yam. The grated mash is whipped thoroughly and scooped into an already boiling pepper sauce containing fish, palm oil, salt to taste and other ingredients, and then steamed on the fire at low heat till it is well cooked (Orkwor, 1998).

2.8.2 Industrial uses

Apart from being served directly as food, yam has many industrial uses but unfortunately has not been processed to any significant extent commercially. Sun drying and milling of the tubers leads to dehydrated yam flours and yam flakes, which are promising both for local and international markets.

2.8.2.1 Dried yam chips/pellets

Yam tubers are prone to physiological deterioration after harvesting due to the lack of appropriate methods of storage at the farmer's level and the high moisture content. They are therefore conveniently processed into yam chips and pellets, which are milled to produce yam flour. This is the only yam product traditionally made at the farmer or village level and also at industrial level. In Nigeria, Benin, and Togo, there has been an increase in the production and marketing of yam chips (Mestres *et al*., 2002). Prospective consumers purchase the chips on the market. The flour produced from them could then be used in the preparation of different dishes such as *amala*, *wassa-wassa* (flour granules) etc. At the industrial level, modification of the traditional flour production has produced quality yam flour suitable for use as composite with wheat flour for baked products, in biscuit production, weaning foods, or plant-based drinks (Personal communication)

2.8.2.2 Poundo flour

Since pounded yam has so much prestige and is a popular way of eating yam, two attempts have been made to commercialize the process. The first was the production of dehydrated pounded yam by drum drying. This product could then be reconstituted without further processing. *Poundo* yam flour or Yam flakes as it is called is now being produced industrially. It is prepared by peeling, cooking and mashing yam tubers which are then dried mechanically, by a roller drier, drum drier or cabinet drier, to produce thin flakes. The flakes are milled into flour or left like that, packaged and sold in the market. On getting to consumers, the flakes are poured into a pot of boiling water and stirred vigorously to make dough. This product is exported and is popular with people who have migrated from yam producing areas to the developed countries. Already *poundo* yam flour is being exported from Nigeria and Ghana to Europe and USA. It is also a convenient product for busy urban consumers owing to the ease of preparation.

2.8.2.3 Fried yam chips

Attempts to manufacture fried yam chips, similar to French fried potatoes have been reported from Puerto Rico and the potential for its production on a commercial level has been highlighted by Abass (2003).

2.8.2.4 Starch, poultry and livestock feed

Yam tubers have also been processed into starch or into poultry and livestock feed just as like cassava (Opara, 1999). Yam starch is used in production of all-purpose adhesives. Producers of cartons, packaging companies, leather and shoes use the adhesives for their products. Yam starches have a lot of industrial uses but their use will not be profitable since other cheaper sources such as cassava exist.

2.9 Food product assessment using sensory evaluation

Sensory evaluation is a scientific discipline used to evoke, measure, analyse and interpret reactions to stimuli perceived through the senses of appearance, smell, taste and touch (Stone and Sidel, 1995). In the food sector, sensory evaluation is adopted to assess the eating quality of food under controlled conditions. People are used for sensory evaluation because they are easy to train, give rapid responses, are easy to interpret and, more importantly are able to provide quantitative and qualitative information. Sensory evaluation is necessary during product development, quality control, recipe change investigation and the measurement of shelf life. It can equally be useful to link to consumer preference data. Even though consumer's total impression is influenced by preparation methods, product cost, packaging, and appearance among others; sensory factors are known to be the major determinant of consumers' attitude toward food and subsequent purchasing behaviour or usage. Sensory analysis provides a clearer understanding of product characteristics and can be used to identify the sensory attributes driving consumers' preferences.

A sensory evaluation method could be consumer-oriented or product-oriented, based on the purpose of the test. Tests used to evaluate the preference, acceptance or degree of liking for food products are termed consumer-oriented. Tests used to determine differences among products or to measure sensory characteristics are termed product-oriented.

2.9.1 Consumer-oriented test

Consumer tests analyse the appreciation of the consumer's attitude towards their likes, dislikes and preferences for a product and information provided is usually subjective. General requirements of acceptability can be obtained using consumer oriented test methods. A large number of untrained people are randomly picked for the panel to represent the general consumer population in this case. For a true consumer test, 100-150 people are questioned or interviewed and results obtained used to predict the attitude of the target population. Results from consumer tests can indicate relative acceptability or identify product defects. A consumer-oriented test is time-consuming and costly. Because of this, usually untrained in-house consumer panels (30-50) are used to provide initial information on product acceptability prior to a true consumer test. In-house testing is easy to control and allows more control of variables and testing conditions and also allows a chance to improve the questionnaire and remove problems associated with the test. However, panellists have to be selected to represent the general populace.

2.9.2 Product-oriented test

A product-oriented test functions as a testing instrument. It is used when there is the need for the identification or measurement of sensory properties. It is therefore used to identify differences among similar products or measure the intensity of specific quality characteristics. Information from product oriented tests is obtained in the laboratory using trained sensory panels. A trained panel of about 5-15 is used to identify differences among similar products or to measure the intensity of specific quality characteristics. A product-oriented test is not used to assess food acceptability but provides an objective perception of a food product. A descriptive test is an example of a product-oriented test. It is used to produce an objective description of the sensory characteristics of products which enable comparisons between products to be made. Descriptive analysis involves the identification, description and quantification of the sensory components of a product by an expert or trained panel. In a descriptive test, appropriate terminologies have to be developed to describe a product. This could be based on standard terminologies for the specific product or based on the perception of a group of trained panellists who are selected for their sensory acuity and have been specially trained for the task to be done. They are used to describe a product in terms of the degree of intensity of a particular attribute. A descriptive test does not measure preferences or the acceptability of a product but the trained panellists measure the true characteristics of a product as it is without bringing their preferences and likings into the test.

2.9.3: Fundamental requirements in using people to assess food products

The following are the fundamental requirements of sensory evaluation that need to be considered when planning a product-oriented sensory test: recruitment, screening, training of panellists and monitoring panellists' performance. These fundamental requirements are necessary to reduce sources of bias and to produce valid and meaningful results.

Recruitment: Panelist/assessors are usually recruited internally (within the same company) or externally and it is done either by word of mouth or through advertisement. The kind of people to be recruited depends on the type of sensory test to be done and products involved

Screening: There is a need for screening assessors after recruitment. This is done because people are different in so many ways. The following are some of the key steps to take when screening assessors:

1. Pre questionnaire to get information on general interest, health, allergies, etc.
2. Tests for color blindness and basic recognition tests to eliminate people who are insensitive to different tastes
3. Sensory acuity tests: tests thresholds, discrimination tests such as ranking, triangle test etc.
4. Descriptive and communication exercise: Test ones ability to communicate or describe what he/she has seen or tasted, discriminate between different samples, ability to score repeatedly, ability to understand simple task and follow instructions

Selection and Training: Selected panelist/assessors are then trained to increase validity and reliability of data, and more importantly to ensure consistency in performance. Individuals are also trained to understand test procedure, increase product knowledge, detect and recognize sensory characteristics and able to provide accurate information.

Generally a potential panelist/assessor must have positive attitude to task and have ability to do the task.

In multiple paired comparison sensory test, differences between a control and subsequent test samples are tested based on quality attributes. A typical scale of 0 to 9 is used. The test can be fatiguing for assessors as they effectively taste a series of sample pairs. Assessors are therefore expected to be trained and have understanding of the attributes being rated. The umber of assessors for a multiple paired sensory test is usually between 8 and 10.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Source of materials

Twenty varieties of *D. alata* and one variety of *D. rotundata* (used as reference) (Table 3.1) were obtained from experimental plots of yam breeding programme at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria. Samples were collected at harvest each year for a period of 3 years. The varieties were planted in April 2004, March 2005 and May 2006 and respectively harvested in December 2004, November 2005 and January 2007. In addition, 18 varieties of *D. alata* were collected from CSIR-Crops Research Institute, Kumasi, Ghana to reflect Ghanaian situation. The varieties were planted at Fumesua near Kumasi in May 2005 and harvested in February 2006. *D. rotundata* locally known as *Pona* bought from the local market in Kumasi, Ghana was used as a reference.

3.2 Experimental procedure

The work was carried out in 3 phases.

Phases 1 and 2: Fresh tubers of 20 *D. alata* varieties (converted to flour) were characterized based on chemical, physicochemical and pasting properties (intrinsic properties). Three popular yam products, pounded yam, boiled yam and *amala*, were prepared from the 20 varieties for sensory evaluation. One landrace variety of *D. rotundata*, TDr 608 (a preferred variety in the study area), was used as a reference sample for all the three products. The two data sets (sensory and intrinsic properties) were subjected to Pearson's correlation analysis to establish any relationship between the intrinsic properties of the tubers and sensory qualities of the three products. In phase 2, all the experiments in Phase 1 were repeated to validate results obtained. Based on reproducibility of obtained results, 12 varieties that were found to be comparable to the reference variety were planted for the third phase.

D. alata varieties (in the form of flour) collected from CSIR-CRI, Ghana, were also characterised in terms of chemical, physicochemical and pasting characteristics. The suitability of the varieties (fresh tubers) for boiled yam, the most consumed product from yam in Ghana was assessed.

Table 3.1: Yam varieties from IITA used for the studies

Serial number	Species/variety	Local/source name	Country of origin	Nature of variety
	D. alata			
1	TDa 00/00103	-	Nigeria	Breeder's line
2	TDa 00/00364	-	Nigeria	Breeder's line
3	TDa 01/00002	-	Nigeria	Breeder's line
4	TDa 01/00024	-	Nigeria	Breeder's line
5	TDa 01/00041	-	Nigeria	Breeder's line
6	TDa 01/00081	-	Nigeria	Breeder's line
7	TDa 85/00250	-	Hybrid line	Breeder's line
8	TDa 92-2	Weredede	Nigeria	Landrace
9	TDa 95/00328	-	Nigeria	Breeder's line
13	TDa 95-310	Brazo Fuerte	Cote d'Ivoire	Landrace
11	TDa 98/01174	-	Nigeria	Breeder's line
16	TDa 98/01176	-	Nigeria	Breeder's line
12	TDa 98/01183	-	Nigeria	Breeder's line
14	TDa 98-159	Ngoul Kaude	Chad	Landrace
15	TDa 99/00332	-	Nigeria	Breeder's line
16	TDa 99/00395	-	Nigeria	Breeder's line
17	TDa 99/00240	-	Nigeria	Breeder's line
18	TDa 291	Forastero	Puerto Rico	Landrace
19	TDa 297	UM 680	Nigeria	Landrace
20	TDa 93-36	Agbo	Nigeria	Landrace
	D. rotundata			
21	TDr 608	Nwopoko	Nigeria	Landrace

Phase 3: a microstructural study was done on the 12 selected varieties and the variety used as reference in Phase 2. The influences of tuber maturity and storage on physicochemical, chemical and pasting properties were also determined using the same 12 selected varieties from Phase 2.

Table 3.2: Yam varieties from CSIR-CRI used for the studies

Serial no.	Species/variety
	D. alata
1	APU
2	TDa 291
3	TDa 297
4	TDa 98/01168
5	TDa 98/01174
6	TDa 98/01176
7	TDa 99/00022
8	TDa 99/00048
9	TDa 99/00049
10	TDa 99/00199
11	TDa 99/00214
12	TDa 99/00395
13	TDa 99/00446
14	TDa 99/00528
15	TDa 99/01169
16	KM 1999
17	WM 2001
18	WM 2003
	D. rotundata
19	*Pona*

3.3 Sampling for laboratory analysis and sensory evaluation

Characterization and sensory studies: Forty healthy tubers per variety were collected for the studies. Six tubers from each variety were selected by simple randomization procedure into 3 separate labelled sacks (for the 3 different products). Tubers within a sack were washed and peeled and each was divided into four longitudinal portions. The 1st two opposite portions from each tuber was selected and pooled together, cut into small pieces (cubes), thoroughly mixed and converted to flour for chemical, physicochemical and pasting analysis. The 2nd two opposite portions were used for the product preparations. Three sets of samples (from the 3 sacks) were thus obtained from each variety for chemical, physicochemical and pasting properties and each laboratory determination was duplicated. The same procedure was used for the varieties obtained from Ghana but only one set of sample for laboratory analysis was obtained because there was only one product (boiled yam) involved.

Microstructural study: The microstructural study was also done on the 12 selected varieties of *D. alata* from phase 2 and the variety of *D. rotundata* used as reference. One healthy tuber was used and samples (small cubes) were taken from the mid portion of the tubers. Mid portion was used because the distal and proximal ends of the yam tuber could have much difference in texture.

Maturity and storage studies: The 12 selected varieties were planted in May 2006 and harvested after 5, 7 and 9 months for maturity studies. Three healthy tubers were randomly picked at each harvest, washed, peeled and cut into small pieces (cubes), thoroughly mixed, dried and converted to flour for chemical, physicochemical and pasting analysis. The remaining healthy tubers harvested at 9 months after planting were packed in wooden boxes and stored on shelves in a conventional open-air yam barn (IITA yam barn, temperature $28.1 \pm 3.5\ ^{o}C$, relative humidity $53.8 \pm 21.5\%$) for a period of 5 months. Three tubers per variety were randomly picked on a monthly basis for chemical, physicochemical and pasting properties. The tubers were washed, peeled and cut into small pieces (cubes), thoroughly mixed, dried and converted to flour for chemical, physicochemical and pasting analysis.

3.3.1 Preparation of yam flour

Peeled yam tubers were cut into small cubes and dried in an air convection oven at 60 ^{o}C for 72 hours (Lape and Treche, 1994). The resulting dried chips were milled into fine flour and stored in whirl-pac sample bags at 20 °C for the assessment of physicochemical, chemical and pasting properties.

3.3.2 Preparation of food products

3.3.2.1 Preparation of boiled yam

A total of 400 g of peeled tuber was sliced into uniform pieces and cooked with 300 ml of water for about 20-23 min (The range is for the different varieties used). A fork was used to judge when the core was soft. Cooked slices were drained, wrapped with cling film (to keep warm) and stored in food styrofoam box until all were ready for sensory evaluation.

3.3.2.2 Preparation of amala

The traditional method of *amala* preparation was adopted with little modification. About 4 kg of peeled fresh tuber was sliced and parboiled by immersion in hot water (63 ± 3 ^{o}C), drained and left covered in plastic containers for 24 hours. The slightly fermented slices were drained, sun-dried for 5-7 days and milled into flour, locally called *elubo* in Nigeria. Ninety grams of the flour was poured into 300 ml of boiling water on fire and stirred continuously with a wooden spoon until a thick consistent paste was obtained.

3.3.2.3 Preparation of pounded yam

Eight hundred grams of peeled and cut pieces of yam were cooked in a mechanical pounder (Model No. sd-900Y National Electronic. Co Ltd. Tokyo) with 300 ml of water for 23 min and pounded for 5 min to form a consistent dough.

3.3.3 Sensory evaluation

3.3.3.1 Selection and Training of potential panellists

Recruitment: Fifteen panellists were selected from the staff of IITA, Ibadan, based on their previous participation in similar sensory studies and willingness to participate. **Screening and training:** Recruited panellist ability to recognise the basic taste (sweet, bitter, sour and salt) was tested. They were then trained for a period of 6 weeks meeting for about an hour twice weekly. In a group discussion, panellists were made to list quality attributes of the 3 products. The listed quality attributes were discussed in details using local descriptors for all panellists to have a common understanding. The following sensory attributes were finally considered for the products evaluation:

1. **Boiled yam**-colour, wetness, taste, hardness and mealiness;

2. *Amala* and pounded yam-colour, smoothness, consistency, elasticity, stickiness and hardness.

The ability to describe and use the attributes in scoring samples was tested using standard methods (such as difference test, descriptive test and ranking test). This was done until all panellists were conversant with the quality attributes and the sensory test procedure to be used. Trained panellist also contributed in developing the questionnaires used for the real study.

Ten of the 15 trained panelists were selected for the sensory evaluation based on their availability and ability to discriminate between levels of the sensory attributes as taught.

3.3.3.2 Sensory test and sample presentation

Multiple paired comparison sensory test (Meilgaard *et al*., 1999) was adopted with a little modification using the 10 trained panellists. At each evaluation session, each of the 10-trained panellists received simultaneously a sample of the reference sample (i.e., boiled yam, pounded yam or *amala* from TDr 608, depending on which product was being assessed) labelled "R" plus four test samples from the *D. alata* varieties labelled with three digit codes (derived from a standard random table). For each attribute, panellists were requested to assess each coded sample, comparing it with the reference and to record the degree of difference using a 9-point scale. On this scale, 1= very much worse, 2= very poor, 3= moderately poor, 4= slightly poor, 5= no difference, 6= slightly better, 7=moderately better, 8= much better, 9=very much better. Thus, an average score of below 4.5 was poor in that particular attribute.

3.3.4 Laboratory analysis

3.3.4.1 Determination of moisture/dry matter content

The method of AOAC (1997) was adopted for moisture determination. Five grams of peeled and chopped fresh yam tuber was weighed into a dried and pre-weighed moisture can. The can with its content was dried in an oven at 105 ^{o}C for 24 hours. It was removed from the oven, cooled in a desiccator and weighed. The moisture content was estimated as weight loss using the formula below:

$$\% \text{ Moisture} = \frac{(\text{wt of pan + fresh sample}) - (\text{wt of pan + dry sample})}{\text{Wt of sample}} \times 100$$

Percentage dry matter =100 - moisture content.

3.3.4.2 Determination of Protein

The method of Hach (1990) was adopted for protein determination. This method measures the crude protein content in foods because it gives the amount of all the reduced nitrogen in the sample in the form of amines, ammonium compounds, urea, amino-acids, etc. The procedure involves digesting samples with concentrated sulphuric acid and hydrogen peroxide to convert nitrogen to ammonium hydrogen sulphate. A catalyst (selenium, potassium sulfate, and mercury) is usually added to accelerate the digestion. On treatment with a dispersing agent, the ammonium salt decomposes to liberate ammonia, which in the presence of Nessler's reagent gives an orange colour. The coloured solution is read at 460 nm for nitrogen calculation. About 0.25 g of flour sample was weighed into Hach digestion tube. To the sample, 4 ml of concentrated sulphuric acid, one tablet of catalyst (selenium) and 4 ml of hydrogen peroxide were added and heated for 3 hr at 440 ^{o}C under a fume hood. The resultant clear digest was allowed to cool and made up to 100 ml with deionised water, covered with paraffin, and mixed thoroughly. One ml of the mixture was pipetted into 25 ml volumetric flask; 3 drops each of mineral stabilizer and polyvinyl alcohol solution were added and made up to 25 ml with distilled water. One millitre Nessler reagent was added for colour development. Absorbance was read at 460 nm within 5 min using a Hach spectrophotometer (Hach Company, Loveland, Colorado, USA, Model, DR /3000) against deionised water (as blank) to determine the concentration of nitrogen. Protein content was calculated using a factor of 6.25 as follows:

$$\% \text{ N} = \frac{0.0075 \times A}{B \times C}$$

% Protein=%N x 6.25

Where A = Concentration in mg/l (reading displayed)

B = g sample digested

C = volume of digest (ml) analyzed

3.3.4.3 Determination of ash

When foods and food products are heated to temperature of 500 ^{o}C and above, water and other volatile constituents evolve as vapours. Organic constituents also burn to carbon dioxide and water. The mineral constituents remain in the residue as oxides, sulphates, phosphates, etc., depending on the conditions of incineration in the food products. The determination of inorganic substances as residues after ignition of the sample at a specific temperature is the basis of ashing. Ash content was determined with the method of AOAC (1997). Two grams of flour sample was weighed into a dried and pre-weighed porcelain crucible. The sample was charred on a hot plate until water and other volatile constituents were eliminated in the form of black fumes. The sample was then ashed by placing in pre-heated muffle furnace at 600 ^{o}C for 6 hours. The crucibles with ashed contents were cooled in a desiccator, weighed and the percentage ash was calculated as follows:

$$\% \text{ Ash} = \frac{\text{wt of crucible + ash – wt of empty crucible}}{\text{Wt of sample}} \times 100$$

3.3.4.4 Determination of total sugar and starch contents

Sugar and starch contents were determined with the method of Dubois *et al*. (1956). Hot ethanol was used to extract starch and sugar from the flour sample. The extract (supernatant) and digest (from the residue) were quantified calorimetrically for sugar and starch respectively, using phenol-sulphuric acid as the colour developing reagent; absorbance was read at 490 nm.

Yam flour sample (20 mg) was weighed into a centrifuge tube and wetted with 1 ml of 95% ethanol. Two ml of distilled water was added followed by 10 ml of hot 95% ethanol. The content was vortexed and centrifuged (GLC-1 Survall 4686, Newton, Connecticut 06470, USA) at 2000 rpm for 10 min. To the supernatant was added 9 ml distilled water. Then 0.2 ml was pipetted into a glass test tube and made up to 1 ml with distilled water. To the residue 7.5 ml perchloric acid was added and sample allowed to digest to its monosaccharides for 1 hour. The digest was diluted to 25 ml with distilled water and filtered through Whatman no. 2 filter paper; 0.05 ml was pipetted from the filtrate and made up to 1 ml with distilled water. A standard curve was prepared by pipetting 0, 0.1, 0.2, 0.3, and 0.4 ml of D. glucose solution (0.01 g/100 ml) into different test tubes. Each was made up to 1 ml corresponding to 0, 10, 20, 30 and 40 μg glucose/ml. To each of the final 1 ml solution obtained (from supernatant, residue and standard) in a test tube, 0.5 ml of 5% phenol and 2.5 ml concentrated sulphuric acid were added to develop colour. The colored solutions were vortexed, left to cool and their absorbance read at 490 nm on a spectrophotometer (Milton Roy Spectronic 601). Percent sugar and starch were calculated as follows:

$$\% \text{ Sugar} = \frac{(A\text{-}I) \times D.F \times V \times 100}{B \times W \times 10^6}$$

$$\% \text{ Starch} = \frac{(A\text{-}I) \times D.F \times V \times 0.9 \times 100}{B \times W \times 10^6}$$

A= Absorbance of sample

I =Intercept of standard curve

D.F = Dilution factor

V = Total extract volume.

B = Slope of the standard curve.

W = Sample weight.

3.3.4.5 Determination of total dietary fibre

Total dietary fibre content was determined by the enzymatic-gravimetric method of Prosky *et al*. (1985), officially known as AOAC method 985.29 (AOAC, 1990). One gram of flour sample was weighed into a 600 ml beaker in duplicate. Then 40 ml MES-TRIS blend buffer solution (pH 8.2) was added to the sample and stirred until the sample was completely dispersed in solution. Fifty microlitres (µl) heat-stable α-amylase solution was added while being stirred at low speed. The beakers were covered with aluminium (Al) foil and placed in a shaking water bath at 95-100 ^{o}C and incubated for 35 min with continuous agitation. The samples were cooled to 60 ^{o}C. Adhered samples on beakers were scrapped with a plastic spatula and the spatula and walls of the beakers were rinsed with 10 ml distilled water. Hundred microlitres protease solution was added to each of the sample, covered with Al foil, and incubated in a water bath at 60±1 ^{o}C for 30 min with continuous agitation. Samples were removed and 5 ml of 0.561 N HCL solution was added. The pH of sample was adjusted between 4.1 and 4.8 with either 5% NaOH or 5% HCL solution. Amyloglucosidase (200 µl) was added to the sample in the beakers with stirring. The beakers were covered with Al foil, placed in a water bath, and heated for 30 min at 60 ^{o}C.

To each sample, 225 ml of 95% ethanol preheated to 60 ^{o}C was added and the samples were covered with large sheets of Al foil. The samples were left at room temperature for 60 min to precipitate. The precipitated enzyme digests were filtered through already prepared and weighed fritted crucibles (Fritted crucibles were ashed overnight at 525 ^{o}C and impurities were removed by suction using a vacuum. They were soaked in 2% cleaning solution for 1 hour, rinsed with water and deionised water. For a final rinse, 15 ml acetone was used and air-dried. 1.0 g of celite acid washed was added to the crucibles and dried at 130 ^{o}C overnight. Crucibles containing celite were cooled for 1 hour and weighed. The celite was wetted with 15 ml ethanol and suction was applied to draw celite unto the crucible as an even mat. With the use of a wash bottle, all remaining samples in the beakers were quantitatively transferred into the crucibles and the residues were successively washed with 15 ml 78% ethanol, 95% ethanol and acetone (twice). The crucibles containing residues were dried overnight in an oven at 103 ^{o}C, cooled for one hr and weighed. One duplicate was analysed for protein and the other was incubated at 525 °C to determine the ash content. Total dietary fibre was calculated as follows:

$$\text{Dietary Fibre (\%)} = \frac{\frac{R1 + R2}{2} - p - A - B}{\frac{M1 + M2}{2}} \times 100$$

$$\text{Blank (B)} = \frac{BR1 + BR2}{2} - BP - BA$$

Where: R1 = residue weight 1 from m1

R2 = residue weight 2 from m2

m1 = sample weight 1

m2 = sample weight 2

A = ash weight from R1

p = protein weight from R2; and

B = blank

BR = blank residue; BP = blank protein from BR1;

BA = blank ash from BR2.

The procedure is presented in Figure 3.1 below:

1 g dried sample

↓

Gelatinization and Amylase incubation
(pH 6.0, 30 min., 100 ^{o}C)

↓

Protease incubation
(pH 7.50, 30 min., 60 ^{o}C)

↓

Amyloglucosedase incubation
(pH 4.50, 30 min., 60 ^{o}C).

↓

Precipitation with 4 volumes of ethanol

↓

Filtration

↓

Washing with ethanol and acetone

↓

Drying
(Correction for undigested protein, ash and blank)

Figure 3.1: Flow Chart for determination of total dietary fibre

3.3.4.6 Determination of amylose/amylopectin

The method of Williams *et al.* (1958) and Juliano (1971) was used. It is a colorimetric method in which amylose forms starch iodine complex (dark blue colour) due to its high affinity for iodine. About 0.1 g of the flour sample was solubilized with 1 ml of 95% ethanol and 9 ml of 1 N NaOH, and heated in a boiling water bath for 10 min; 1 ml of the extract was made up to 10 ml with distilled water. To 0.5 ml of the diluted extract was added 0.1 ml I N acetic acid and 0.2 ml iodine solution (0.2 g I_2+2.0 g KI in 100 ml of distilled water) to develop a dark blue colour. The coloured solution was made up to 10 ml with distilled water and allowed to stand for 20 min for complete colour development. The solution was vortexed and its absorbance was read on a spectrophotometer (Milton Roy Spectronic 601) at 620 nm**.** Absorbance of standard corn amylose with known amylose concentration was used to estimate the amylose content in the sample as follows:

$$\% \text{ Amylose} = \frac{\% \text{ amylose of standard x Absorbance of sample}}{\text{Absorbance of standard}}$$

3.3.4.7 Determination of swelling power and solubility index

Starch or flour in the presence of water and heat imbibes water and swells. As a result of swelling, starch solubility increases. Swelling and solubility provide evidence of the magnitude of interaction between starch chains. Swelling is defined as the swollen sediment weight (g) per g of dry starch/flour and solubility is expressed as the percentage (by weight) of the starch/flour sample that is dissolved molecularly after being heated in water between 85 and 95 ^{o}C. The method of Leach *et al*. (1959) was used. One gram of flour sample was weighed into 100 ml conical flask, hydrated with 15 ml of distilled water and shaken for 5 min on a Wrist action shaker (Burrel Wrist action Shaker model 75, Pittsburgh PA, U. S. A.). The conical flask with its contents was put in a shaking water bath maintained between 80 and 85 ^{o}C for 40 min. After heating, the sample was quantitatively transferred into centrifuge tube by washing with 7.5 ml distilled water and centrifuged at 2,200 rpm for 20 min. The supernatant was decanted into a pre-weighed moisture can and dried at 100 ^{o}C to a constant weight. The sediment was weighed and swelling power and solubility were calculated as follows:

$$\text{Swelling power} = \frac{\text{Weight of sediment}}{\text{Sample weight} - \text{Weight of soluble}}$$

$$\%\ \text{Solubility index} = \frac{\text{Weight of soluble}}{\text{Weight of sample}} \times 100$$

3.3.4.8 Determination of water binding capacity

Water binding capacity was determined with the method of Medcalf and Gilles (1965). About 1.25 g of yam flour was weighed into a 100 ml pre-weighed centrifuge tube and 18.75 ml of distilled water was added. The contents were shaken on a Wrist action shaker (Burrel Wrist action Shaker model 75, Pittsburgh PA, U. S. A.) for 1 hour and centrifuged in a Beckman centrifuge (GLC Survall 4686, Newton, Connecticut 06470, USA) for 20 min at 2,500 rpm. The resulting supernatant was decanted and the remaining water allowed to drain by tilting the centrifuge tube. The tube with its wet content was weighed and water binding capacity was calculated as follows:

$$\text{Water binding capacity (\%)} = \frac{\text{Weight of bound water}}{\text{Weight of starch}} \times 100$$

3.3.4.9 Determination of pasting characteristics

Pasting characteristics were determined with a Rapid Visco Analyser (RVA super 3, Newport Scientific pty. Ltd, Australia) by Newport Scientific (1998). The Rapid Visco-Analyser (RVA) is a rapid and simple-to-use equipment which measures the viscosity of starch/flour dispersion in a temperature/time profile during and after cooking. It mimics cooking processes and provides results that are highly correlated with the end-product. Three grams of flour (at 14% moisture level) was mixed in 25 ml of water in a sample canister using the formula below. The sample was thoroughly mixed and fitted into the RVA as recommended by Newport Scientific (1998). With the use of the 12-min profile, the slurry was heated from 50 ^{o}C to 95 ^{o}C with a holding time of 2 min followed by cooling to 50 ^{o}C with another 2 min holding time. Both the heating and cooling was at a constant rate of 11.25 ^{o}C / min with constant shear at 160 rpm. Corresponding values for peak viscosity, trough, breakdown, final viscosity, setback, peak time, and pasting temperature from the pasting profile were read on a computer connected to the RVA.

$$S = \frac{86 \times A}{100 - M}$$

W=25 + (A –S)

Where S= corrected sample mass

A=sample weight at 14% moisture basis (depending on the type of sample, this is taken from the general guide on weight of sample from RVA manual)

M=actual moisture of the sample (% as is)

W=corrected water mass

3.3.4.10 Determination of Minerals

Mineral analysis was done with the method of Hunter *et al.* (1984) and Benton *et al.* (1990).

Sample digestion: The flour sample (0.48–0.52 g) was weighed into a clean ceramic crucible. An empty crucible was included as a blank. The crucible was placed in a muffle furnace and heated to 500 ^{o}C over a period of 2 hr. The sample was allowed to ash for another 2 hr and cooled. The ashed sample was transferred into 50 ml centrifuge tube and the crucible was subsequently rinsed with 5 ml distilled water and 5 ml (3 times) of *aqua* *regia* making a total added volume of 20 ml. The sample was vortexed to mix the contents thoroughly and centrifuged at 3000 rpm for 10 min. The supernatant was decanted into micro-vials.

Mineral determination: Ca, Mg, K, Na, Zn, Cu, Mn and Fe were determined using flame atomic absorption spectrophotometer (model Buck 205 from Buck Scientific, USA). Aqua regia was prepared as follows: In a 2 L volumetric flask was poured 1.2 L distilled water, 400 ml conc. HCL and 133 ml of 70% nitric acid were carefully added and the volume was made to 2 L.

3.3.4.11 Microstructural studies

Theory:

The microstructural study was done on fresh and cooked yam tissues to examine the cell wall, cell shape, size and arrangement of starch granules in the cell using light microscopy. A slight modification of the micro-technique procedure of Sass (1958) was used. The method employs the use of formalin Acetic Acid (FAA) to fix and harden sample tissue, which is then dehydrated in progressively increasing concentrations (grades 1 to 5) of tertiary butyl alcohol (TBA) for at least 1 hour in each. The tissue is then infiltrated with paraffin (wax) and embedded in hard wax to support and hold tissue parts. Embedded tissues are cast into boxes and thin sections of 10 μm are serially cut using microtome, differentially stained with safranin-fast green, before being mounted on slides using egg albumen as an adhesive. Prepared slides are examined under the light microscope and photographs of the microstructure are taken with a camera mounted on the microscope.

Sample Preparation

A fresh yam tuber was washed, peeled, and rectangular shapes were cut at the mid-portion with a Jung rotary microtome (model 820). The cut samples were put in FAA and stored inside a glass vial. The samples were dehydrated in TBA in grades of 1-5 (in increasing order of alcohol concentration) for 1 hr in each grade. Dehydrated samples were infiltrated by dissolving soft paraffin in the solvent containing them (TBA). The concentration of paraffin was gradually increased with decreasing solvent concentration. Samples were put in a convection oven maintained at 40-43 ^{o}C. The solvent (TBA) was completely eliminated by changing the paraffin 3-4 times. Hard paraplast was melted and poured on the samples which were then maintained at 60 ^{o}C for about 3 hr, a process called embedding, to support the tissues and their contents during cutting. They were transferred into match boxes and allowed to harden. Excess paraffin was trimmed off each sample before they were fixed onto wooden mounting blocks using melted paraffin. The sample on the mount was fixed into a Jung rotary microtome (model 820) and sections of 10 μm were serially cut and placed on slides (75 x 25 mm) using egg albumen as an adhesive. Differential staining was carried out using safranin-fast green combination.

Cell structure examination

After proper staining had been attained, 2-3 drops of DPX-mountant were put on the stained sample and it was carefully covered with 22 by 50 mm cover slips. The prepared slides were observed under microscope (Olympus BX51, Japan) and photographs of yam microstructure taken with the aid of a camera (Wild MPS 51, Heerbrugg Switzerland) mounted on the microscope.

Examination of starch granules:

The size and shape of native starch granules were obtained on fresh yam samples. A small portion of fresh yam tuber was scraped with a surgical blade at the mid-section and placed on a clean micro-slide (75 x 25 mm). A drop of distilled water was added and distributed thinly on the slide with the finger tip. Starch granules were observed under a light microscope (Wild Leitzt GMBH, Portugal) and sizes were determined by measuring the granule diameter with an ocular micrometer fixed to the lens of the microscope. The actual sizes of the granules were calculated by multiplying their mean diameters by a factor of 2.5 μm (i. e. the factor for objective magnification that was used). A minimum of 10 granules were selected randomly and measured for each variety.

3.4 Statistical analysis

Statistical Analysis Systems (SAS) package (version of SAS Institute Inc, 2003) was used for statistical analysis. Analysis of variance and means separations were done by the general linear model procedure. Least significant difference (LSD) test was used to test significant differences ($p \leq 0.05$) between means. Potential relationships between sensory quality of the products and physicochemical/chemical/pasting properties of the varieties were examined by the use of Pearson correlation.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Chemical, physicochemical and pasting characteristics of water yam (*Dioscorea alata*) and white yam (*Dioscorea rotundata*)

4.1.1Chemical and mineral characteristics of yam

4.1.1a Chemical characteristics of yam

The chemical composition of the varieties is presented in Table 4.1. The moisture content of a food sample reflects the amount of solid matter in the sample. The higher the moisture content, the higher the rate of spoilage. Moisture content of the *D. alata* varieties ranged between 66.2% for TDa 98-159 and 80.9% for TDa 99/00240 with a mean of 72.2%. There were significant ($P<0.05$) varietal differences in moisture content among the test varieties and also between the average test variety and the reference variety. All the *D. alata* varieties had higher moisture content than the reference sample, TDr 608, which had a value of 64.4%. These observed high moisture levels may influence the textural quality and keeping quality of *D. alata* fresh tubers and their food products. It is presumed that the name ‘water yam’ given to *D. alata* stems from its high moisture content in the tubers. The yam tuber, in general, has high moisture content and a low level of dry matter which make it more prone to losses during the harvesting season. Yam is, however, processed to flour and stored for various food products throughout the bumper and the lean seasons.

Table 4.1: Chemical composition (mean %) of *Dioscorea alata* and *D. rotundata* flour

		Fresh Tuber		Flour				
Serial no	Specie/variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch	TDF*
	D. alata							
1	TDa 00/00103	71.2	28.8	5.9	3.8	4.3	68.6	7.3
2	TDa 00/00364	72.3	27.7	5.1	3.6	3.9	69.6	6.5
3	TDa 01/00002	72.3	27.7	4.3	3.3	3.7	66.6	5.8
4	TDa 01/00024	71.9	28.1	6.7	4.1	5.9	71.3	7.1
5	TDa 01/00041	74.1	25.9	6.9	3.9	3.6	64.6	6.3
6	TDa 01/00081	72.0	28.0	5.1	3.7	4.7	70.3	5.6
7	TDa 85/00250	76.7	23.3	8.7	4.0	8.4	69.7	7.0
8	TDa 92-2	77.7	22.3	5.7	3.1	8.7	69.3	7.0
9	TDa 95/00328	76.5	23.5	6.1	3.5	11.0	60.3	11.0
10	TDa 95-310	69.3	30.7	5.3	3.7	4.6	68.5	8.1
11	TDa 98/01174	71.4	28.6	6.5	3.4	5.6	72.7	4.1
12	TDa 98/01176	69.8	30.2	5.7	2.9	6.7	67.7	9.2
13	TDa 98/01183	66.9	33.1	5.3	3.1	5.7	68.6	8.2
14	TDa 98-159	66.2	33.8	6.2	4.1	4.2	74.4	5.2
15	TDa 99/00332	71.8	28.2	5.4	3.0	5.0	62.0	6.6
16	TDa 99/00395	71.1	28.9	5.0	3.2	5.7	68.6	5.4
17	TDa 99/00240	80.9	19.1	8.0	4.3	7.5	65.2	10.3
18	TDa 291	69.3	30.7	5.9	3.2	5.2	69.8	5.0
18	TDa 297	71.6	28.4	7.1	4.3	4.3	67.2	5.7
20	TDa 93-36	70.3	29.7	5.6	3.6	5.0	72.1	7.1
	Min	66.2	19.1	4.3	2.9	3.6	60.3	4.1
	Max	80.9	33.8	8.7	4.3	11.0	74.4	11.0
	Mean	72.2	27.8	6.0	3.6	5.7	68.4	6.9
	SE	0.8	0.8	0.2	0.1	0.4	0.8	0.4
	LSD	3.37	3.37	1.12	0.55	1.77	3.87	
	D. rotundata							
	TDr 608	64.4	35.6	5.2	4.0	4.5	78.3	5.2

*TDF: Total dietary fibre

Dry matter content ranged between 19.1 and 33.8% with a mean of 27.8%. TDa 99/00240 had the lowest and TDa 98-159, the highest values (Table 4.1). A comparable range of 13.68 - 37.4% dry matter content for *D. alata* varieties has been reported in the literature (Maziya-Dixon and Asiedu, 2003; Lebot *et al.*, 2005). Lebot *et al.* (2005) observed that *D. alata* varieties with good eating quality are characterized by high dry matter, starch and amylose contents. Similarly, Martin (1974) associated high dry matter content with good eating quality, while Olorunda *et al.* (1981) reported that it is an important chemical index of food quality in root and tuber crops which has an influence on the textural perception of foods (Izutsu and Wani, 1985).

Protein is essential in the human diet for growth. Protein content of the *D. alata* varieties ranged between 4.3% for TDa 01/00002 and 8.7% for TDa 85/00250 with a mean of 6.0%. There were also varietal differences in protein content of the test varieties. The protein contents of *D. alata* varieties were generally higher than in the reference variety, TDr 608 which had a mean value of 5.2%. A similar observation was made by Lape and Treche (1994) who reported 8.2% protein content for *D. alata* and 7.0% for *D. rotundata* varieties. Lebot *et al.* (2005) had an average of 11.95% protein content when characterizing the physicochemical properties of *D. alata* tubers from Vanuatu. Many authors found a higher nutritional content (with regard to proteins and vitamin C) in *D. alata* than in *D. rotundata* as well as in other root and tuber crops such as cassava, sweetpotato and dasheen (Asemota, 1990; Osagie, 1992; Muzac-Tucker *et al.*, 1993; Sefah-Dedeh and Agyir-Sackey, 2002).

Ash content is a reflection of mineral status, even though contamination can indicate a high concentration in a sample. Values ranged between 2.9 and 4.3% with a mean of 3.6%. The lowest value obtained was from TDa 98/01176 and the highest from TDa 99/00240. Significant differences ($P<0.05$) were observed among the test varieties which may be attributed to varietal effect. Comparable ash content (2.50-4.90%) has been reported for *D. alata* tubers (Lebot *et al.*, 2005). The amount of ash in a tuber depends on the type of soil from which it was harvested, the moisture content and the maturity of the crop (Osagie, 1992).

Percentage sugar content ranged between 3.6 for TDa 01/00041 and 11.0% for TDa 95/00328 with a mean of 5.7% (Table 4.1). There were significant differences ($P<0.05$) among the test varieties. TDr 608 had a value of 4.5% sugar. A comparable range of 0.6-15.8% sugar has been reported for *D. alata* varieties (Maziya-Dixon and Asiedu, 2003; Lebot *et al.*, 2005). Sugar in yam confers sweetness in the cooked tuber which influences food quality (Lebot *et al.*, 2005). Pona, a variety of *D. rotundata*, is preferred for boiled yam because of its sweet taste (Otegbayo *et al*., 2001). Percentage starch, on the other hand, ranged between 60.3% for TDa 95/00328 and 74.4% for TDa 98/159. The highest starch content obtained (78.3%) was from the reference variety, TDr 608 (Table 4.1). Significant differences ($P<0.05$) existed among the test varieties. Similar starch contents (39.9-84.9%) have been reported in *D. alata* varieties (Maziya-Dixon and Asiedu, 2003; Lebot *et al*., 2005). Starch is known to account for about 80% on a dry weight basis of yam carbohydrate (Degras, 1986; Muthukumarasamy and Panneerselvam, 2000); hence, it is a dominant factor in determining the physicochemical, rheological, and textural characteristics of yam food products. The differences in sugar and total starch contents may be as a result of differences in the activity of enzymes involved in starch biosynthesis (Krossmann and Lloyd, 2000).

Total dietary fibre (TDF) content ranged between 4.1% for TDa 98/001174 and 11.0% for TDa 92-2 with a mean of 6.8%. Most of the *D. alata* varieties had comparatively more total dietary fibre than the reference variety which had a value of 5.2%. Dietary fibre (DF) is an essential component in human and animal nutrition (Johansen *et al.*, 1993). A high intake of DF is positively related to different physiological and metabolic effects. It contributes less to calories, and can bind and flush cholesterol, carcinogens and undesirable chemicals from the body. It provides bulk, regulates intestinal motility and thereby helps to prevent the development of diverticulosis, and chronic diseases including coronary heart disease, colonal cancer and other disorders of the gastrointestinal lining (Topping and Clifton, 2001). Cereal grains, particularly whole grains are the most important sources of DF (Dongowski *et al.*, 2002). Whole oat flour typically has 14% TDF, whole wheat flour 12% and whole brown rice 5%. Even at these low levels, the fibre contents of whole-grain flours would have a significant impact on performance (Best, 2005). With the exception of TDa 98/01174, all the test varieties had higher TDF than the 5% reported in brown rice while specific varieties such as TDa 95/00328 (11.0%) and TDa 99/00240 (10.3%) had TDF values comparable to the 12% reported in whole wheat flour. Woolfe (1987) reported that yam flour has higher levels of fibre than potato flour, refined wheat flour, maize and rice. Intake of TDF could therefore be increased by the consumption of foods from *D. alata* or by incorporating it into other sensorially accepted foods. The variations in TDF of *D. alata* flour could also be of significance in the formulation of diets for diabetics and other health conscious individuals. This study supports the reports that *D. alata* is nutritionally superior to *D. rotundata* (Osagie, 1992; Lape and Treche, 1994) with regard to its higher protein and total dietary fibre contents. Sambucetti and Zuleta (1996) observed a high positive correlation between TDF and amylose content. The high amylose contents (Table 4.2) obtained for *D. alata* varieties might have contributed to the high TDF obtained in this study. The high TDF content of *D. alata* (Table 4.2) could have also contributed to the lower peak and final viscosities (Table 4.3) observed in *D. alata* varieties. High fibre content is known to contribute to lower viscosity by reducing starch cohesiveness (Houssou and Ayernor, 2002).

4.1.1b Mineral Composition of yam

Mineral deficiency, in particular, is a major health issue especially deficiencies of micronutrients which can lead to several health consequences. Researchers aim at investigating the mineral levels in commonly consumed foods for possible improvement. This section of the study investigated the mineral content of the test (*D. alata*) and the reference (*D. rotundata*) varieties with the aim of providing scientific information for the use of breeding programmes that aim at increasing mineral levels in local staples.

4.1.1c Macro mineral composition

The macro mineral composition of the test and reference varieties is presented in Table 4.2 There were significant ($P<0.05$) varietal differences among all the macro minerals across the 20 test varieties. Phosphorus (P) is found in most foods because it is a critical component of all living organisms. About 800 mg of P is recommended for adults per day. A range of 877 to 2053 mg/kg of P was obtained for the *D. alata* varieties while the reference variety had a value of 1310 mg/kg. Yam starches are reported to contain 3-4 times as much phosphorus as found in cassava and aroid ones (Moorthy, 1994). Peroni *et al.* (2006) reported higher phosphorus in yam (0.022%) compared to other root and tuber crops. Similarly, Moorthy and Nair (1989) reported 0.11 and 0.015% phosphorus in *D. rotundata* grown in India. The average value being reported in this study (1563.34 mg/kg or 0.156%) is higher than found in other studies and this could be due to varietal and environmental differences.

Table 4.2: Macro mineral composition of yam flour (mg/kg)

Serial no.	Species/variety	Phosphorus	Calcium	Magnesium	Potassium	Sodium
	D. alata					
1	TDa 00/00103	2054	285	485	17150	101
2	TDa 00/00364	1531	310	500	14450	104
3	TDa 01/00002	1517	310	405	14150	118
4	TDa 01/00024	1603	335	475	17950	106
5	TDa 01/00041	1774	335	580	19950	112
6	TDa 01/00081	1900	410	390	17050	113
7	TDa 85/00250	1801	385	490	20100	131
8	TDa 92-2	1484	410	515	15600	115
9	TDa 95/00328	1502	360	410	16000	111
10	TDa 95-310	1208	335	460	17200	89
11	TDa 98/01174	1800	335	500	17400	119
12	TDa 98/01176	1554	310	515	12700	95
13	TDa 98/01183	1614	260	420	13800	119
14	TDa 98-159	1457	310	500	10550	101
15	TDa 99/00332	878	260	500	11100	84
16	TDa 99/00395	1605	310	490	15250	97
17	TDa 99/0240	1748	535	540	18700	84
18	TDa 291	1343	285	435	12100	96
19	TDa 297	1292	285	575	14650	96
20	TDa 93-36	1603	335	595	13100	108
	Min	877	260	390	10550	83
	Max	2053	535	595	20100	131
	Mean	1563	335	489	15447	104
	SE	58	14	12	616	2
	LSD	0	127	139	3973	34
	D. rotundata					
	TDr	1310	310	510	15910	104

Calcium contents of the *D. alata* varieties ranged between 260 and 535 with a mean of 335 mg/kg. There were significant differences among the test varieties. The reference variety had a value of 310 mg/kg. In a similar study on yam, Dilworth *et al.* (2007) obtained 300 mg/kg calcium in cooked yellow yam and 410 mg/kg calcium in the uncooked. 14.3–46.9 mg/100g (fresh weight) has also been reported in wild yams (Bhandari *et al*., 2003). The RDA for calcium is about 800-1200 mg for adults. The mineral calcium is vital for the development of healthy bones and teeth. It is also needed for muscle contraction and regulation of the heartbeat, and, is involved in the formation of blood clots. A long-term shortage of calcium can lead to osteoporosis, when the bones become brittle and break easily. Yam, from this study, may contribute to calcium requirement to its consumers.

The average test variety had potassium content of about 15447 ranging from 10550 to 20100 mg/kg. The reference variety had a value of 15910 mg/kg. Bhandari *et al*. (2003) obtained 250–560 mg/100 g K on fresh weight bases unlike dry bases in this study. Potassium is a mineral that helps the kidneys to function normally and control blood pressure. With this appreciable content of K in the varieties, both the test varieties and the reference could be recommended for people with high blood pressure (Osagie 1992) but may not be suitable for people with renal failure. The proper balance of potassium in the body depends on sodium. Therefore, an excessive use of sodium may deplete the body's stores of potassium. Daily intake of potassium (K) between 1875 and 5625 mg is considered adequate and safe, however, too much can be harmful. Magnesium content ranged between 390 and 595 with a mean of 489 mg/kg for the test varieties while the reference variety had a value of 510 mg/kg. In a similar study, Bhandari *et al*. (2003) obtained Mg contents of 18.3–27.3 mg/100 g (fresh weight) in wild yams. The RDA of Mg is set at 300 mg for women and 350 mg for men. From the results, *D. alata* could be very good source of Mg. Yam is considered a good source of magnesium.

The mineral sodium (Na) is important for the control of water balance in the body. It also helps with normal nerve impulse regulation and muscle contraction. Na content of test varieties ranged between 84 and 131 with a mean of 104 mg/kg. The reference variety also had a Na content of 104 mg/kg. The recommended daily intake is between 1110 and 3300 mg, however, too much can be harmful to the body. The result of this study shows that *D. alata* is a low sodium source. The high potassium and low sodium contents of the yam varieties may make them good potassium-sodium balance in the human body, and so protect against osteoporosis and heart diseases (Walsh, 2003).

Daily consumption of yam in most yam producing areas is quite high. Nweke *et al*. (1992) established that people in major yam producing rural areas in Southeast Nigeria consumed as high as 757 calories per capita per day as compared to other root and tuber crops with lower but comparable figures in urban areas. However, yam consumption varies greatly across countries as well as across zones in individual countries. The average yam consumed per capita per day is estimated by FAOSTAT (2005) at 108.0 kcal in West and Central Africa, 4.5 kcal in East and Southern Africa, 2.0 kcal in Asia, 70.0 kcal in the Pacific, 33.0 kcal in the Caribbean and 7.8 kcal in Latin America. With the high consumption of yam particularly in West Africa and the appreciable contents of macro-minerals in the varieties, yam could be an important contributor to their RDA.

4.1.1d Trace or micro minerals

Billions of people in developing countries suffer from micronutrient malnutrition, also known as "hidden hunger," that is caused by lack of sufficient micronutrients in the diet. These include vitamins and minerals such as Vitamin A, zinc, and iron. Diets deficient in micronutrients are characterized by high intakes of staple food crops (such as maize, wheat and rice), but low consumption of foods rich in bioavailable micronutrients such as fruits, vegetables, and animal and fish products.

The micro mineral composition is presented in Table 4.3. The *D. alata* varieties had manganese (Mn) content ranging from 5 to 25 mg/kg while the reference variety had a significantly higher value of 34.5 mg/kg. There were significant differences among the test varieties. Comparably low Mn (0.14–0.35 mg/100 g fresh weights) has been reported in the literature (Bhandari *et al*., 2003). Mn is part of the bones and 2.5 to 5 mg per day is considered adequate and safe. Too much can be harmful.

Table 4.3: Micro mineral composition of yam flour (mg/kg)

Serial no.	Species/variety	Manganese	Iron	Cupper	Zinc
1	TDa 00/00103	12.2	25.1	12.6	17.6
2	TDa 00/00364	9.7	36.2	13.5	11.9
3	TDa 01/00002	4.8	24.9	12.3	12.9
4	TDa 01/00024	9.7	42.3	13.2	10.8
5	TDa 01/00041	4.8	30.4	12.7	12.8
6	TDa 01/00081	6.4	27.3	13.5	10.7
7	TDa 85/00250	8.1	48.9	15.5	10.1
8	TDa 92-2	5.6	29.8	15.1	12
9	TDa 95/00328	15.4	32.8	14.7	12.3
10	TDa 95-310	12.5	35.4	15.7	12.2
11	TDa 98/01174	12.1	28.9	12.9	11.5
12	TDa 98/01176	12.4	29.5	14.1	12.2
13	TDa 98/01183	15.2	29.6	14.4	12.1
14	TDa 98-159	13.2	32	15.6	12.3
15	TDa 99/00332	22.1	35.8	14.4	13.6
16	TDa 99/00395	13.3	31.4	13.9	14.1
17	TDa 99/0240	12.1	42.3	12.4	13.9
18	TDa 291	21.9	52.7	13.7	12.9
19	TDa 297	15.5	60.3	11.9	13
20	TDa 93-36	24.5	60.6	10.1	12.2
	Min	4.8	24.9	10.1	10.1
	Max	24.5	60.6	15.7	17.6
	Mean	12.6	36.8	13.6	12.6
	SE	1.2	2.4	0.3	0.4
	LSD	21.19	35.45	8.62	3.9
	D. rotundata				
	TDr 608	34.5	80.5	9.5	12.3

Unusually high iron contents were obtained for the test varieties ranging from 24.9 to 60.6 mg/kg with a mean of 36.81 mg/kg. The reference variety also had a significantly higher value of 80.5 mg/kg. The high iron values obtained in this study could be due to possible contamination during samples preparation. A range of 9-15 mg/kg of iron in boiled yam and 11-20 mg/kg in yam flour were obtained in a similar study on yam

(Personal communication, Maziya-Dixon *et al.*, 2007a, unpublished). An appreciable content of vitamin C (5-10 mg/100 g) has been reported in yam (Osagie, 1992) which may help in absorption of iron

The content of Cu ranged between 10.10 and 15.67 mg/kg of yam flour. The reference variety had a value of 9.5 mg/kg. The values in this study seem to be high as compared to what was obtained (0.10–0.21 mg/100 g fresh weights) in wild yams by Bhandari *et al.* (2003). Again the high values could possibly be due to sample contamination. Too much Cu can be harmful. However, 2 to 3 mg/day intake is considered adequate and safe. Good sources are liver, shellfish, whole grains, legumes, and nuts; Cu is believed to help the body to absorb and use iron in making haemoglobin. It also helps the body to get energy from food.

Contents of Zn ranged between 10.10 and 17.64 mg/kg. The amount recommended is 15 mg/day for adults and good sources are sea foods, meat, fish, and whole grains. With the range of zinc content of *D. alata* flour, the species could be recommended for diet formulations for hypertensive patients. Similar zinc contents were obtained in boiled yam (6.7-13.0 mg/kg) and yam flour (5.7-15.0 mg/kg) (Personal communication, Maziya-Dixon *et al.*, 2007b, unpublished). Zn helps to regulate many of the human body's processes. It is essential for survival and deficiency has serious consequences for health (Brown and Wuehler, 2000).

Significant variations ($P<0.05$) in mineral contents were observed among the *D. alata* varieties which suggest the potential for improvement through breeding. The results indicate that yam is a good source of both macro- and micro- minerals for its consumers. However, further studies could be done on bioavailability of the minerals.

4.1.2. Physicochemical characteristics of yam flour

Table 4.4 shows the physicochemical parameters of flour samples from *D. alata* varieties (test varieties) and the reference variety of *D. rotundata* (TDr 608). Quantifying physicochemical properties is important for food processing and quality because they influence the functional properties of flour (Moorthy, 1994; Gerard *et al.*, 2001; You and Izidorczyk, 2002) which may affect the textural quality of food products. There were significant differences ($p<0.05$) among the test varieties. In the flour (amylose and amylopectin) measurements, *D. alata* varieties were found to be significantly higher in amylose content but lower amylopectin content as compared to the reference *D. rotundata* variety (Table 4.4). Amylose content ranged between 26.7 for TDa 01/00081 and 32.3% for TDa 99/00240 with a mean of 29.4%; TDr 608 had a mean value of 26.6%. Yam starches generally have higher amylose contents than those from other root and tuber crops. Amylose values between 27.6 and 38.2% have been reported for *D. alata* by other researchers (McPherson and Jane, 1999; Hoover, 2001; Moorthy, 2001; Peroni *et al.*, 2006). Sahorè *et al*. (2005) obtained amylose content between 2.32 and >25% for wild yam species. In the present work, amylopectin content ranged from 67.7 to 73.3% for the test varieties with a mean of 70.6% while the reference sample had a value of 73.4%. Krossmann and Lloyd (2000) explained that differences in amylose/amylopectin ratio of starches might occur because of the activity of the enzymes involved in biosynthesis of the various starches.

Table 4.4: Physicochemical characteristics (mean %) of *Dioscorea alata* and *D. rotundata* flour

Serial no.	Species/variety	Amylose	Amylopectin	Swelling Power	Solubility	WBC*
	D. alata					
1	TDa 00/00103	29.5	70.5	10.4	13.3	173.0
2	TDa 00/00364	29.1	70.9	9.4	11.2	191.8
3	TDa 01/00002	28.2	71.8	9.9	10.3	162.4
4	TDa 01/00024	31.0	69.0	8.9	10.4	193.7
5	TDa 01/00041	29.5	70.5	10.7	9.8	171.4
6	TDa 01/00081	26.7	73.3	9.8	9.7	171.7
7	TDa 85/00250	28.6	71.4	8.3	14.8	179.3
8	TDa 92-2	27.7	72.3	9.9	12.5	188.5
9	TDa 95/00328	30.2	69.8	8.6	16.1	202.4
10	TDa 95-310	31.6	68.4	9.6	9.3	179.4
11	TDa 98/01174	29.5	70.5	9.2	11.2	181.9
12	TDa 98/01176	27.9	72.1	10.5	14.0	168.8
13	TDa 98/01183	29.0	71.0	11.2	11.0	168.4
14	TDa 98-159	29.8	70.2	11.6	15.3	159.7
15	TDa 99/00332	30.0	70.0	11.2	11.1	180.9
16	TDa 99/00395	29.4	70.6	10.2	11.6	192.0
17	TDa 99/0240	32.3	67.7	8.0	14.4	200.3
18	TDa 291	27.2	72.8	9.6	10.9	173.6
18	TDa 297	30.9	69.1	10.0	10.2	187.7
20	TDa 93-36	30.3	69.7	10.1	9.6	167.2
	Min	26.7	67.7	8.0	9.3	159.7
	Max	32.3	73.3	11.6	16.1	202.4
	Mean	29.4	70.6	9.9	11.8	179.7
	SE	0.32	0.32	0.21	0.47	2.76
	LSD	2.16	2.16	1.79	3.54	21.56
	D. rotundata					
	TDr 608	26.6	73.4	11.0	8.6	163.3

*WBC: Water binding capacity

Amylose/amylopectin ratio has been reported to impart definite characteristics and functionality to starches by determining the basic texture and nature of their products (Moorthy, 1994; Scott, 1996). According to Singh *et al.* (2006), the viscosity parameters during pasting are cooperatively controlled partly by the properties of the swollen granules and the soluble materials leached out (mainly amylose) from the granules. Collado and Corke (1997) reported that peak viscosity in sweetpotato was significantly negatively correlated with amylose content. High amylose starches are also reported to have high gelatinization temperatures (Richardson *et al*. 2000). In rice, amylose content has been customarily used as a principal criterion in making selection and cross linking aimed at developing rice cultivars for parboil-canning application (Juliano and Hicks, 1996).

Swelling power ranged between 8.0 for TDa 99/00240 and 11.6% for TDa 98-159 with a mean of 9.9% while TDr 608 had a comparable value of 11.0%. The species of the reference variety, *D. rotundata*, is known to have higher swelling power than other yam species (Walter *et al*., 2000). In this study, a few of the *D. alata* varieties had significantly lower swelling power (e.g. TDa 01/00024, TDa 85/00250, TDa 95/00328, TDa 98/01174, TDa 99/0240) to the reference variety. The comparatively higher amylose contents of these varieties (Table 4.4) could have influenced their swelling power. High amylose content has been linked to low swelling power due to greater reinforcement of the internal network by amylose molecules (Lorenz and Collins, 1990; Richardson *et al*., 2000; Hoover, 2001). In a study on yam, Riley *et al*. (2006) observed higher swelling power in yam varieties with lower amylose content. According to Jane and Chen (1992), amylopectin contributes to granule swelling while amylose and lipids inhibit it. Highly associated starch granules with an extensive and strongly bonded structure also exhibit resistance toward swelling (Leach *et al.*, 1959). The lower swelling power in some *D. alata* varieties may also be due to stronger bonding forces in their starch granules although this was not measured in this study. Flours (hence varieties) with high swelling capacity will constitute better thickening as well as bulking agents (Iwuoha and Nwakanma, 1998).

Solubility values ranged between 9.3 for TDa 95/310 and 16.3% for TDa 95/00328 with a mean of 11.8% (Table 4.4). A relatively low solubility (8.6%) was obtained for the reference, TDr 608. High solubility has been associated with high content of amylose which is believed to leach out easily during the swelling process (Soni *et al*., 1993). This is in agreement with the findings in this study where *D. alata* varieties had higher amylose and solubility values relative to the reference variety, TDr 608. However, this observation is contrary to the findings of Riley *et al.* (2006) who reported that solubility increased with decreasing amylose content in *Dioscorea alata* cultivars. The difference in the two studies could be attributed to varietal differences, environmental effect, maturity of the tuber, and differences in inherent characteristics such as granule sizes and their arrangement within their cells. According to Asiedu (1986) differences in growing environment, maturity stage and species may influence yam tuber composition. Tang *et al*. (2001) also reported that small-sized granule fraction of barley had lower amylose than the large fractions.

WBC ranged between 159.7 and 202.0% for TDa 98-159 and TDa 95/00328 with a mean of 179.8 %. Most of the *D. alata* varieties had higher WBC than the reference variety, TDr 608 (Table 4.4). This is in agreement with the findings of Osagie (1992) and Iwuoha (2004) when they assessed the physicochemical properties of different yam species. High WBC is attributed to loose structure of starch polymers. Water absorption is an important parameter to be considered in the preparation of mash, snack foods, extruded foods, and baked products. Higher absorption is preferred for making mash while lower absorption values are more desirable for making thinner gruels. It is an important functional characteristic in the development of ready-to-eat foods since high water absorption capacity may assure product cohesiveness (Kulkani *et al*., 1996). The higher water binding capacity may have implication in the use of *D. alata* flour in bakery products.

This is because higher values increase the unit yield of products. The higher the WBC, the greater the amount of water required to make dough or batter of the predetermined consistency, and this is used as a baking guide (Pomeranz, 1971)

4.1.3 Pasting characteristics of yam flour

The behaviour of flour/starch during cooking, gelatinization and pasting has been linked to its quality and suitability of use (Rasper and Coursey, 1967; Crosbie 1991; Moorthy, 2002). Pasting properties are therefore an important quality index in predicting the behaviour of yam paste during and after cooking. The parameters recorded for each flour sample during the pasting cycle were pasting temperature, peak viscosity, viscosity at 95 ^{o}C (trough), viscosity at constant 95 ^{o}C (breakdown), viscosity at 50 ^{o}C (final viscosity) and viscosity at constant 50 ^{o}C (setback). Figure 4.1 shows representative pasting curves of the *D. alata* varieties and the *D. rotundata* reference variety TDr 608 used in this study. The corresponding values of the pasting characteristics are also presented in Table 4.5. Figure 4.1 shows a relatively lower viscosity for the test varieties than the reference variety. The minimum viscosity on the graph, i.e., trough viscosity, also shows less granule breakdown in the test varieties than in the reference variety. Significant variations ($p<0.05$) were observed among the *D. alata* varieties in all the pasting characteristics (Table 4.5).

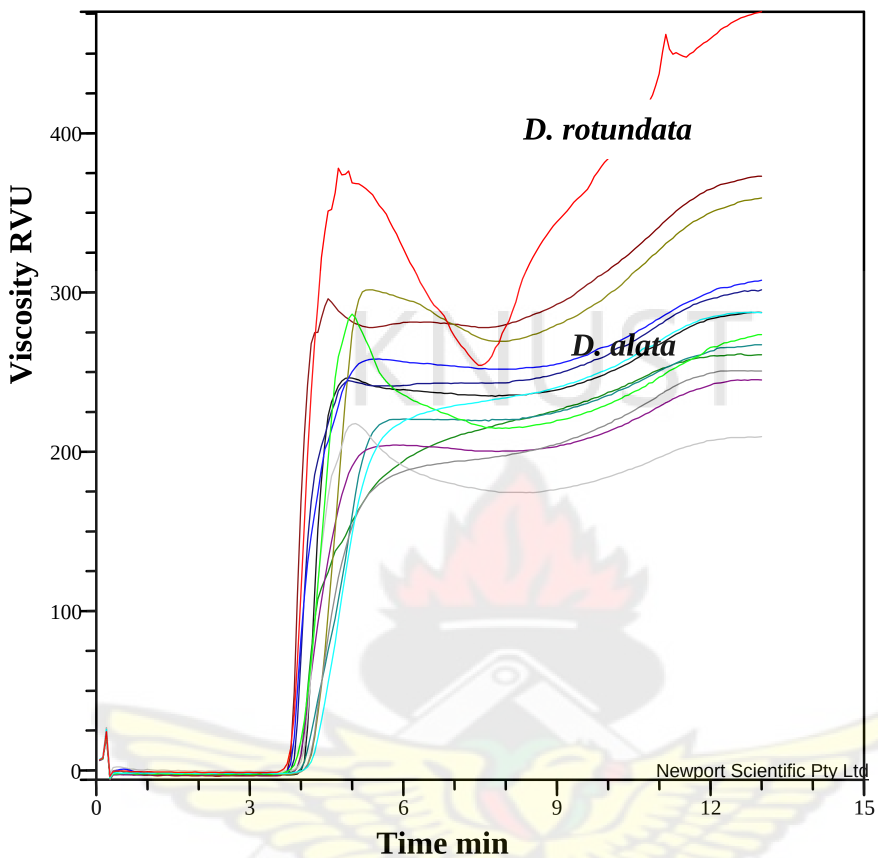


Figure 4.1: Representative pasting curves of reference sample, *D. rotundata* (TDr 608) and *D. alata* varieties (description/labelling of the various portions of the curves are provided in figure 2.2)

When starch is heated in an aqueous environment, it undergoes a series of changes known as gelatinization which is characterized by swelling and change in viscosity. Viscosity is low at the beginning of gelatinization but it increases as the temperature increases. The temperature at which the viscosity of the stirred starch/flour slurry begins to rise is the pasting temperature. It is an index characterized by an initial change in viscosity due to the swelling of starch (Afoakwa and Sefa-Dedeh, 2002). It gives an indication of the minimum temperature required to cook a given flour/starch sample and this has implications for the suitability of other food components (with different gelatinization temperature) in a food formula (Newport Scientific, 1998).

Pasting temperature and peak time were comparatively higher in most of the *D. alata* varieties than the reference variety. Values ranged from 82.8 ^{o}C for TDa 01/00081 to 88.5 ^{o}C for TDa 01/00024 with a mean of 84.2 ^{o}C and the reference variety, TDr 608 had a value of 82.9 ^{o}C (Table 4.5). Peak time ranged from 4.9 min to 7.0 min with a mean of 6.3 min for the *D. alata* varieties while the reference variety had a value of 5.0 min. Similar pasting temperature values (80.0-87.0 ^{o}C) have been reported for different yam species in the literature (Rasper and Coursey, 1967; Sahorè *et al.*, 2005; Otegbayo *et al.*, 2006). Rasper and Coursey (1967) and Otegbayo *et al.* (2006) reported comparatively lower pasting temperatures for *D. rotundata*. The slightly higher pasting temperatures and peak time for some *D. alata* varieties suggest that those varieties have a higher gelatinization temperature and a longer cooking time than the reference variety. For technical and economic reasons, starches/flours with low pasting time and temperature may be preferred when all other properties are equal.

Table 4.5: Pasting characteristics (mean %) of *Dioscorea alata* and *D. rotundata* flour

Serial no.	Species/Variety	Peak Visc. † (RVU)	Trough (RVU)	B. Down‡ (RVU)	Final Visc. (RVU)	Setback (RVU)	Peak time (Min)	Pasting temp. (^{o}c)
	D. alata							
1	TDa 00/00103	236.1	219.9	16.2	284.2	64.3	6.4	84.4
2	TDa 00/00364	181.0	171.1	9.9	237.6	66.5	7.0	83.8
3	TDa 01/00002	233.6	227.3	6.3	286.5	59.3	6.9	83.0
4	TDa 01/00024	63.5	57.6	5.8	98.1	40.5	7.0	88.5
5	TDa 01/00041	215.6	209.4	6.1	256.1	46.7	6.3	84.2
6	TDa 01/00081	196.3	192.0	4.3	264.7	72.7	6.7	82.8
7	TDa 85/00250	100.6	98.3	2.4	131.0	32.7	7.0	84.3
8	TDa 92-2	260.1	232.5	27.5	280.7	48.1	5.3	84.0
9	TDa 95/00328	98.5	94.2	4.4	137.9	43.7	7.0	86.1
10	TDa 95-310	226.3	220.1	6.3	279.9	59.9	6.5	83.8
11	TDa 98/01174	221.2	198.2	23.0	252.1	53.9	6.0	82.8
12	TDa 98/01176	246.1	230.0	16.1	277.2	47.3	5.7	83.8
13	TDa 98/01183	289.4	236.8	52.6	316.3	79.5	5.1	82.8
14	TDa 98-159	267.8	233.4	34.4	296.8	63.4	5.4	83.3
15	TDa 99/00332	197.1	168.1	29.0	226.1	58.0	6.0	85.3
16	TDa 99/00395	186.5	180.5	6.0	232.7	52.2	6.8	84.0
17	TDa 99/00240	295.5	262.6	32.9	322.9	60.3	6.1	84.0
18	TDa 291	252.5	245.3	7.1	308.9	63.6	7.0	84.2
18	TDa 297	289.4	227.8	61.6	298.3	70.6	4.9	83.6
20	TDa 93-36	277.6	268.2	9.3	331.2	63.0	6.9	86.0
	Min	63.5	57.6	2.4	98.1	32.7	4.9	82.8
	Max	295.5	268.2	61.6	331.2	79.5	7.0	88.5
	Mean	215.7	198.7	18.1	256.0	57.3	6.3	84.2
	SE	15.0	12.7	3.8	14.5	2.6	0.2	0.3
	LSD	79.52	69.81	29.83	76.94	19.87	1.22	5.07
	D. rotundata							
	TDr 608	322.6	187.8	134.8	359.3	171.5	5.0	82.9

† visc. = viscosity; ‡ B. Down=breakdown

Peak viscosity is the maximum viscosity attained by the paste during the heating cycle (i.e., from 50 to 95 ^{o}C) due to starch granules swelling and leaching out of the soluble components into the solution. It reflects the ability of starch granules to swell freely before their physical breakdown (Singh *et al.*, 2003) and often correlates with product quality. Peak viscosity ranged between 63.5 RVU for TDa 01/00024 and 295.5 RVU for TDa 99/00240 with a mean of 216.7 RVU while the highest value of 322.6 RVU was obtained for the reference variety, TDr 608 (Table 4.5). The lower peak viscosity of flour from test varieties may be due to the lower swelling power observed in some of the varieties (Table 4.4), lower starch and higher dietary fibre contents (Table 4.1). The relatively longer time taken for most of the *D. alata* flour to paste further indicates stronger bonding forces in their starch granules. Yam starches generally have some level of resistance to swelling which in this case is more pronounced in some *D. alata* varieties. Rickard *et al.* (1991) reported that cassava starch has a high peak viscosity because it exhibits a high degree of swelling.

TDa 01/00024, TDa 85/00250 and TDa 95/00328 among the 20 varieties from Nigeria had the lowest pasting viscosities (peak, trough, breakdown, final and setback); however, their peak time and pasting temperatures were relatively high (Table 4.5). These 3 varieties also had higher amylose contents and lower swelling powers (Table 4.4). The results indicate strong internal forces between their starch granules which resulted in lower swelling power pasting viscosities. High amylose content has been linked to low swelling power due to greater reinforcement of the internal network by amylose molecules (Lorenz and Collins, 1990; Richardson *et al*., 2000; Hoover, 2001). Highly associated starch granules with an extensive and strongly bonded structure also exhibit resistance toward swelling (Leach *et al.*, 1959). According to Rickard *et al*. (1991) and Singh *et al*. (2001) pasting viscosities and swelling are positively related. The higher the swelling power of a sample, the higher the pasting viscosities.

High peak viscosity contributes to good texture of pounded yam, which basically depends on high viscosity and moderately high gel strength (Rasper, 1967; Otegbayo *et al.*, 2006). Rasper (1967) observed that *D. alata* starches have relatively low viscosity (as obtained in this study) but high gel strength when compared with *D. rotundata*. *D. alata* varieties may therefore, be more suitable for products which require high gel strength and a low viscosity or they could be parboiled and processed to flour for products such as *amala*. Sensory results in section 4.2.3 showed that *amala* prepared from the test varieties were as good as the *amala* from reference variety. High viscosity is desirable for industrial use where high thickening power at high temperatures is required (Kim *et al.*, 1995). Starch or flour with a higher peak viscosity is also required for making food products such as jelly or binders while those with lower viscosity are desirable for preparing weaning foods and lighter gruels (Kulkani *et al.*, 1996). This means that the reference variety and test varieties that had relatively high pasting viscosities (TDa 92-2, TDa 98/01183, TDa 98-159, TDa 99/00240, TDa 291, TDa 297, TDa 93-36) could be utilized in products that require high thickening power such as binders or adhesives while the varieties with lower pasting viscosities could be used for weaning food and lighter glues.

As part of the pasting characteristics study, the flour sample subjected to RVA was heated to 95 ^{o}C and held at that temperature for a couple of minutes under mechanical shear stress. As a result of starch granule disruption and the leaching out of amylose into the solution, under the mechanical shear stress, viscosity decreases. The period provides the minimum viscosity value in the constant temperature pasting profile. Trough is considered as a measure of the breakdown of hot starch paste. The ability of a paste to withstand the heating and shear stress is an important factor for most food processing operations and is also a factor in describing the quality of starch gels (Madsen and Christensen, 1996). High paste stability is a requirement for industrial users of starch (Bainbridge *et al.,* 1996). This is because drastic changes in paste during and after processing could lead to textural changes that may be undesirable. Trough values obtained ranged between 57.6 RVU for TDa 85/00024 and 268.2 RVU for TDa 93-36. The reference variety, TDr 608 had a trough value of 187.8 RVU and the highest breakdown value of 134.8 RVU. Breakdown values for the *D. alata* varieties ranged between 2.4 RVU for TDa 85/00250 and 61.6 RVU for TDa 297 with a mean of 18.1 RVU. In general, the *D. alata* varieties had higher trough and lower breakdown values than the reference sample, TDr 608, which indicates greater ability to withstand shear at high temperatures and higher cooked paste stability (Farhat *et al.*, 1999; Rasper, 1969). Starch with a low trough value would have greater need for cross-linking than one with a high value (Oduro *et al.*, 2000). *D. alata* starch could therefore be targeted for industrial uses because of its hot paste stability. Starches of *D. cayenensis* and *D. alata* were shown to be characterized by high hot paste viscosity (trough) and high stability on prolonged heating and stirring (Rasper, 1969). The comparatively higher pasting temperature and thermal stability of *D. alata* varieties suggest that strong bonding forces are present within the starch granules (Hoover, 2001). Rickard *et al*. (1991) reported that *D. rotundata* behaved quite differently from other yam species in that, at high concentrations, considerable paste breakdown occurred on prolonged heating and stirring, as observed in this study.

The viscosity after cooling cooked paste to 50 ^{o}C is the final viscosity**.** Anonymous (1990) reported that starch paste increases in viscosity when cooled. The increase in viscosity is not only caused by simple kinetic effect of cooling but also by re-association of molecules (particularly amylose). Final viscosity is the most commonly used parameter to determine the quality of starch-based samples because it indicates starch/flour ability to form a gel after cooking. All the varieties studied had higher final viscosities as compared with their peak viscosities (Table 4.5). Values for *D. alata* varieties ranged between 98.1 RVU for TDa 01/00024 and 331.2 RVU for TDa 93-36 with a mean of 256.0 RVU. The highest value (359.3 RVU) was obtained from the reference sample, TDr 608. Yam flour is thixotropic and, as observed in this study, has a higher cooled paste viscosity than hot paste viscosity. The observation supports the general fact that yam pastes form firm gels rather than viscous gels after cooking and cooling. This has implications for the kind of products yam flour could be used for, such as weaning diets or crackers. Yam starch paste is noted for high retrogradation during cooling and this might have accounted for the increase in final viscosities during cooling. This is brought about by the high degree of association between the starch-water systems and their high ability to re-crystallize, resulting in progressively higher viscosities during cooling of yam starches (Ayernor, 1985; Anonymous, 1990). Ayernor (1985) reported that the rate at which the development of rigidity occurs in yam starches is dependent on the degree of starch-water binding which can be affected through processes that influence the interaction between the starch particles and water.

Setback is the phase of the pasting profile where re-association between starch molecules occurs to a greater or lesser degree. It is the phase of the pasting curve after cooling of the starches to 50 ^{o}C. Setback value is the difference between final viscosity and trough. Setback viscosity was significantly ($P<0.05$) higher (171.5 RVU) for the reference sample than any of the *D. alata* samples (32.7-79.5 RVU). Mali *et al*. (2003) and Peroni *et al*. (2006) reported that yam starch has a high setback as a result of retrogradation in comparison with other root and tuber crops. Generally the tendency of yam starch paste to retrograde is a limiting factor for the use of yam in food industries. However, hydrocolloids such as gums have been used to prevent such undesirable textural changes (Mali *et al.*, 2003). When starch gel is held for a prolonged period of time, it shrinks and some of the liquid phase separates from it which has a negative effect on textural and sensory properties of food. Setback is hence considered as an important parameter in food processing operations, such as canning (Beta and Corke, 2001). The lower setback observed for *D. alata* flour samples in this study (Table 4.5) suggest that its flour/starch is relatively more stable when cooked and will have a lower tendency to undergo retrogradation during freeze/thaw cycles than the reference sample. Textural changes leading to undesirable properties, such as staling in bread, as well as skin formation, paste gelling and loss of clarity in prepared starch paste has been associated with retrogradation (Sackey, 1998).

High setback value has been associated with cohesive paste (Kim *et al*., 1995) and a good pounded yam or *fufu* (Oduro *et al.*, 2000; Adebowale *et al.*, 2005; Otegbayo *et al.*, 2006). The higher setback observed for the reference variety explains why it is preferred for pounded yam in Nigeria and most *D. alata* varieties are not.

The results for pasting viscosities in conjunction with the physicochemical properties of the test varieties suggest the presence of strong bonding forces between their starch granules. According to McPherson and Jane (1999), linear and strongly associated molecules keep the integrity of granules providing higher resistance to mechanical agitation and higher pasting temperatures. This contributes to low peak viscosity as a result of limited swelling of starch granules as observed for most *D. alata* varieties in this study. The high thermal and mechanical stability of *D. alata* may make them good ingredients for processed foods such as instant soups and noodles.

Significant variations (P<0.05) existed among the different *D. alata* varieties in physicochemical, pasting and chemical properties. For example TDa 95/00328 had significantly higher amylose and lower swelling power which influenced its pasting properties (lower pasting viscosities). However, the significantly higher swelling power obtained for TDa 98-159 reflected in its higher pasting viscosities. It was also observed that TDa 98-159 had significantly higher dry matter and starch content as compared to TDa 95/00328.

4.1.4 Effect of variety and location on chemical, physicochemical and pasting properties of *D. alata*

The following five varieties: TDa 98/01174, TDa 98/01176, TDa 99/00395, TDa 291 and TDa 297 were present in both Ghana and Nigeria batches. The varieties obtained from Ghana were significantly (P<0.05) different from the Nigeria ones in terms of chemical, physicochemical and pasting properties (Tables 4.6-4.8). Significant differences were also found within the varieties from the same location.

TDa 98/01174, TDa 98/01176 and TDa 99/00395TDa from Ghana had significantly (P<0.05) lower moisture and higher dry matter contents than the ones obtained from Nigeria (Table 4.6), however, TDa 297 from Ghana had significantly higher moisture content.

Table 4.6: Chemical properties of *D. alata* varieties at two different locations

		Fresh Tuber		Flour			
Serial no	Variety	Moisture	Dry matter	Protein	Ash	Sugar	Starch
	Ghana						
1	TDa 98/01174	69.93	30.07	6.04	3.66	3.31	70.52
2	TDa 98/01176	56.47	43.53	5.07	4.54	3.18	77.56
3	TDa 99/00395	69.07	30.94	6.18	3.36	5.31	65.58
4	TDa 291	70.16	29.85	5.87	2.57	2.86	64.01
5	TDa 297	79.31	20.70	7.88	4.32	6.91	63.76
	Mean	68.99	31.02	6.21	3.69	4.31	68.29
	LSD	5.99	5.99	0.19	0.31	1.29	3.75
	Nigeria						
1	TDa 98/01174	71.40	28.60	6.50	3.40	5.60	72.70
2	TDa 98/01176	69.80	30.20	5.70	2.90	6.70	67.70
3	TDa 99/00395	71.10	28.90	5.00	3.20	5.70	68.60
4	TDa 291	69.30	30.70	5.90	3.20	5.20	69.80
5	TDa 297	71.60	28.40	7.10	4.30	4.30	67.20
	Mean	70.64	29.36	6.04	3.40	5.50	69.20
	LSD	3.57	3.57	1.29	0.53	1.54	3.53

Moisture and protein contents of TDa 291 were about the same from both countries. While two of the varieties obtained from Ghana (TDa 98/01174 and TDa 98/01176) had lower protein contents, the other two varieties (TDa 99/00395 and and TDa 297) had higher protein contents than the ones obtained from Nigeria. Sugar contents were lower for Ghana varieties with the exception of TDa 297. Comparatively lower starch contents were obtained for all the varieties obtained from Ghana with the exception of TDa 98/01176 than the Nigerian ones.

Table 4.7: Physicochemical properties of *D. alata* varieties at two different locations

Serial no.	Variety	Amylose	Amylopectin	Swelling Power	Solubility	WBC*
	Ghana					
1	TDa 98/01174	25.54	74.46	7.39	9.19	179.50
2	TDa 98/01176	21.69	78.31	7.36	10.47	192.32
3	TDa 99/00395	23.33	76.67	6.23	8.81	228.96
4	TDa 291	28.19	71.81	6.78	10.26	158.69
5	TDa 297	23.63	76.37	8.87	16.15	232.04
	Mean	24.48	75.52	7.33	10.98	198.30
	LSD	3.87	3.87	1.16	2.4	17.62
	Nigeria					
1	TDa 98/01174	29.50	70.50	9.20	11.20	181.90
2	TDa 98/01176	27.90	72.10	10.50	14.00	168.80
3	TDa 99/00395	29.40	70.60	10.20	11.60	192.00
4	TDa 291	27.20	72.80	9.60	10.90	173.60
5	TDa 297	30.90	69.10	10.00	10.20	187.70
	Mean	28.98	71.02	9.90	11.58	180.80
	LSD	1.89	1.89	2.11	4.11	17.19

Generally physicochemical properties (amylose, swelling power, solubility) of the varieties collected from Ghana were lower than the ones obtained from Nigeria with the exception of WBC. However, TDa 291 from Ghana had higher amylose content than TDa from Nigeria and TDa 297 also had comparatively higher solubility than the same variety from Nigeria.

The varieties obtained from Ghana had comparatively lower pasting viscosities (peak, trough, final and setback viscosities). Break down viscosity, peak time and pasting temperatures were however higher for the varieties obtained from Ghana with the exception of TDa 291.

4.8: Pasting properties of *D. alata* varieties at two different locations

Serial no.	Variety	Peak Visc.† (RVU)	Trough (RVU)	B. Down‡ (RVU)	Final Visc. (RVU)	Setback (RVU)	Peak time (Min)	Pasting temp. (^{o}c)
	Ghana							
1	TDa 98/01174	177.40	174.00	40.50	210.00	36.00	7.00	86.90
2	TDa 98/01176	165.90	163.90	23.00	222.40	58.50	6.70	84.10
3	TDa 99/00395	93.20	88.60	55.00	131.30	42.70	7.00	85.50
4	TDa 291	190.10	175.10	179.50	210.70	35.60	5.30	83.60
5	TDa 297	146.70	143.30	41.00	178.80	35.60	7.00	87.20
	Mean	154.66	148.98	67.80	190.64	41.68	6.60	85.46
	LSD	16.13	15.9	17.47	20.81	5.36	0.12	1.87
	Nigeria							
1	TDa 98/01174	221.20	198.20	23.00	252.10	53.90	6.00	82.80
2	TDa 98/01176	246.10	230.00	16.10	277.20	47.30	5.70	83.80
3	TDa 99/00395	186.50	180.50	6.00	232.70	52.20	6.80	84.00
4	TDa 291	252.50	245.30	7.10	308.90	63.60	7.00	84.20
5	TDa 297	289.40	227.80	61.60	298.30	70.60	4.90	83.60
	Mean	239.14	216.36	22.76	273.84	57.52	6.08	83.68
	LSD	72.71	59.62	41.18	78.07	22.98	1.56	3.11

The differences among the varieties at the 2 different locations are attributed to genotype by environment interaction (GxE). According to Dixon *et al.* (1991), GxE is defined as the change in a cultivar's relative performance over environment, resulting from differential response of cultivar to various edaphic, climatic and biotic factors. This means that the five varieties planted at the two different locations (Countries) responded differently at each location as a result of differences in edaphic, climatic and bioctic factors. Differences in rainfall pattern and soil properties at different locations were reported to have contributed to variation in tuber yield of cassava (Baafi and Safo-Kantanka (2008). GxE is reported to limit progress of crop improvement beyond the breeder's station and hence it is very important information which enhances improvement of specific varieties at specific locations for domestic and industrial uses.

4.2 Sensory quality of three major traditional yam products from water yam (*Dioscorea alata*)

4.2. Pounded yam

Table 4.9 shows the mean values of sensory attributes of pounded yam prepared from the test and reference varieties. Significant differences ($P<0.05$) were found among all the varieties across the quality attributes. Pounded yam prepared from *D. alata* varieties was generally rated poor compared with that from the reference variety across the quality attributes (Table 4.9). It was observed during preparation that pounded yam from most of the *D. alata* varieties was too sticky and lumpy or soft and not consistent. The observed quality of pounded yam of test varieties might have been influenced by the differences in chemical, physicochemical and pasting characteristics discussed above. However, pounded yam from TDa 00/00103, TDa 98-159, TDa 291, TDa 297, and TDa 93-36 (as shown in Table 4.9) were scored quite close to the reference product in most of the quality attributes. TDa 01/00024, TDa 95/00328 and TDa 92-2 were rated as the poorest compared with the reference sample in terms of all the quality attributes. Texture, which in this case consists of smoothness, elasticity, consistency, stickiness and hardness, is one of the main factors for acceptability used by consumers to evaluate the quality of pounded yam (Egesi *et al*., 2003; Bourne, 1990). The poor performance of most *D. alata* varieties for pounded yam in this study could be the reason why the species is rarely used for this purpose; however, the promising varieties (TDa 00/00103, TDa 98-159, TDa 291, TDa 297, and TDa 93-36) could be closely studied for further genetic improvement.

Table 4.9: Sensory quality attributes of pounded yam from 20 varieties of *Dioscorea alata*† as compared with the reference sample, *D. rotundata*

Serial no	Variety	Colour	Smoothness	Consistency	Elasticity	Stickiness	Hardness
1	TDa 00/00103	5.3	4.3	4.8	4.3	4.6	5.3
2	TDa 00/00364	2.7	3.9	3.8	3.3	3.9	4.2
3	TDa 01/00002	4.9	3.5	4.1	3.4	3.5	4.2
4	TDa 01/00024	2.3	2.5	2.9	2.9	3.2	3.6
5	TDa 01/00041	4.8	4.3	4.7	3.4	3.2	4.5
6	TDa 01/00081	5.5	4.4	3.9	3.0	3.3	4.1
7	TDa 85/00250	4.5	3.3	3.1	3.5	3.1	4.4
8	TDa 92-2	3.6	3.4	3.0	2.7	3.5	3.8
9	TDa 95/00328	1.9	3.3	3.1	2.9	3.4	3.5
10	TDa 95-310	3.1	4.4	4.0	3.2	3.5	5.0
11	TDa 98/01174	4.8	4.2	4.2	3.8	4.2	4.7
12	TDa 98/01176	5.1	4.1	3.9	3.8	4.0	5.2
13	TDa 98/01183	3.7	3.5	3.8	3.3	3.0	4.5
14	TDa 98-159	5.4	4.2	5.0	4.5	4.7	5.0
15	TDa 99/00332	3.8	3.3	4.7	4.0	3.9	5.2
16	TDa 99/00395	2.6	3.9	4.7	3.7	3.9	5.0
17	TDa 99/0240	3.2	3.9	3.8	3.6	3.5	4.1
18	TDa 291	5.4	4.7	5.0	3.8	4.7	5.2
19	TDa 297	5.0	4.4	4.9	4.1	4.8	5.2
20	TDa 93-36	5.5	4.5	4.7	3.8	4.2	5.1
	Min	1.9	2.5	2.9	2.7	3.0	3.5
	Max	5.5	4.7	5.0	4.5	4.8	5.3
	Mean	4.1	3.9	4.1	3.5	3.8	4.6
	SE	0.3	0.1	0.2	0.1	0.1	0.1
	LSD	0.67	0.78	0.92	0.82	0.98	0.93

†Values are means of 20 observations
Scale of 1 to 9, where 1= very much worse, 2= very poor, 3= moderately poor, 4= slightly poor, 5= no difference, 6= slightly better, 7=moderately better, 8= much better, 9=very much better compared to pounded yam from TDr 608 (*D. rotundata*)
Pounded yam from TDr 608 was assumed to have a value of 5.0

4.2.2 Boiled yam

Tables 4.10 and 4.11 show the mean values of sensory attributes of boiled yam prepared using *D. alata* varieties from Nigeria and Ghana respectively. Mean scores for wetness and hardness were about equal for all the varieties from Nigeria; however significant differences ($P < 0.05$) existed among the varieties in terms of colour, taste and mealiness

(Table 4.10). Similar results were obtained from the Ghana varieties (Table 4.11). With the exception of wetness, there were significant differences among the varieties in terms of all the boiled yam quality attributes. Colour, mealiness and taste/flavour are reported to be key quality parameters of boiled yam (Abass *et al*., 2003 and Egesi *et. al.*, 2003).

Table 4.10: Sensory quality attributes of boiled yam from 20 varieties of *Dioscorea alata*† *as* compared with the reference sample, *D. rotundata*

Serial no	Variety	Colour	Wetness	Taste	Hardness	Mealiness
1	TDa 00/00103	3.9	5.1	3.9	4.4	3.0
2	TDa 00/00364	1.8	4.3	3.6	4.9	3.1
3	TDa 01/00002	4.4	4.5	4.2	4.8	2.9
4	TDa 01/00024	2.7	4.4	3.2	4.8	3.0
5	TDa 01/00041	4.2	4.6	4.0	5.5	3.7
6	TDa 01/00081	4.9	5.1	4.7	4.6	4.3
7	TDa 85/00250	3.5	4.0	3.9	4.1	2.7
8	TDa 92-2	4.0	4.3	5.6	4.8	3.1
9	TDa 95/00328	1.6	4.4	2.7	4.5	2.8
10	TDa 95-310	3.2	4.7	4.3	4.6	4.7
11	TDa 98/01174	3.2	4.9	4.0	4.7	4.9
12	TDa 98/01176	4.5	4.9	5.3	5.1	4.3
13	TDa 98/01183	3.4	4.7	4.7	4.7	3.6
14	TDa 98-159	5.6	5.8	4.6	4.6	5.0
15	TDa 99/00332	2.7	4.4	4.1	4.3	2.8
16	TDa 99/00395	2.3	4.2	4.2	3.8	3.3
17	TDa 99/0240	1.7	3.7	2.5	4.0	2.1
18	TDa 291	4.3	4.8	4.6	5.5	3.6
19	TDa 297	4.7	4.7	4.7	5.6	3.8
20	TDa 93-36	4.6	4.4	5.2	5.3	3.2
	Min	1.6	3.7	2.5	3.8	2.1
	Max	5.6	5.8	5.6	5.6	5.0
	Mean	3.5	4.6	4.2	4.7	3.5
	SE	0.3	0.1	0.2	0.1	0.2
	LSD	1.09	1.03	1.29	0.99	1.11

† Values are means of 20 observations
Scale of 1 to 9, where 1= extremely inferior, 2= much inferior, 3= moderately inferior, 4 = slightly inferior, 5= no difference, 6= slightly better, 7=moderately better, 8=much better, 9= extremely better compared to pounded yam from TDr 608 (*D. rotundata*)
Pounded yam from TDr 608 was assumed to have a value of 5.0

About 30% of boiled yam samples from the test varieties were comparable to the reference variety. Wetness and hardness in particular were generally comparable to the reference, however, colour, taste and mealiness had average scores lower than 4.5, thus comparably poor to the reference (Table 4.10). Otegbayo *et al*. (2001) reported that boiled yam from *pona*, a cultivar of *D. rotundata* was rated superior to other cultivars in cooking quality attributes due to its sweet taste, softness and mealy texture after cooking. *Pona* has a higher price on the market than other yam varieties due to these quality characteristics. Lebot *et al*. (2005) also observed that *maligni*; a variety of *D. alata* is famous and appreciated throughout Vanuatu because of its sweet taste. Traditionally *D. alata* is stored for months after harvesting before consumption. This is because storage is believed to reduce moisture content and increase sugar level in *D. alata* thereby improving the texture and taste of it.

It was observed during the preparation of boiled yam that the flesh of most of the test varieties was more prone to browning than the reference variety, hence the low score for colour. Acceptable boiled yam is white, creamy, or yellowish in appearance (personal communication). Browning is attributed to enzymatic oxidation of polyphenols in yam. The rate of browning in yam has been positively correlated with the amount of phenolic compounds and polyphenol oxidases in yam tuber (Asemota *et al*., 1992; Muzac-Tucker *et al*., 1993). Muzac-Tucker *et al*. (1993) reported of a range of 0.061-10.50 g/100g dry weight phenolics in *D. alata* varieties while 0.023-0.034 g/100g dry weight was obtained for *D. rotundata* varieties. These values correlated well with the rate at which browning occurred in the varieties studied.

Table 4.11: Sensory quality attributes of boiled yam from 18 varieties of *Dioscorea alata*[†] from Ghana as compared with the reference sample, *D. rotundata*

Serial no	Variety	Colour	Wetness	Taste	Hardness	Mealiness
1	Apu	2.88	4.75	2.25	2.88	2.38
2	TDa 291	4.38	4.38	3.25	3.75	4.13
3	TDa 297	1.38	4.63	1.50	2.25	2.25
4	TDa 98/01168	4.75	5.00	3.38	4.63	3.88
5	TDa 98/01174	4.63	5.25	2.63	4.13	3.75
6	TDa 98/01176	4.70	4.90	5.10	5.10	4.60
7	TDa 99/00022	4.30	4.30	5.60	4.10	2.90
8	TDa 99/00048	1.70	4.10	3.50	3.40	3.10
9	TDa 98/00049	3.10	4.40	3.70	3.50	2.60
10	TDa 99/00199	1.60	3.70	2.70	3.10	3.40
11	TDa 99/00214	1.80	4.40	2.90	4.00	3.60
12	TDa 99/00395	1.10	3.50	3.00	2.70	2.20
13	TDa 99/00446	4.90	4.80	3.60	5.10	5.80
14	TDa 99/00528	4.40	4.50	3.50	4.20	3.80
15	TDa 99/01169	4.10	4.40	4.20	3.30	3.30
16	KM 1999	6.10	5.10	5.10	3.90	4.60
17	WM 2001	5.40	4.60	4.20	5.10	4.80
18	WM 2003	5.70	5.10	5.40	3.80	3.20
	Min	1.10	3.50	1.50	2.25	2.20
	Max	6.10	5.25	5.60	5.10	5.80
	Mean	3.72	4.55	3.64	3.83	3.57
	SE	0.38	0.11	0.26	0.19	0.23
	LSD	1.3	1.6	1.4	1.45	1.69

[†] Values are means of 20 observations
Scale of 1 to 9, where 1= extremely inferior, 2= much inferior, 3= moderately inferior, 4 = slightly inferior, 5= no difference, 6= slightly better, 7=moderately better, 8=much better, 9= extremely better compared to boiled yam from *Pona* (*D. rotundata*)
Boiled yam from *Pona* was assumed to have a value of 5.0

Boiled yam from TDa 98-159 was the best-rated among the test varieties while boiled yam from TDa 99/00240 was the poorest compared with the reference variety in terms of all the quality attributes (Table 4.10). From the Ghana varieties, TDa 98/01176, TDa 99.00446, KM 1999, WM 2001 and WM 2003 compared quite well with the *Pona* reference. However, TDa 297 was the poorest in quality among the test varieties from Ghana. Contrary to this observation, the same variety (TDa 297) collected from IITA; Nigeria was among those whose boiled yam compared well with the reference, TDr 608. This observation could be attributed to variety by environmental effect. Dixon *et al.*

(1991) reported that a variety may perform differently at a different location as a result of differences in soil composition, climatic conditions and edaphic factors.

4.2.3 Amala

Amala is a traditional thick paste (made from yam flour) consumed in West Africa (Nigeria, Benin and Togo) (Akissoe *et al*. 2006). *Amala*, according to Akissoe *et al*. (2001) and Hounhouigan *et al*. (2003) should be elastic, non sticky, soft, smooth and firm. In a preliminary discussion with panellists in this study, good quality *amala* should in addition be light-to-dark brown in colour. Table 4.12 shows the mean sensory attributes of *amala* prepared from the test varieties. With the exception of colour which was significantly different ($P<0.05$) among the varieties, the samples of *amala* from the different varieties were about the same in terms of smoothness, elasticity, stickiness and hardness.

Generally, *amala* prepared from the test varieties were comparable to the reference variety (Table 4.12). They were either better or not different; TDa 93-36 was the best rated variety in terms of all the quality attributes evaluated. The colour of *amala* in particular from the *D. alata* varieties was rated better than that from the reference sample, TDr 608. It was observed during the preparation that *amala* from test varieties were browner than that from the reference sample, which again could be due to a higher content of phenolic compounds in the test varieties as reported by Asemota *et al*. (1992) and Muzac-Tucker *et al*. (1993). The presence of protein and sugar, which were comparatively higher in *D. alata* varieties, could also be responsible for the observed brown colour of *amala*. Amino acids and proteins when heated can react nonenzymatically with sugars forming brown-coloured compounds commonly called Maillard reaction products (Maillard, 1912 in Farombi *et al*., 2000). These reactions are reported to be responsible for the brown colour associated with browned yam flour products (Farombi *et al*., 2000).

Table 12: Sensory quality attributes of *amala* from 20 varieties of *Dioscorea alata*† as compared with a variety of *D. rotundata*

Serial no	Variety	Colour	Smoothness	Consistency	Elasticity	Stickiness	Hardness
1	TDa 00/00103	5.4	5.1	5.0	4.8	4.4	5.0
2	TDa 00/00364	4.8	5.3	5.3	5.3	4.2	5.0
3	TDa 01/00002	6.5	5.1	4.8	4.7	4.7	5.5
4	TDa 01/00024	6.0	5.3	4.8	4.5	4.3	5.5
5	TDa 01/00041	6.5	4.8	5.1	5.2	4.6	5.6
6	TDa 01/00081	6.9	5.3	5.4	5.4	4.5	5.0
7	TDa 85/00250	6.1	5.2	4.8	4.1	4.2	5.3
8	TDa 92-2	6.3	4.9	5.0	4.6	4.5	4.7
9	TDa 95/00328	5.6	4.9	4.4	4.4	3.8	4.3
10	TDa 95-310	6.5	5.0	5.1	4.8	4.4	4.6
11	TDa 98/01174	6.4	5.1	4.9	5.3	4.6	5.2
12	TDa 98/01176	5.6	5.2	4.9	5.3	4.2	5.2
13	TDa 98/01183	6.1	5.2	4.7	4.9	4.4	5.3
14	TDa 98-159	5.5	4.8	4.9	5.1	4.5	5.0
15	TDa 99/00332	5.5	4.9	4.7	4.7	4.4	5.0
16	TDa 99/00395	5.6	5.6	5.1	5.0	4.4	5.2
17	TDa 99/0240	5.1	5.0	4.6	5.0	4.1	5.0
18	TDa 291	6.3	5.5	5.0	4.9	4.7	4.9
19	TDa 297	5.9	5.2	5.0	4.9	4.6	5.0
20	TDa 93-36	6.6	5.9	5.7	5.7	5.1	5.4
	Min	4.8	4.8	4.4	4.1	3.8	4.3
	Max	6.9	5.9	5.7	5.7	5.1	5.6
	Mean	5.9	5.1	4.9	4.9	4.4	5.1
	SE	0.1	0.1	0.1	0.1	0.1	0.1
	LSD	1.01	0.75	0.82	0.88	0.78	0.98

† Values are means of 20 observations

Scale of 1 to 9, where 1= extremely inferior, 2= much inferior, 3= moderately inferior, 4 = slightly inferior, 5= no difference, 6= slightly better, 7=moderately better, 8=much better, 9= extremely better compared to pounded yam from TDr 608 (*D. rotundata*)
Pounded yam from TDr 608 was assumed to have a value of 5.0

It must be noted that although browning in boiled yam caused some of the *D. alata* varieties to receive low scores in appearance, the same browning characteristic of *D.*

alata in *amala* product made them have better scores than the reference. This implies that different yam varieties with diverse quality characteristics will be good for different end products.. *D. alata* is reported to exhibit high variation among culinary and palatability properties, some varieties being suitable for certain types of preparations, while others are not (Lebot *et al.*, 2005). Browning of cut yam tubers affects the quality and appearance of yam (Ikediobi, 1983) and can therefore hamper the development of products from yam. There is the need therefore to select specific varieties for foods in which browning is undesirable like pounded yam and boiled while varieties that are prone to brown could be used for the preparation of *amala*, a brown paste from yam flour

The greater suitability of test varieties for *amala* (that is made from yam flour) could be attributed to the parboiling of the tubers before being dried. Parboiling has been linked to increased pasting characteristics of yam flour due to annealing and cross-linking (retrogradation and recrystalization) between hydroxyl groups of the different molecules within the starch granules (Afoakwa and Sefa-Dedeh, 2002). From personal discussion with *amala* consumers, *D. alata* flour is widely used for *amala*. However it is sometimes mixed with cassava flour to increase the product's viscosity to the desired level.

The varieties TDa 98-159, TDa 291, TDa 297 and 93 -36 performed comparably better among the test varieties in all the three products. These varieties gave comparably smooth and consistent pounded yam as the reference. In terms of boiled yam quality, they all had comparably good scores for colour, taste and hardness. However, with the exception of TDa 98-159, their scores for mealiness were poor/low. *Amala* from these varieties had slightly better colour to the reference, they were also rated to be smooth, consistent and elastic as the reference variety.

Multiple paired comparison sensory analysis has shown that samples of *amala* from *D. alata* varieties are either better or not different from that of the reference variety of *D. rotundata*. About 30% of the test varieties when boiled had sensory attributes that were comparable to the reference; however, colour and mealiness were comparably poor in all the varieties with the exception of TDa 98-159. With a few exceptions, pounded yam of the test varieties was relatively poor in terms of colour and texture. To increase production, market value, and diversify the food uses of water yam, specific varieties of the species should be promoted for products such as *amala*, where they have a comparative advantage over *D. rotundata*. Also promising varieties for boiled yam and pounded yam should be genetically improved to meet consumers' preferred quality while research is increased to develop novel products to meet the needs of diverse consumers.

4.3 Relationships between sensory and chemical, physicochemical and pasting characteristics of *D. alata*

Tuber flour and starches are used in the food, feed, and other industries. Organoleptic/sensory characteristics of the food products in which they are incorporated are influenced by chemical, physicochemical, and functional properties of the tubers. Results from Pearson correlation analyses between products from *D. alata* varieties and their chemical, pasting, and physicochemical properties are shown in Tables 4.13 to 4.21. From the analyses, significant correlations ($P<0.05$) were found among sensory quality of the food products and the chemical/pasting/physicochemical characteristics.

4.3.1 Correlation between pounded yam and chemical characteristics

Strong correlations were found between sensory quality attributes of pounded yam and the chemical characteristics of the yam tubers. Among the chemical properties, moisture/dry matter, sugar, and starch were more related to the quality parameters of pounded yam. There were positive correlations between consistency and dry matter (0.53), consistency and sugar (0.69); but a negative correlation between consistency and moisture content (r=-0.53). While a positive correlation was found between hardness and dry matter (0.59), a negative one was observed between hardness and moisture content (-0.59) as well as hardness and sugar content (-0.52). Significant correlations existed among all the sensory parameters. Among the chemical properties, dry matter was found to correlate positively with starch (0.46) content but its relationship with sugar content (-0.60) was negative. The results imply that the higher the dry matter content, the higher the starch and lower the sugar contents. The relatively higher moisture and sugar contents but lower dry matter and starch contents of *D. alata* varieties (Table 4.13) might have influenced their performance for pounded yam as observed in Table 4.9.

4.3.2 Correlation between pounded yam and pasting characteristics

All the sensory quality parameters of pounded yam related with one another and positively with peak, trough, final, and setback viscosities. An inverse but weak correlation was also observed between the smoothness of pounded yam and pasting temperature (-0.44). The implication is that the lower the pasting temperature of the tuber and the higher the peak, trough, final and setback viscosities, the better the quality of pounded yam. The lower pasting properties and higher pasting temperatures observed for *D. alata* as compared to the reference *D. rotundata* variety (Table 4.14) might have contributed to the relatively poor performance of most of the former species for pounded yam (Table 4.9).

Table 4.13: Correlation co-efficients (r) between eating quality of pounded yam and chemical properties of *Dioscorea alata* flour†

Serial no.	**Eating quality**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	Colour	1											
2	Smoothness	0.63**	1										
3	Consistency	0.58*	0.72**	1									
4	Elasticity	0.56*	0.48*	0.81**	1								
5	Stickiness	0.48*	0.59*	0.73**	0.79**	1							
6	Hardness	0.56*	0.64**	0.83**	0.82**	0.7	1						
	Chemical												
7	Moisture	-0.36	-0.34	-0.53*	-0.43	-0.41	-0.59*	1					
8	Dry matter	0.36	0.34	0.53*	0.43	0.41	0.59*	-1	1				
9	Protein	0.01	-0.12	-0.2	0.12	-0.07	-0.12	0.51*	-0.51*	1			
10	Ash	0.03	0.07	0.01	0.14	0.05	-0.15	0.25	-0.25	0.65**	1		
11	Sugar	-0.47*	-0.47*	-0.69**	-0.44	-0.36	-0.52*	0.60*	-0.60*	0.37	-0.12	1	
12	Starch	0.39	0.26	0.11	0.2	0.3	0.19	-0.46*	0.46*	-0.02	0.16	-0.34	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of pounded yam and 7-12 represent chemical properties of *D. alata* flour

Various studies have shown that the eating qualities of yam products are related to the pasting viscosities as observed in this study (Oduro *et al.*, 2000; Adebowale *et al.*, 2005; Otegbayo *et al.*, 2006). Pasting properties could, therefore, be used as a convenient method for assessing the suitability of *D. alata* tubers for pounded yam in quality improvement breeding programmes.

Table 4.14: Correlation co-efficients (r) between eating quality of pounded yam and pasting properties of *Dioscorea alata* flour†

Serial no.	Eating quality	1	2	3	4	5	6	7	8	9	10	11	12	13
1	Colour	1												
2	Smoothness	0.63**	1											
3	Consistency	0.58*	0.72**	1										
4	Elasticity	0.56*	0.48*	0.81**	1									
5	Stickiness	0.48*	0.59*	0.73**	0.79**	1								
6	Hardness	0.56*	0.64**	0.83**	0.82**	0.70**	1							
	Pasting													
7	Peak	0.54*	0.60*	0.60*	0.55*	0.51*	0.51*	1						
8	Trough	0.58*	0.67**	0.62**	0.52*	0.51*	0.52*	0.98**	1					
9	Break down	0.16	0.07	0.26	0.41	0.33	0.25	0.66**	0.49*	1				
10	Final visc.	0.57*	0.66**	0.64**	0.54*	0.52*	0.51*	0.98**	0.99**	0.53*	1			
11	Setback	0.38	0.45*	0.55*	0.49*	0.47*	0.35	0.76**	0.72**	0.59*	0.81**	1		
12	Peak time	-0.21	-0.1	-0.17	-0.27	-0.2	-0.25	-0.63**	-0.49*	-0.89**	-0.49*	-0.39	1	
13	Pasting temp.	-0.31	-0.44	-0.16	-0.01	0.03	-0.2	-0.33	-0.34	-0.15	-0.32	-0.13	0.29	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of pounded yam and 7-13 represent pasting properties of *D. alata* flour

4.3.3 Correlation between pounded yam and physicochemical characteristics

The correlation between the physicochemical properties and sensory quality of pounded yam showed that swelling power and water binding capacity were more related to the eating quality of pounded yam (Table 4.15) than the other parameters. Positive correlations were observed between swelling power and the following quality attributes of pounded yam: consistency (0.60), elasticity (0.45) and hardness (0.55). There was negative correlation between WBC and consistency (-0.47) as well as between WBC and hardness (-0.49, $P<0.05$).

Table 4.15: Correlation co-efficients (r) between eating quality of pounded yam and physicochemical properties of *Dioscorea alata* flour†

Serial no.	Eating quality	1	2	3	4	5	6	7	8	9	10	11
1	Colour	1										
2	Smoothness	0.63**	1									
3	Consistency	0.58*	0.72**	1								
4	Elasticity	0.56*	0.48*	0.81**	1							
5	Stickiness	0.48*	0.59*	0.73**	0.79**	1						
6	Hardness	0.56*	0.64**	0.83**	0.82**	0.70**	1					
	Physicochemical											
7	Amylose	-0.44	-0.12	0.03	0.15	0.02	0.01	1				
8	Amylopectin	0.44	0.12	-0.03	-0.15	-0.02	-0.01	-1	1			
9	Swelling P.	0.4	0.25	0.60*	0.45*	0.31	0.55*	-0.23	0.23	1		
10	Solubility	-0.16	-0.25	-0.27	0.17	0.05	-0.17	0.05	-0.05	-0.21	1	
11	WBC	-0.79	-0.4	-0.47*	-0.41	-0.2	-0.49*	0.44	-0.44	-0.66**	0.22	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of pounded yam and 7-11 represent physicochemical properties of *D. alata* flour

4.3.4 Correlation between boiled yam and chemical characteristics

The sensory quality of boiled yam and the chemical properties of *D. alata* were correlated (Table 4.16). Significant correlations were found between wetness and the following: moisture (-0.73), dry matter (0.73), and sugar (-0.44, P<0.05) contents. Positive correlations were found between taste and dry matter (0.48) as well as between taste and ash (0.45) contents. While mealiness was positively correlated with dry matter (0.66) and starch (0.51) contents, an inverse correlation was obtained between mealiness and moisture content (-0.66). The results imply that the higher the dry matter and starch content of *D. alata* tuber, the better the taste and mealiness of its boiled yam. Taste and mealiness are reported to be key quality parameters of boiled yam (Otegbayo *et al.*, 2001; Egesi *et al.*, 2003). Lebot *et al.* (2005) also reported that *D. alata* varieties of good eating quality were characterised by high dry matter and starch contents. The comparatively lower dry matter and starch contents observed in most of the *D. alata* varieties partially explains their poor performance when boiled especially in terms of mealiness (Table 4.11)

Table 16: Correlation co-efficients (r) between eating quality of boiled yam and chemical properties of *Dioscorea alata* flour†

Serial no.	Eating quality	1	2	3	4	5	6	7	8	9	10	11
1	Colour	1										
2	Wetness	0.68**	1									
3	Taste	0.74**	0.41	1								
4	Softness	0.52	0.3	0.44	1							
5	Mealiness	0.54*	0.79**	0.47*	0.31	1						
	Chemical											
6	Moisture	-0.48*	-0.73**	-0.48*	-0.3	-0.66**	1					
7	Dry matter	0.48*	0.73**	0.48*	0.3	0.66**	-1	1				
8	Protein	-0.11	-0.3	-0.38	-0.08	-0.22	0.51*	-0.51*	1			
9	Ash	0.04	-0.02	-0.45*	0	-0.06	0.25	-0.25	0.65**	1		
10	Sugar	-0.44	-0.44	-0.26	-0.36	-0.38	0.60*	-0.60*	0.37	-0.12	1	
11	Starch	0.47*	0.43	0.42	0.12	0.51	-0.46*	0.46*	-0.02	0.16	-0.34	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-5 represent eating quality of boiled yam and 6-11 represent chemical properties of *D. alata* flour

4.3.5 Correlation between boiled yam and pasting characteristics

Positive correlation was found between wetness of boiled yam and final viscosity (0.51) as well as between wetness and setback viscosity (0.66) (Table 4.17). There was also correlation between taste and peak viscosity (0.49) and also between taste and final viscosity (0.48). A weak but positive correlation was observed between mealiness and setback viscosity (0.45). The characteristic pasting properties of *D. alata* may have influenced the quality of their boiled yam.

4.3.6 Correlation between boiled yam and physicochemical characteristics

The relationship between the eating quality of boiled yam and physicochemical characteristics is presented in Table 4.18. Amylose, solubility, and water binding capacity which were found to be higher in *D. alata* varieties (Table 4.2) all correlated negatively with the eating quality attributes of boiled yam. Amylose content of *D. alata* flour correlated inversely with the taste of boiled yam (-0.54) while solubility and softness were also weakly and inversely correlated (-0.45, P<0.05). Swelling power correlated positively with wetness (0.62) and taste (0.60) but water binding capacity was negatively correlated with wetness (-0.65), taste (-0.60) and mealiness (-0.48). However, according to Lebot *et al*. (2005), good quality *D. alata* was characterised by high amylose content.

Table 4.17: Correlation co-efficients (r) between eating quality of boiled yam and pasting properties of *Dioscorea alata* flour†

No	**Eating quality**	1	2	3	4	5	6	7	8	9	10	11	12
1	Color	1											
2	Wetness	0.68**	1										
3	Taste	0.74**	0.41	1									
4	Hardness	0.52*	0.3	0.44	1								
5	Mealiness	0.54*	0.79**	0.47*	0.31	1							
	Pasting												
6	Peak viscosity	0.54*	0.44	0.49*	0.25	0.38	1						
7	Trough	0.56*	0.44	0.50*	0.26	0.39	0.98**	1					
8	Break down	0.21	0.25	0.22	0.12	0.18	0.66**	0.49*	1				
9	Final viscosity	0.56*	0.51*	0.48*	0.24	0.42	0.98**	0.99**	0.53*	1			
10	Setback	0.44	0.66**	0.27	0.11	0.45*	0.76**	0.72**	0.59*	0.81**	1		
11	Peak time	-0.32	-0.29	-0.43	-0.18	-0.32	-0.63**	-0.49*	-0.89**	-0.49*	-0.39	1	
12	Pasting temp.	-0.14	-0.02	-0.3	-0.01	-0.23	-0.33	-0.34	-0.15	-0.32	-0.13	0.29	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-5 represent eating quality of boiled yam and 6-12 represent pasting properties of *D. lata* flour

Table 4.18: Correlation co-efficients (r) between eating quality of boiled yam and physicochemical properties of *Dioscorea alata* flour†

Serial no.	Eating quality	1	2	3	4	5	6	7	8	9	10
1	colour	1									
2	wetness	0.68**	1								
3	Taste	0.74**	0.41	1							
4	Softness	0.52*	0.3	0.44	1						
5	Mealiness	0.54*	0.79**	0.47*	0.31	1					
	Physicochemical										
6	Amylose	-0.44	-0.29	-0.54*	-0.19	-0.17	1				
7	Amylopectin	0.44	0.29	0.54*	0.19	0.17	-1	1			
8	Swelling P.	0.54*	0.62**	0.60*	0.24	0.43	-0.23	0.23	1		
9	Solubility	-0.2	-0.01	-0.32	-0.45*	-0.21	0.05	-0.05	-0.21	1	
10	WBC	-0.82**	-0.65**	-0.62**	-0.33	-0.48*	0.44	-0.44	-0.66**	0.22	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-5 represent eating quality of boiled yam and 6-11 represent physicochemical properties of *D. alata* flour

4.3.7 Correlation between amala and chemical characteristics

Sugar and starch were the main chemical properties that were significantly ($P<0.05$) correlated with the eating quality of *amala* (Table 4.19). There were negative correlations between sugar content and the following quality attributes of *amala*: consistency (-0.53), elasticity (-0.52), stickiness (-0.61) and hardness (-0.48). Starch content on the other hand was observed to correlate positively with consistency (0.53) and stickiness (0.48). Colour, elasticity, stickiness, smoothness, and consistency are reported to be important quality parameters of *amala* (Akissoe *et al*., 2001; 2006).

Table 4.19: Correlation co-efficients (r) between eating quality of *amala* and chemical properties of *Dioscorea alata* flour†

No	Eating quality	1	2	3	4	5	6	7	8	9	10	11	12
1	colour	1											
2	smoothness	0.18	1										
3	consistency	0.36	0.60*	1									
4	elasticity	0.11	0.38	0.69**	1								
5	stickiness	0.61**	0.44	0.66**	0.50*	1							
6	hardness	0.24	0.31	0.24	0.25	0.46*	1						
	Chemical												
7	Moisture	-0.15	-0.26	-0.3	-0.37	-0.42	-0.18	1					
8	Dry matter	0.15	0.26	0.3	0.37	0.42	0.18	-1	1				
9	Protein	-0.14	-0.2	-0.31	-0.33	-0.27	0.09	0.51*	-0.51*	1			
10	Ash	-0.11	-0.14	0.03	-0.08	-0.08	0.09	0.25	-0.25	0.65**	1		
11	Sugar	-0.14	-0.15	-0.53*	-0.52*	-0.61**	-0.48*	0.60*	-0.60*	0.37	-0.12	1	
12	Starch	0.24	0.4	0.53*	0.36	0.48*	0.3	-0.46*	0.46*	-0.02	0.16	-0.34	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of *amala* and 7-12 represent chemical properties of *D. alata* flour

4.3.8 Correlation between amala and pasting characteristics

Only elasticity and stickiness of *amala* had a significant relationship with pasting properties. Elasticity was significantly correlated with the following pasting properties; peak viscosity (0.50), trough (0.56) and final viscosity (0.56) (Table 4.20). Stickiness was also correlated with the same pasting parameters but at different correlation coefficients. Starch, swelling power and viscosity are observed to play determinant roles in the firmness of '*to*', a maize paste like *amala* (Akissoe *et al.*, 2001; Fliedel, 1994).

Table 4.20: Correlation co-efficients (r) between eating quality of *amala* and pasting properties of *Dioscorea alata* flour†

	Eating quality	1	2	3	4	5	6	7	8	9	10	11	12	13
1	colour	1												
2	smoothness	0.18	1											
3	consistency	0.36	0.60*	1										
4	elasticity	0.11	0.38	0.69**	1									
5	stickiness	0.61**	0.44	0.66**	0.50*	1								
6	hardness	0.24	0.31	0.24	0.25	0.46*	1							
	Pasting													
7	Peak viscosity	-0.02	-0.09	0.2	0.50*	0.46*	-0.01	1						
8	Trough	0.05	-0.02	0.3	0.56*	0.52*	0.01	0.98**	1					
9	Break down	-0.25	-0.27	-0.24	0.07	0.07	-0.07	0.66**	0.49*	1				
10	Final viscosity	0.02	-0.03	0.29	0.56*	0.50*	-0.01	0.98**	0.99**	0.53*	1			
11	Setback	-0.11	-0.05	0.2	0.44	0.3	-0.09	0.76*	0.72**	0.59*	0.81**	1		
12	Peak time	0.08	0.4	0.19	-0.1	-0.07	0.07	-0.63**	-0.49*	-0.89**	-0.49*	-0.39	1	
13	Pasting temp.	-0.2	0.04	-0.12	-0.25	-0.13	0.01	-0.33	-0.34	-0.15	-0.32	-0.13	0.29	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of *amala* and 7-13 represent pasting properties of *D. alata* flour

4.3.9 Correlation between amala and physicochemical characteristics

The Pearson correlation between quality of *amala* and physicochemical properties is presented in Table 4.21. Significant correlations were found between solubility and consistency (0.58) and also between solubility and stickiness (0.66) of *amala*. Likewise water binding capacity and stickiness were also correlated (0.61). The correlations between the quality of *amala* and physicochemical parameters were all negative. Even though *amala* from *D. alata* varieties compared very well with *amala* from the reference variety, this correlation implies that the higher the values of solubility and water binding capacity, the lower the quality of *amala*. The results further confirm that the better suitability of test varieties for *amala* (Table 4.12) could be attributed more to the parboiling of the tubers before being dried. Parboiling has been linked to increased pasting characteristics of yam flour due to annealing and cross-linking between hydroxyl groups of the different molecules within the starch granules (Afoakwa and Sefa-Dedeh, 2002). Cassava flour is sometimes added to yam flour to give the desired viscosity (Personal communication).

4.21: Correlation co-efficients (r) between eating quality of *amala* and physicochemical properties of *Dioscorea alata* flour†

Serial no.	Eating quality	1	2	3	4	5	6	7	8	9	10	11
1	Colour	1										
2	Smoothness	0.18	1									
3	Consistency	0.36	0.60*	1								
4	Elasticity	0.11	0.38	0.69**	1							
5	Stickiness	0.61**	0.44	0.66**	0.50*	1						
6	Hardness	0.24	0.31	0.24	0.25	0.46*	1					
	Physicochemical											
7	Amylose	-0.35	-0.16	-0.23	-0.09	-0.2	-0.09	1				
8	Amylopectin	0.35	0.16	0.23	0.09	0.2	0.09	-1	1			
9	Swelling P.	0.05	-0.11	0.21	0.34	0.41	0.2	-0.23	0.23	1		
10	Solubility	-0.57*	-0.38	-0.58*	-0.38	-0.66**	-0.38	0.05	-0.05	-0.21	1	
11	WBC	-0.44	-0.07	-0.34	-0.35	-0.61**	-0.43	0.44	-0.44	-0.66**	0.22	1

Level of significance: *at 0.05, **at 0.01. †Nos 1-6 represent eating quality of *amala* and 7-11 represent physicochemical properties of *D. alata* flour

Significant correlations were found among the organoleptic properties of the products and chemical (Dry matter, sugar and starch), physicochemical (amylose, swelling power and water binding capacity) and pasting properties (peak viscosity, trough, breakdown, final viscosity, and pasting temperature) of *D. alata* tubers. The lower starch content, swelling power and pasting viscosities of test varieties as discussed in section 4.1 might have in no doubt influenced the quality of their pounded yam while the process of parboiling explains the more suitability of test varieties for *amala*. The information obtained in this section may be of use to breeders who wish to genetically improve *D. alata* food quality for diverse uses.

4.5 Microstructural studies on yam tubers

The current section looked at the microstructure (cell structure, starch granule morphology and the influence of cooking on them) and its implication for food uses. This was done on tubers from 12 selected *D. alata* varieties and the reference TDr 608.

Photographs of native starch granules from fresh yam tubers are presented in Figures 4.2-4.3 Granule sizes and shapes are also summarized in Table 4.22. It is assumed that starches with a range of granular structures behave uniquely, thus providing a range of functional attributes. Variable shapes and sizes were found even within a single variety; however, both the test varieties and the reference variety were not widely different. Starch granules were predominantly oval, round, elliptical or triangular with a few being irregular. Similar shapes of yam starch granules have been reported in the literature (Moorthy, 1994; 2002; Brunnschweiler *et al.*, 2004; Otegbayo, 2004). The pictures show size distribution with high proportion of large granules. A minimum of 10 randomly selected granules within a variety were used for average granule size determination and they ranged between 29.5 and 41.5 µm for *D. alata* varieties. An average value of 37.25 µm was obtained for *D. rotundat*a, the reference variety.

According to Moorthy (1994), starch granules of *D. esculenta* are very small (2-15 µm), and *D. alata* granules are very large (6-100 µm, average 35 µm). Brunnschweiler *et al*. (2004) observed starch granule sizes ranging between 19 and 52 µm for *D. alata* and from 19 to 50 µm for *D. cayenensis-rotundata* complex. Peroni *et al.* (2006) also reported an average granule size of 25.3 µm for *D. alata*.

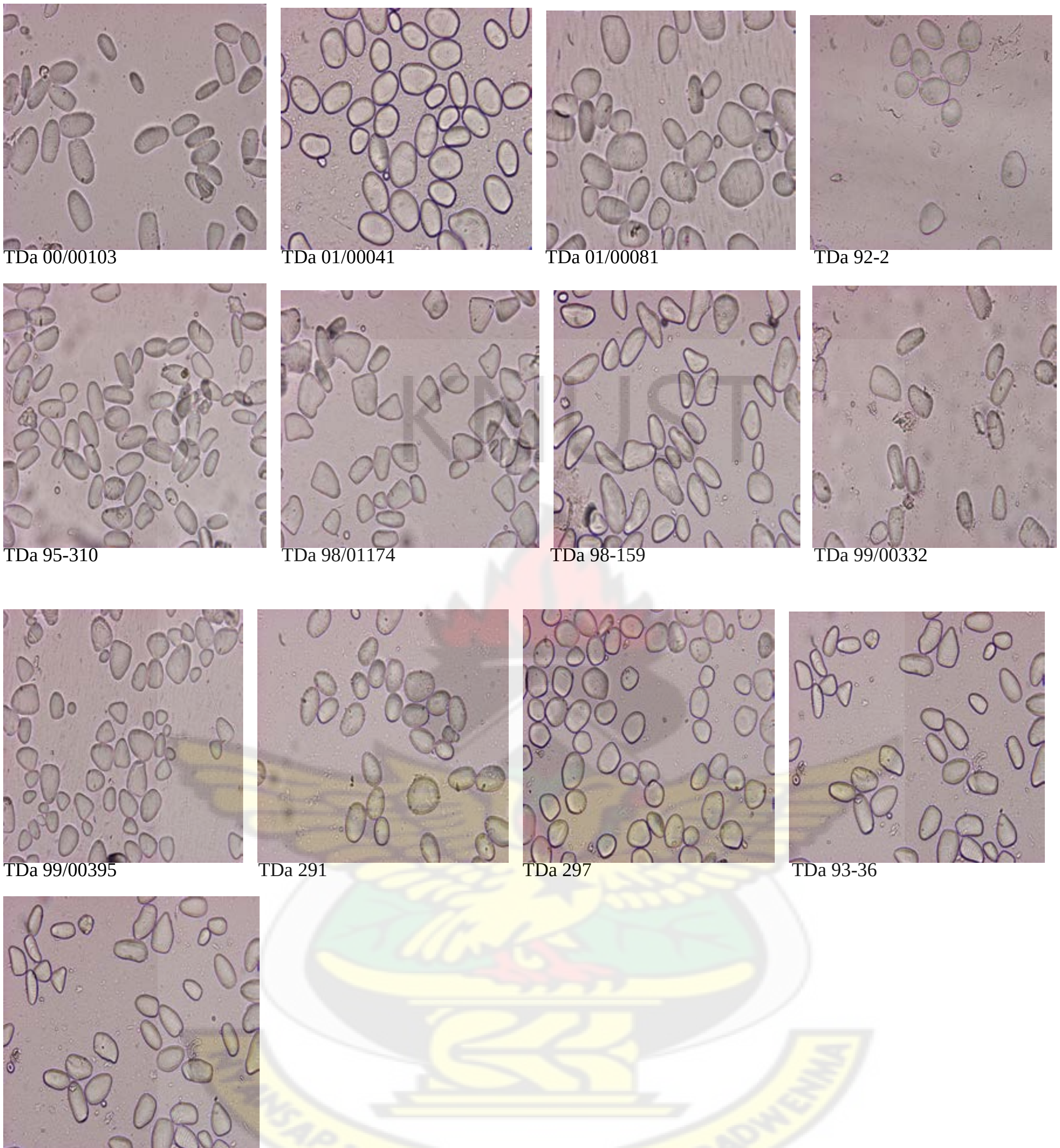


Figure 4.2: Light micrographs of yam starch granules (mgx40) showing the different shape and size proportions within and between test varieties and the reference variety

Table 4.22: Granule size and shape of yam starch

Serial no.	Species/variety	Average granule size (µm)	Granule shape
	D. alata		
1	TDa 00/00103	37.5	Elliptical with different sizes
2	TDa 01/00041	40.5	Oval and rounded
3	TDa 01/00081	41.5	Oval, elliptical more rounded
4	TDa 92-2	30.5	Oval and rounded
5	TDa 95-310	35	Elliptical, few rounded and irregular
6	TDa 98/01174	34.5	Triangular with one truncated, trapezoidal, few cones
7	TDa 98-159	36.25	Elliptical, few rounded and cone and irregular
8	TDa 99/00332	37.25	Elliptical and cylindrical
9	TDa 99/00395	32.25	Oval, rounded, triangular, different sizes
10	TDa 291	39	Elliptical and rounded
11	TDa 297	37.75	Oval, elliptical, rounded
12	TDa 93-36	29.5	Rounded and oval
	Min	29.5	
	Max	41.5	
	Mean	35.71	
	SE	1.08	
	LSD	1.77	
	D. rotundata		
13	TDr 608	37.25	Elliptical, coned, oval

The granule size and shape affect the functional properties of starches and may influence their industrial uses. Granule size is known to contribute to swelling power, gelatinization temperature and viscosity (Singh *et al.*, 2003). Large starch granules are reported to increase swelling (Fortuna *et al.*, 2000). According to Lindeboom *et al.* (2004), starch composition, gelatinization and pasting properties, enzyme susceptibility, crystalline structure, swelling and solubility are all affected by granule size. Granule shape and size are also important characteristics for the starch extraction industry since they define mesh size for application and purification sieves (Leonel *et al.*, 2003).

Figure 4.2 and 4.3 show representative pictures of yam cell structures when two different methods were used. The former (Figure 4.2) reveals cell structure of fresh yam tissues using the slightly modified procedure of botanical microtechnique (Sass, 1958) and the latter (Figure 4.3) shows hand microtome sectioned raw yam tissues. In both figures, the tissues show numerous starch granules aggregated within individual cells with cell walls separating the neighbouring cells. Cells are polyhedral in shape with some being small and others large and elongated.

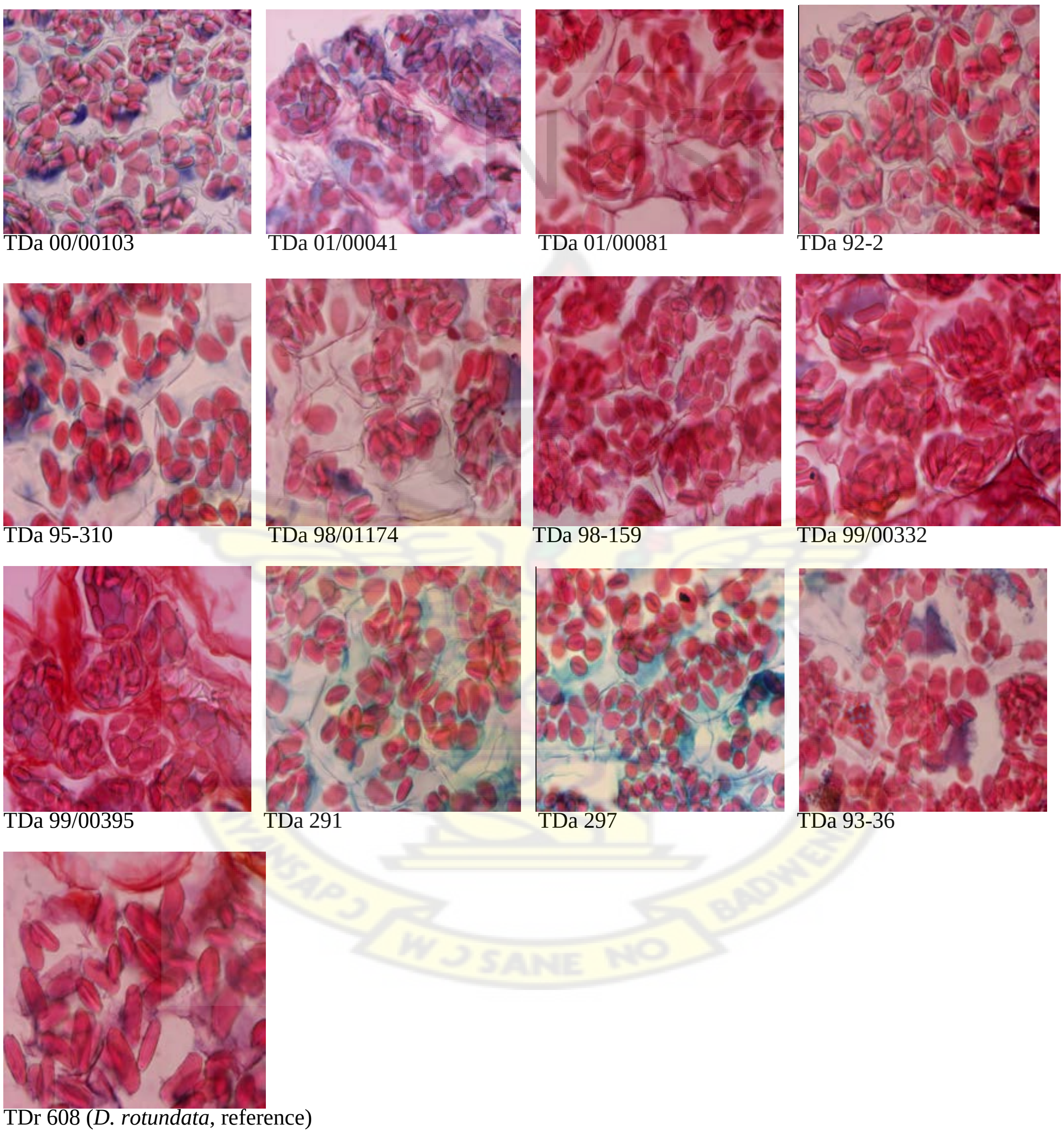
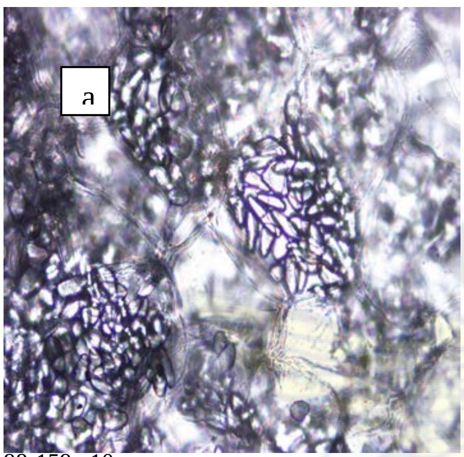
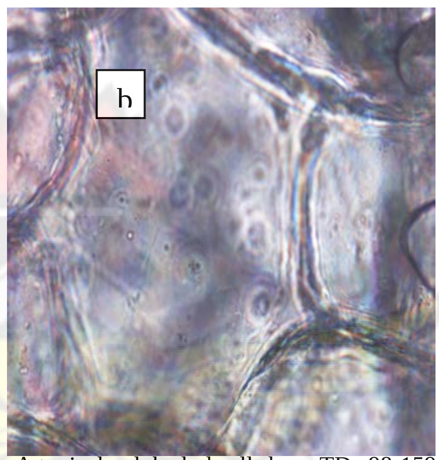


Figure 4.3: Light micrographs of raw yam tissue from test varieties and the reference TDr 608 showing aggregated starch granules within cells (mgx40)

Cell walls are not so obvious in figure 4.2 and 4.3 even though the aggregated and densely packed starch granules within cells are quite visible. The cell walls act as a boundary which separates adjacent cells (Figure 4.4b) and provides rigidity, strength and shape to the plant cell. The cell wall plays very significant role in that the non-starchy components they contain (cellulose, lignin, hemicellulose and pectin) are partly responsible for the texture and mechanical properties of mature tissues and hence the textural properties of the plant-based food (Brett and Waldron, 1996).

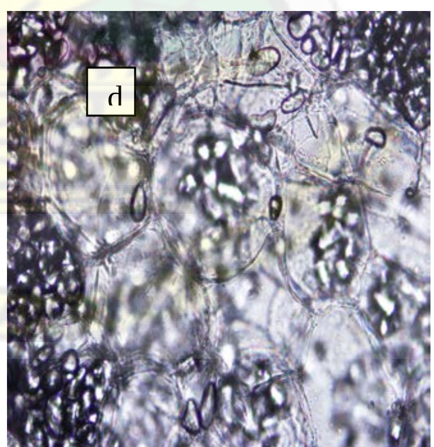


98-159 x10mg



A typical polyhedral cell shape TDa 98-159 x 100

TDa 00/00103 x10 mg



TDa 297 x10 mg

Figure 4.4: Light micrographs of hand microtome sectioned yam tissues showing cell shapes, walls separating neighbouring cells (b) and densely packed starch granules within cells (a, c and d)

Figure 4.5 shows the various changes of yam starch granules during gelatinization. As a result of heating in the presence of water, native starch granules swell reversibly at temperatures below their gelatinization temperature due to their stable semi-crystalline structure. The water absorption is usually less than 40%. When the temperature of the suspension of starch granules increases to the gelatinization temperature, they lose their birefringence and crystallinity, with concurrent swelling. This change is irreversible and called gelatinization. The total gelatinization usually occurs over a temperature range from 10 to 15 °C (Evans and Haisman 1982). The intact cell walls are broken to release individual granules when the tissue is heated beyond its gelatinization point.

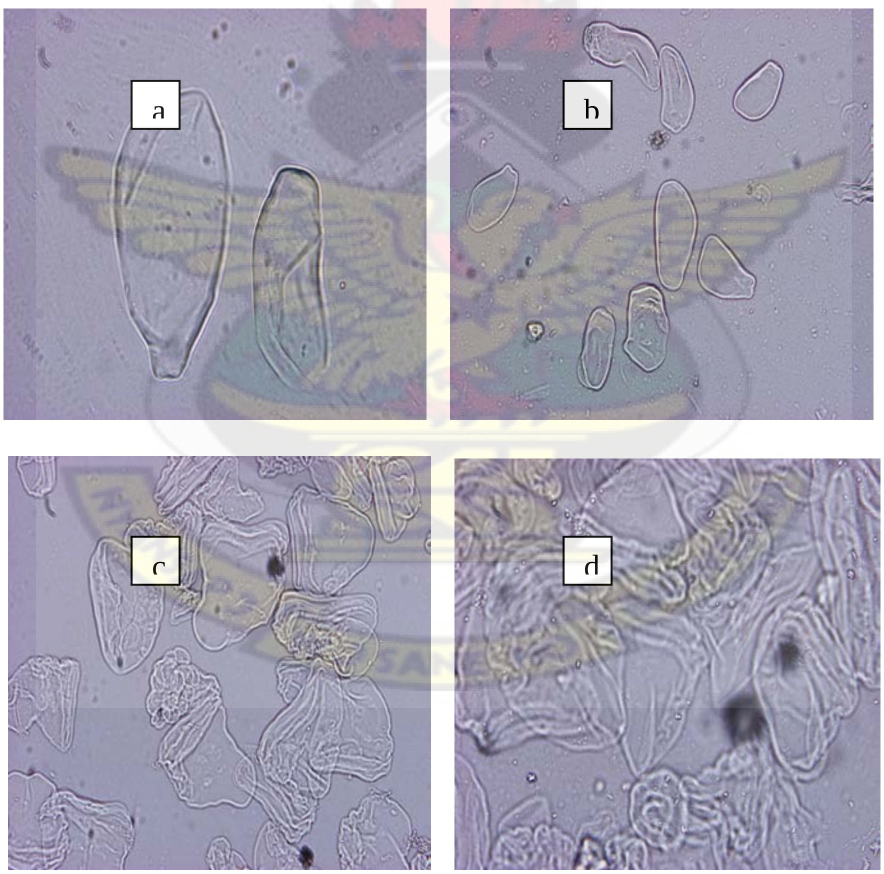


Figure 4.5 Light micrographs of starch granule elongation (a & b), rupture and release of amylose into solution (c & d) as a result of heating in the presence of water

The organized shapes of the starch granules became elongated at the onset of gelatinization (Figures 4.5a and 4.5b) followed by more swelling of starch granules. Finally there was a complete breakdown of the granules as a result of phase separation and the release of amylose into solution (Figures 4.5c and 4.5d).

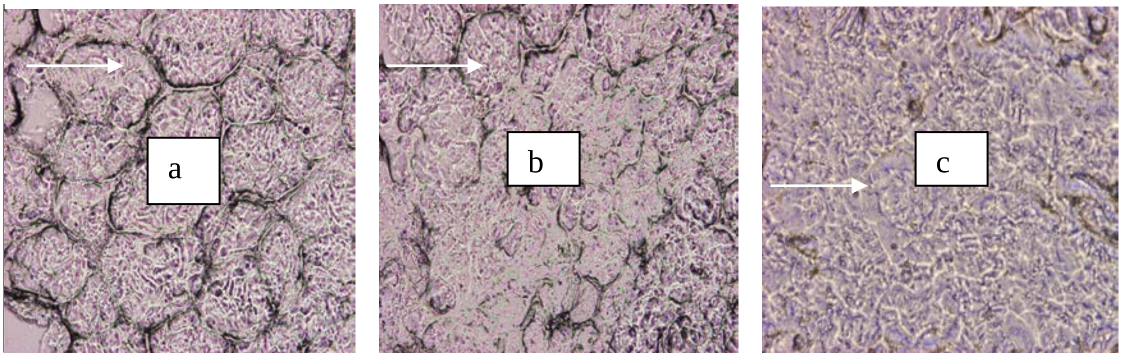
Granule elongation at the onset of gelatinization has been reported in yam and other root crops such as sweetpotato and Tania (Valetudie *et al.*, 1995). The same authors observed amylose leaching as filamentous structures by micropores and cracks as a result of granule rupture as observed in Figures 4.5c and 4.5d. The gelatinized and swollen starch granules together with leached out amylose, starch fragments and cell wall fragments are all together believed to influence the rheology and thus the texture of starch-based food products. The rheology of mashed potato is most probably determined by the extent of cell cohesiveness, cell rigidity, and the volume fraction of cells as dispersed phase as well as by the free starch solubulised in the intracellular, continuous phase (Lamberti, 2004). Lamberti (2004) reported that before granule disruption, some materials (mainly amylose) had already started to leach out from the granule.

4.5.1: Effect of cooking on *D. alata* and *D. rotundata* (Reference) tissue microstructure

Figure 4.6 and 4.7 show representative cells of cooked yam tissues from selected *D. alata* varieties and the reference, TDr 608. They show intact polyhedral cell structure (a), opened cell (b) as well as cell completely destroyed (c) as a result of cooking. Cooked tissues of both species showed general characteristic loss of structural integrity with cellular disorganisation (Figure 4.6). This observation is in agreement with the report of

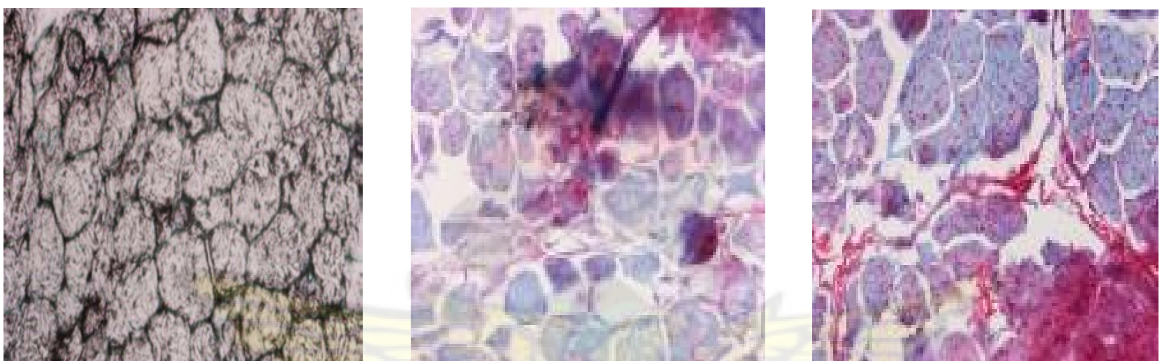
Edward (1999) and Casañas *et al*. (2002). They explained that when vegetable tissues are cooked in water a series of changes such as loss of turgescence with cellular disorganisation and progressive hydration of polysaccharides of the cell walls occur.

The degree of cell destruction as a result of cooking was higher in the reference variety as compared with the test varieties and also varied within the test varieties (Figures 4.6 to 4.7). According to Edward (1999), the degree of cell disruption depends on inherent rigidity of the cell wall, the strength of the middle lamella and the degree of support from within the cell due to structures such as starch granules and from other tissues such as fibres. The less cell disruptions in test varieties could therefore mean more rigidity in their cell walls. Again the comparatively higher TDF contents observed in the test varieties (*D. alata*) as compared to the reference variety (*D. rotundata*) partly explains the differences between the two species when cooked. According to Brett and Waldron (1996), the non-starchy components of yam (cellulose, lignin, hemicellulose and pectin which are together quantified as TDF in this study) are present in the cell walls and are partly responsible for the textural properties of the plant-based food. The cell walls are reported to provide rigidity, strength and shape to the plant cells (Degras, 1986).



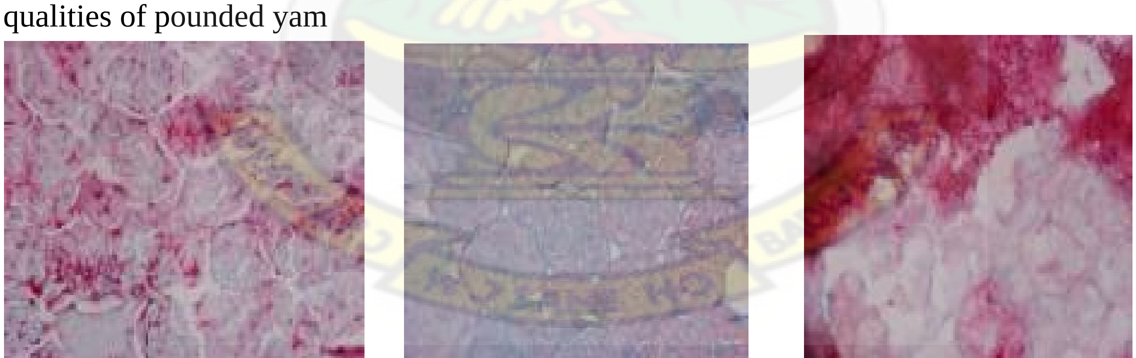
TDa 92-2 TDa 99/00332 TDr 608 (*D. rotundata*)

Figure 4.6: Microstructure of cooked yam tissues showing the impact of cooking on cells containing starch granules: intact cells (a), half ruptured cells (b) and completely ruptured cells (c)



TDa 95-310 TDa 98/01174 TDa 99/00395

Figure 4.7a Microstructure of cooked tissues from TDa 95-310, TDa 98/01174 and TDa 99/00395 showing more proportion of intact cells. These varieties had poor textural qualities of pounded yam



TDa 98-159 TDa 297 TDr 608

Figure 4.8 Microstructure of cooked tissues from TDa 98-159, TDa 297 and TDr 608 showing more/ complete cell disruption. These varieties had good textural qualities of pounded yam

TDa 98-159 and TDa 297 among the test varieties had higher degree of cell disruption (comparable to the reference variety) (Figure 4.8) within the same period of cooking.

These same varieties, had lower TDF (5.2% and 5.7% respectively) similar to the reference variety and were among the varieties that had comparably good scores for boiled yam and pounded yam (section 4.2). TDa 92-2, TDa 99/00332, TDa 95-310, TDa 98/01174 and TDa 99/00395 which seem to have retained more of their cellular integrity after cooking had their boiled yam and pounded yam products rated inferior in quality to the reference. Thus the *D. alata* varieties that gave comparable texture characteristics of boiled and pounded yam (TDa 98-159 and TDa 297) to the reference TDr 608 had similar characteristics of more disruption of cells after cooking. The partial retention of cellular integrity by these varieties, TDa 92-2, TDa 99/00332, TDa 95-310, TDa 98/01174 and TDa 99/00395, might have subsequently reduced exudation of starch contents and may be responsible for the poor textural qualities of their boiled yam and pounded yam. The observation could also be among the reasons why the cooked texture of most *D. alata* varieties are less suitable than *D. rotundata* species for the preferred yam products (sticky and doughy) in West Africa (Scott *et al*., 2000a).

4.6 Influence of tuber maturity and storage on *D. alata* inherent characteristics

4.6.1 Tuber maturity

Tables 4.23a-b show the influence of yam tuber maturity at harvest on chemical, physicochemical and pasting characteristics. The yam tubers were harvested every other month from 5 to 9 months after planting (MAP) and converted to flour for the determinations. Detailed results for the different varieties are also presented in appendix 4, 5 and 6.

Moisture content decreased gradually from 74.53% at 5 MAP to 71.76% at 9 MAP with a corresponding increase in dry matter content (25.47-28.24% respectively). Treche and Agbor-Egbe (1996) reported of maximum dry matter accumulation at 9 months post emergence in 2 different cultivars of yam. Similar increases in dry matter content have been reported in cassava and potato during growth to a maximum point followed by decreases afterwards (Ngedahayo and Dixon, 1998; Missah and Kissiedu, 1994).

According to Craufurd *et al*. (2001) on their review on the growth of yam, yam exhibits a sigmoidal growth pattern with initial slow growth during establishment, followed by a phase of rapid exponential growth as the canopy reaches maximum area. The growth rate finally declines as the canopy senesces. Okoli (1980) also indicated that dry matter accumulation in tubers of yam species peaked with subsequent reduction at complete senescence of the vines.

Table 4.23: Summary of the influence of *D. alata* tuber maturity on chemical, physicochemical and pasting properties

Table 4.23 *(a): Chemical and physicochemical properties (%)*

Months After Planting	**5MAP**	**7MAP**	**9MAP**	**LSD**	**SEM**
Moisture	74.53	72.20	71.76	1.05	0.36
Dry matter	25.47	27.80	28.24	1.05	0.36
Protein	6.79	6.39	6.85	0.09	0.03
Ash	2.34	3.21	2.63	0.41	0.14
Sugar	4.54	6.63	4.70	0.14	0.05
Starch	65.92	71.33	72.01	0.30	0.10
Amylose	25.26	26.26	29.72	0.63	0.22
Amylo-pectin	74.74	73.74	70.29	0.63	0.22
Swelling power	10.36	6.47	6.07	0.20	0.07
Solubility	13.65	9.60	9.45	1.21	0.41
WBC	171.10	186.08	155.44	7.48	2.56

Starch content increased rapidly from the 5 MAP (65.92%) to the 7 MAP (71.33%) and then slightly to the 9th MAP (72.01%) with exception of varieties TDa 01/00081 and TDa 297 (Appendix 4). Treche (1984) also reported a similar increase in starch content up to the eight month of yam vegetative growth but a decrease during storage. The increases in dry matter and starch contents with age of *D. alata* in this study could be due to large amounts of photosynthates transported from leaves and vines for storage before vine senesce (Okoli, 1980; Akinwande *et al*., 2007)

The 9th month after planting in which maximum dry matter and starch contents were recorded coincided with dryness of vines of the yam plants. This presupposes that the tubers might have been harvested at the peak period where there is accumulation of dry matter and starch, i.e., just before their decline as explained by Okoli (1980). Traditionally, farmers use the dryness of vines as a sign of tuber maturity and, according to Abass *et al*. (2003), higher tuber yields and better quality foods were obtained from tubers harvested when the vines were dried. Akinwande *et al*. (2007) also reported steady increases in the dry matter content of yam tubers from 3 months to 6 months after vine emergence. Harvesting yam tubers just as vines begin to dry up will be of more economic value for both farmers and processors because of the higher dry matter and starch contents as shown in this study.

Sugar and ash contents did not follow any specific trend for the 3 different harvesting periods; however, both were highest at 7 MAP (6.63% and 3.20% respectively) while protein was highest at the ninth month (6.85%). Treche and Agbor-Egbe (1996) reported slight but significant increase in crude protein during growth of 2 yam cultivars. Highest sugar content at the 7th month means that more photosynthetic materials were being produced, transported and deposited as reserve mainly in the form of starch.

Amylose content increased from 25.26-29.72% with increasing growth period but amylopectin (74.74-70.29%), swelling power (10.36-6.07%), and solubility (13.65-9.45%) decreased. The changes were significant ($P<0.05$) across the three sampling periods. The changes in amylose and amylopectin contents could be due to inter-conversion between the two starch molecules. Similar results were obtained for other crops, such as maize, rice, and potato, whose amylose storage reserve increased with the age of the crops (Shannon and Garwood, 1984; Sugimoto *et al*., 1995). Contrary to these results, Noda *et al*. (2004) observed a significant decrease in the amylose content of late harvested potatoes. Lower swelling power at the ninth month of harvest might have been influenced by the increase in amylose content. Amylose is believed to restrict swelling by reinforcing the internal network. Lower swelling was also associated with lower solubility. Solubility is the ease with which solubles, especially amylose, leach out into solution as the sample swells. The lower swelling values obtained could be due to a corresponding lower solubility observed. Water binding capacity however did not follow any specific trend even though all the varieties with the exception of TDa 00/00103, TDa 01/00041 and TDa 01/00081 decreased in values at the end of the 9th month after planting (Table 4.23a and Appendix 5)

Significant increases ($P< 0.05$) were obtained for peak viscosity (171.31-242.53 RVU), trough (153.21-222.17 RVU) and final viscosity (210.25-285.30 RVU) and setback (57.04-63.14 RVU) with the age of the tuber. Noda *et al*. (2004) indicated significant increases in peak viscosity and breakdown, and slightly but significant lower pasting temperature in late harvested potato than in early harvest. Similar increases in peak viscosity during growth of the potato tuber have also been observed (Madsen and Christensen, 1996 and Lui *et al*., 2003). The increases in pasting viscosities in this study could be due to the higher dry matter and starch contents obtained (Table 4.23a). Pasting time decreased significantly at the 9th MAP, however, pasting temperature did not follow any particular trend.

Table 4.23 ***(b): Pasting properties (RVU)***

Months after planting	Peak viscosity	Trough	Breakdown	Final viscosity	Setback	Pasting time (min)	Pasting temperature (^{o}C)
5MAP	171.31	153.21	18.20	210.25	57.04	6.47	86.69
7MAP	228.96	203.00	25.99	253.97	50.97	5.46	88.10
9MAP	242.53	222.17	20.37	285.30	63.14	5.69	86.73
LSD	4.94	5.37	2.85	5.13	2.85	0.09	0.53
SEM	1.69	1.84	0.98	1.76	0.98	0.03	0.18

4.6.2 Tuber storage

Represented in Table 4.24a-b are the summary results for all parameters determined during 5 months of *D. alata* tubers storage. Detailed results for the different varieties are also presented in appendix 7, 8 and 9.

Moisture content decreased significantly ($P<0.05$) with expected increase in dry matter content from harvest to the fifth month of storage. While moisture content decreased from 71.76% to 67.07%, dry matter content increased from 28.24 to 32.92%. The lowest moisture content was obtained at the fourth month of storage (66.63%) then increased slightly but insignificantly to 67.07% in the fifth month. Abass *et al*. (2003) reported a significant moisture loss (72.02-59.03%) during a 5-month storage period of yam tubers. Moisture loss during storage could be attributed to respiration and desiccation of tubers.

Stored yam tubers continue to respire in the dormant state at reduced levels after harvesting. Consequently, they undergo some physiological and biochemical changes such as loss of tuber weight, sprouting, breakdown of starch to sugars, changes in protein and other tuber constituents. These are reported to affect stored yam tuber quality positively or negatively (Mozie, 1988; Onayemi and Idowu, 1988; Treche and Agbor-Egbe, 1996; Girardin *et al*., 1998; Tschannen *et al.*, 2003).

Changes in protein content did not follow any particular trend. Treche and Agbor-Egbe (1996) also observed storage did not cause any significant changes in crude protein of varieties studied. However, a significant and gradual reduction in crude protein contents has been reported in stored yam tubers of *D. rotundata* and *D. cayenensis* (Onayemi and Idowu, 1988).

Table 4.24(a): Summary of the influence of storage of *D. alata* tubers on chemical, physicochemical and pasting properties

(a): Chemical and physicochemical properties (%)

Month of storage	0	1	2	3	4	5	LSD	SEM
Moisture	71.76	70.87	72.30	69.93	66.63	67.07	0.81	0.29
Dry matter	28.24	29.13	27.70	30.07	33.37	32.92	0.81	0.29
Protein	6.85	7.18	6.46	6.96	6.85	6.64	0.17	0.06
Ash	2.63	2.87	2.90	3.01	2.80	3.32	0.05	0.02
Sugar	4.70	8.29	6.21	4.67	5.77	6.83	0.26	0.09
Starch	72.01	68.11	70.77	75.04	63.16	66.55	1.11	0.39
Amylose	29.72	25.26	26.07	25.38	24.06	24.15	0.67	0.24
Amylopectin	70.29	74.74	73.93	74.62	75.94	75.85	0.67	0.24
Swelling power	6.07	6.26	7.80	7.80	8.24	9.03	0.11	0.04
Solubility	9.45	10.59	10.38	8.42	10.28	9.22	0.58	0.20
WBC	155.44	138.19	150.40	147.06	143.18	157.39	6.16	2.18

Generally, ash content of the varieties increased significant with storage period with the exception of TDa 01/00081, TDa 98-159 and TDa 297 varieties (Table 4.24a and appendix 7). Similar increases in ash contents were observed in *D. rotundata* and *D. dumetorum* (Treche and Agbor-Egbe, 1996; Medoua *et al.*, 2005). The increase of ash content is probably due to tuber moisture loss during storage.

Changes in starch content did not follow any regular trend during the first three months of storage; however, there was a general and significant ($P<0.05$) decrease from the third month of storage to the last month (75.04 to 66.52%). All the varieties had considerable decreases in starch at the end of the storage period (Appendix 7). Jaleel *et al*. (2007) observed similar fluctuations where highest starch content was recorded in the early storage periods, decline slightly after 30 days of storage and decreased further throughout the storage period. Sugar content did not follow any particular trend in the 1st 2 months of storage as well. It only increased consistently and significantly ($P<0.05$) from the third month (4.67 %) to the end of the storage period (6.83%) i.e. the fifth month. A similar trend of sugar increases in stored yam tubers have been reported (Jaleel *et al.*, 2007; Hariprakash and Nambisan, 1996). Hariprakash and Nambisan (1996) reported of starch constituent's breakdown, mainly glucose and sucrose to maltose and fructose during storage of tubers of *D. alata* and *D. rotundata*. Onayemi and Idowu (1988) also reported that after 120 days of yam storage there was an increase in sugar content of tubers of *D. rotundata* and *D. cayenensis* with *D. rotundata* tubers showing a higher increase. These changes in the starch and sugar contents are attributed to the hydrolysis of starch to sugar during storage. According to Osagie (1992) sugar and starch exist in a state of dynamic equilibrium during storage.

Amylose content decreased significantly from 29.72 to 24.15% in stored tubers while amylopectin increased from 70.29 to 75.85% (Table 4.24a and appendix 8) which suggest changes in starch constituency during tuber storage. This is in agreement with the findings of Hariprakash and Nambisan (1996) who observed decreases in amylose content when yam tubers from different species were studied under storage. However, swelling power increased steadily (6.01 to 9.03%) with the length of storage period. The increase in swelling power observed could be due to the increased dry matter content (conversely due to the reduced moisture content) of the stored tubers and the decrease in amylose content. Low amylose content is linked to high swelling power as a result of greater reinforcement of the internal network by amylose molecules (Lorenz and Collins, 1990; Richardson *et al*., 2000; Hoover, 2001). On the average, there was no regular trend for water binding capacity even though it showed a significant decrease at the end of the storage period when compared with the 1st month of storage (138.19-157.39%). It must also be noted that while half of the varieties studied actually increased in water binding capacity with storage period, the other half decreased (Appendix 8). Medoua *et al*. (2005) observed increases in water binding capacity in stored *D. dumetorum* as observed in some of the varieties in this study. Solubility increased significantly during the 1st two months of storage and then the 4th month. Otegbayo (2004) observed significant increases in swelling power and solubility index of *D. alata* starches when stored as observed in this study.

Generally the pasting viscosities increased from the 1st month of storage even though some of the varieties had decreases (Table 4.24b and appendix 9). Similar increases in viscosities of stored *D. alata* tubers have been reported (Otegbayo, 2004). Pasting temperature however, decreased from 86.50 to 83.81 ^{o}C. This implies that stored tubers may need relatively less energy and time to cook compared to freshly harvested tubers. A similar observation has been reported in *D. dumetorum* species by Afoakwa and Sefa-Dede (2002).

Table 4.24 ***(b): Pasting properties (RVU)***

Month of storage	Peak viscosity	Trough	Breakdown	Final viscosity	Setback	Pasting time (min)	Pasting temperature (^{o}C)
0	242.53	222.17	20.37	285.30	63.14	5.69	86.74
1	209.15	167.33	41.82	218.47	51.14	5.53	86.64
2	228.65	178.20	50.45	223.00	44.81	5.11	85.71
3	185.76	172.80	12.95	222.14	49.33	6.35	86.86
4	233.54	205.83	27.71	273.00	67.17	6.17	85.74
5	257.48	225.30	32.18	316.24	90.94	5.84	83.81
LSD	6.25	6.75	3.58	5.85	4.13	0.07	0.55
SEM	2.21	2.39	1.26	2.07	1.46	0.03	0.20

Peak viscosity increased significantly ($P<0.05$) from the first month of storage (209.15 RVU) to the fifth month (257.48 RVU). The same trend was observed for final viscosity (218.47-316.24 RVU). This could be attributed to the steady and gradual increase in swelling power (Table 4.24a and appendix 8). Trough viscosity decreased at the 1st month of storage but increased thereafter throughout the storage period even though there were varietal differences (Appendix 9). The following parameters also increased in values at the end of storage, even though there were no specific trends: breakdown (20.37-32.18 RVU) and setback (63.14-90.94 RVU). With the significant decrease in starch content of varieties towards the end of storage period (Table 4.24a and appendix 7), swelling power and pasting viscosities were expected to decrease along with storage period; however, the reverse was observed. This could be attributed to increased dry matter content (Table 4.24a). The increases in peak, trough, final, and setback may be among the reasons why traditionally *D. alata* is stored for some time before being used for products that require a thick cohesive paste such as pounded yam.

The results have demonstrated that tuber maturity and storage period have influence on the moisture/dry matter, amylose, starch and sugar contents, swelling power and pasting viscosities. Pasting viscosities, dry matter and starch contents were highest at the 9 MAP. Thus from this study, *D. alata* can be harvested at 9 MAP or when vines begin to dry up. The increases in dry matter and sugar contents, swelling power and pasting viscosities of stored tubers will have significant improvement in their organoleptic and textural properties. The observation may also be among the reasons why *D. alata* is said to store well and even improve in quality during storage (personal communication). Farmers and processors may therefore harvest yam tubers at specific growth stages and store them for specific periods depending on the intended use.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

D. alata has been relegated to the background as a result of traditional bias which fails to recognise the unique quality characteristics of the tuber and the agronomic flexibility of the species. *D. alata* has high yield, high multiplication ratio and better tuber storability, than the preferred indigenous *D. rotundata.* It has been shown from this study that *D. alata* possesses diverse and unique quality characteristics worth exploiting especially in the food industry. These characteristics of *D. alata* coupled with the flexibility in production gives it an advantage for sustainable cultivation especially when yam production seems to be on the decline as a result of high cost of production, low yields and post harvest losses among others.

Many opportunities and challenges abound to explore the promotion of *D. alata* especially during this period that prices of other common staples such as cereals are escalating. We need to eat what is locally available and can afford. Products diversification seems to be an obvious option for a better impact. More research is therefore needed to improve the species for specific promising products as well as improving the technological processing systems at all levels. It is also imperative to better understand market and consumers demands while all stake holders make use of valuable information such as those contained in this study. In general, the continuous generation of improved post harvest technologies linked to improvement in food marketing beyond the farm gate is essential.

From the results, *D. alata* will make good flour in composite with other flours for bread making and other bakery products. These are important information for both processors and breeders in terms of food diversification and tuber quality improvement for specific uses.

The physicochemical properties in conjunction with pasting properties of *D. alata* suggest that the species will be suitable for weaning foods and other products that require low viscosity. It could also be a good source of ingredient for processed foods, especially those that require thermal sterilization. Food technologist and processors alike may experiment and explore the possibility of using *D. alata* for different food products based on the results of this study.

D. alata should be promoted for products such as *amala*, (where they have a comparative advantage over *D. rotundata)* especially in countries like Ghana and other yam producing areas where *amala* is not a common product, to increase utilization and production. Further research is also needed to come out with diverse and novel processing technologies while improving the traditional processing of the species. However, the promising varieties for boiled yam and pounded yam in this study (TDa 98-159, TDa 291, TDa 297 and 93 -36) should be genetically improved to meet consumers' preferred qualities. These varieties could also be improved specifically for *poundo* flour (poundo flour is an instant pounded yam flour) which is now an export commodity with very high revenue potential.

Significant correlations were found among the organoleptic properties of the products and the chemical (dry matter, sugar and starch contents), physicochemical (amylose, swelling power and water binding capacity) and pasting properties (peak viscosity, trough, breakdown, final viscosity, and pasting temperature) of *D. alata* tubers. These food quality parameters would be of use in screening out varieties for specific end uses by yam breeders.

The nutritional superiority of *D. alata* varieties over *D. rotundata* with respect to protein and total dietary fibre (TDF) could be exploited in nutritional applications and diet formulation because of the health benefits of TDF. The significant mineral variations observed among *D. alata* varieties is also an indicative of the potential for mineral improvement through breeding programmes that aim at increasing macro- and micro-nutrient levels in available, affordable and preferred staple crops such as yam.

Microstructural studies of the cooked cells in majority of the *D. alata* varieties (71%) showed incomplete disruption of the cells and consequently reducing exudation of starch contents. This feature partly accounts for less suitability of *D. alata* for sticky and doughy yam products like pounded yam in production areas.

The results of the maturity and storage studies on *D. alata* demonstrated that tuber maturity and storage period have influence on physicochemical, chemical and pasting properties. This information is of use to both farmers and processors who may harvest yam tubers at specific growth stages and store for specific periods for more economic value.

5.2: Recommendations

The following are further recommended based on the findings of this study:

1. *D. alata* should be promoted for products for which it has comparative advantage such as *amala*.

2. Specific varieties (TDa 98-159, TDa 291, TDa 297 and 93 -36) should also be genetically improved for other preferred yam products.
3. Breeders involved in improving the quality of *D. alata* can make use of data on dry matter and starch content, amylose and swelling power as well as pasting characteristics of varieties to do their varietal selection in the early stages of the selection cycle.
4. Based on the significant differences in physicochemical and pasting characteristics of the varieties used, the potential for innovative products with higher added values should be exploited to increase utilization of the species.
5. Further studies should be done on bioavailability of the minerals in *D. alata*.
6. Further screening for *D. alata* varieties with high dietary fibre and good physicochemical properties that would make them suitable for incorporation into other food products is recommended because of the health benefits of dietary fibre.