



EFFECT OF EXTRUSION PROCESS ON PERFORMANCE OF AN INDIGENOUS EXTRUDER AND QUALITY OF CASSAVA PRODUCTS

¹Satimehin A., ¹*Fayose, F., ²Adewale D., ²Adewoyin, O.

¹Department of Agricultural and Bioresources Engineering, University of Oye-Ekiti
Ikole-Ekiti Campus, Oye Ekiti 37010, Nigeria

²Department of Crop and Horticultural Sciences, Federal University Oye Ekiti, Nigeria

*Corresponding author: folasayo.fayose@fuoye.edu.ng

Satimehin, A., Fayose, F. *, Adewale, D. and Adewoyin, O. (2022): Effect of Extrusion Process on Performance of an Indigenous Extruder and Quality of Cassava Products *Journal of Engineering and Engineering Technology*/16(1), 170-177

Received 14-03-22

Accepted: 10-05-22

Abstract

A locally developed autogenous single screw extruder was used to investigate the process for screw extrusion of the flour and starch of cassava, in a bid to find alternate uses for the commodity. The experiment was conducted with a factorial design and completely randomized. Analysis of Variance and Tukey Honestly Significant Difference methods were utilized as follow up test to check the result of extrusion variables: feed moisture (25, 30, 40%) and extruder temperature built up by varying the duration of sampling (2, 10, 18, 24, 30 minutes) on some product quality attributes and system parameters. The product quality attributes considered include water absorption index (WAI) and water solubility index (WSI), product moisture (PQ_MC), transverse expansion (ExR), cold and hot paste viscosities (CPV and HPV), Melt viscosity (MV) and strength properties of extrudates (CP) while the system parameters are product temperature (PT), mean residence time (MRT), and specific energy input (SME). All system parameters PT, MRT and SME varied directly with duration of operation. Also, PQ_MC, CP, WAI, WSI, MV, CPV and HPV varied reciprocally whereas ExR, and MV varied directly with duration of operation. The extrudates' water loss is directly proportional with ExR. It was observed that extruded cassava starch was less stable than cassava flour extrudates. Moreover, the specific end uses to which the extruded products can be put were identified. All the treatments and their interactions are highly significant ($P \leq 0.001$).

Keywords: Cassava starch, flour, extrusion, system parameters, product quality attributes, Nigeria

Introduction

In Nigeria and West Africa, starches from cereals, roots and tubers are usually consumed as a staple food and diet among the people (Viduranga 2018; Chandrasekara and Kumar, 2016). Cassava (*Manihot esculenta*, Crantz) may be a starch-riched root tuber crops that adds to the economic expansion and food stability, above all in an economically food sufficient and deficient countries which is attributable to its inherent characteristics (Enesi *et al.*, 2021). Cassava stands periods of drought; hence they are not easily affected by hash-climate or even climatic change. Also, Nigeria is the highest producer of cassava globally, with around 70 million tonnes of cassava turn out yearly (Yisa, 2009). Nevertheless, the production has reduced from more than 70 million tonnes in the 2000s to 59 million in 2017 (IITA, 2017) and that reduction has been the trend ever since (Okon, 2017).

One reason for this was because a high percentage of the crops produced are lost because of inadequate processing thereby discouraging farmers from increased production (Okon, 2017). So, to maximize

the production potential of cassava, there is need for alternative processing options to add to its value and for it to be sustained (Ume *et al.*, 2020), Research Program on Root Tuber and Banana 2016). One of the ways to arrest the issues of loss of the harvested crops is by expansion of the processing technology. One of the modern technologies for developing new food products is food extrusion. It is a process whereby food constituents are forced to flow, using one of the many conditions of mixing, heating and shear, through a die that forms and/or puff-dries the ingredients, may be a versatile method that helps within the enlargement of the process strategies of crops (Olusegun *et al.*, 2016). A variety of product with totally different shapes, nutrients, texture, colour, sizes etc. are made from basic materials that thereby increasing the range of food products in the diet. Cassava as a starchy crop has high potential for production of extruded food.

The extrusion process operates in a very dynamic equilibrium wherever the inputs are stable with the output (Guy, 2001). So as to obtain the specified characteristics in an extrudate, a range of values of

extrusion parameters must be attained. These extrusion parameters including system parameters, process parameters and produce quality attributes are necessary for optimization. Furthermore, it is necessary as indicators of extrusion process (Chang and Halek; 2006). Moreover, understanding the thermo - mechanical history of the product with the extruder can help to quantify and predict product conversion (Camire, 2016; McCarthy *et al.*, 2016). Loads of analysis has been reportedly carry out on cassava at recent pasts. However, it is not an understatement that the crop continues to be underutilized in low-income states like Nigeria, thereby reducing the potential for increasing its growth. Therefore, the aim of this study is to evaluate the effect of extrusion process on different system parameters and product quality attributes on cassava thus, providing info on extrusion of cassava which can be helpful to the food industry.

Materials and Methods

Series of experiments were carried out to evaluate the effect of extrusion method on cassava by means of a domestically developed extruder. These are reported in this section.

Sample Preparation and Extrusion

Cassava tubers (*Manihot esculenta* Crantz) TMS 30572, sourced from experimental farm of Federal College of Agriculture, Akure and processed into flour and starch in keeping with International Starch Institute Standards (International Starch, 2005). The materials were made to pass through a 300um sieve separately and also the proximate analysis and water contents of the samples were determined as delineated by AOAC (1995) Approved method.

Table 1: Proximate composition of cassava flour and starch used

	Moisture content	Protein	Fat	Ash	Fibre	Carbohydrate
Cassava starch	1.47	0.31	1.50	0.20	0.12	96.40
Cassava flour	1.90	7.36	1.4	1.62	0.24	87.48

The extruder utilized in this study is the dry, autogenic type and it had been developed locally. The screw is of single flight, increasing diameter and tapering/decreasing pitch with (L\D- 12:1, CR – 4.4:1, die diameter 6mm) configuration. The pictorial view of the extruder is shown in Figure 1. Samples were fed into the extruder at a constant feed rate 10kg/h, room temperature and screw speed of 100 rpm until steady state. The extrudates were extruded as ribbons and later cut manually to a length of 10 cm each. The samples' moisture levels were varied by calculating the quantity of water required to make up the moisture level and added it to the sample before mixing it up with it as shown in equation 1.

$$\text{Mass of water required} = \frac{\text{Moisture content (dry basis)} \times \text{mass of dry sample}}{100} \quad (1)$$

The extruder was operated to steady state for every set of condition. Balanced and steady state extrusion condition is assumed to be reached wherever there is a constant extrusion rate and for all the samples studied, these conditions were attained in 30 minutes.

Preparation of Samples for Analysis

The extruded samples were dehydrated at 45oC for 16-24 h in order to bring the ultimate product to around a

constant water content (5-7% d.b.) according to Nrema *et al.* (2011). Some of the dried materials were coarsely ground in a very high-speed laboratory grinder (Waring Industrial Heavy Duty Blender, New Hartford, Conn. U.S.A) and processed in a domestic blender (Martex, Dawan) to pass through a 300um sieve. These materials were utilized in subsequent analysis.

Data Collection and Analysis

Moisture contents (extrudates PQ_MC) were determined immediately after extrusion on a dry basis by an oven method using equation 1 according to AOAC (1995) method 950.46. Approximately 2g each sample was placed in an air oven at 100 + 2oC for 16 to 18 hours. Expansion ratio (ExR) of extrudates was calculated according to Oke *et al.* (2013). Extrudates' diameters were measured using a calliper. Radial expansion ratios of the extrudates were calculated as shown in equation 2.

$$\text{ExR} = \frac{D}{d} \quad (2)$$

where D is the extrudate's diameter while d is the diameter of the die.

The consistency, representing the relative melt viscosity (MV) of the each extrudate was determined with Capillary Viscometer Method, AOAC (1995) using equation 3.

$$\text{MV} = \frac{\text{Flow rate of sample solution at } 20^{\circ}\text{C} \times \text{specific gravity of sample solution}}{\text{Flow rate of water} \times 1.002 (\text{specific gravity of water})} \quad (3)$$

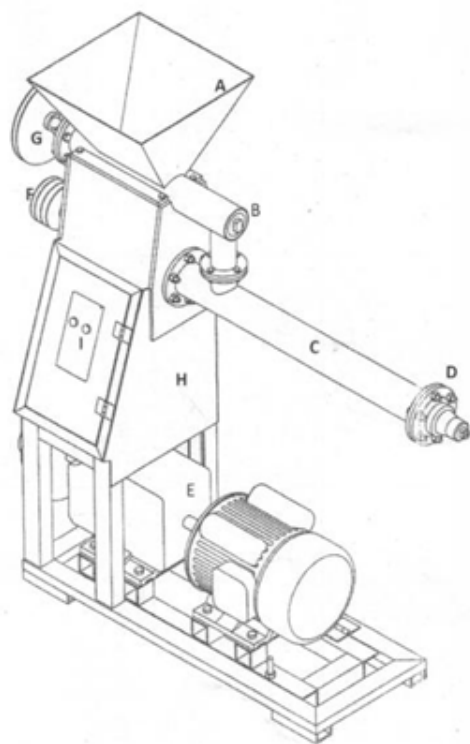


Fig. 1. Isometric view of the extruder (LEGEND: A- Hopper, B- Feeding Conveyor, C- Extruder worm, D- Die Unit, E- Power train, F- Conveyor pulley, G- Extruder pulley, H- Extruder Housing, I- Control switch).

The water absorption index (WAI) and water solubility index (WSI) were determined using the procedure by Danshy and Bovell (2003). WAI is the weight of gel obtained per g of dry sample while WSI is the weight of dry solids in the supernatant expressed as a percentage of the original weight of sample. Pasting Properties (Hot ,HPV and Cold paste viscosity, CPV) were determined as described by Amani et al (2004) using the Rion viscotester (VT – O4E – Japan). Specific mechanical energy requirement (SME) was calculated as described by Chi- Chuang and Yeh (2004)

$$SME = \frac{2\pi \times \tau \times S_s}{60F_r} \times 3.6 \quad (3)$$

Where τ is the corrected torque (N m), S_s the screw speed (rpm), F_r the feed rate (kg/h) and equivalent to the product output at stable conditions.

Compression strength (CP), which was used as a measure of the hardness of the extrudates, was measured according to Guan and Hanna (2004) using the Testometrics Universal Testing machine 500-532 (Testometric, Co l.t.d. Unit, Lincoln, Business Park, Lancashin, England.) at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State of Nigeria. Mean Residence Time (MRT) was

determined by monitoring of potassium permanganate using an Atomic Absorption/Emission Spectrophotometer AAS (type: Buck scientific 2.0) by a tracer technique as described by Seker (2005). Product temperature (PT) was determined as described by Chessari and Sellahewa (2001). with Portec CAI 001 thermometer probe (Portec instrumental, Milton Keynes, UK) inserted into the melt immediately before passage of the mass out of the die. The result was read out from a digital meter. The measurements of each parameter was an average of triplicate analysis.

Statistical Design and Analysis

This experiment was conducted as a factorial in completely randomised design employing two levels of product classification, three levels of initial water content and five levels of duration of sampling of extrudates before attaining steady state. The three experimental variable levels were pre-selected based on results of preliminary tests. The data were analysed using analysis of variance to investigate the interactions between moisture content and duration of sampling to study their significant effect at $\alpha = 0.05$ using the GLM procedure of Statistical Analysis System (SAS) software v.9.R4 (SAS Institute, Cary, NC.). Comparison of means was performed with Tukey's Studentized Range (HSD) Test to reduce Type I error.

Results and Discussion

Many extrusion trials were performed to evaluate the performance of the extruder and also the parameters ranges utilized in this research work. The preliminary results were reportable in Fayose *et al.* (2017).

Effect of Extrusion Variables on System Parameters

Tables 2 and 3 show the analysis of variance effect of extrusion variables (initial water content and the duration of sampling) on system parameters (PT, MRT and SME) of the extrusion process of cassava flour and cassava starch at 100 rpm respectively, whereas Table 4 shows their mean performances. The analysis shows that every system parameter (PT, MRT and SME) vary directly with duration of sampling. The parameters improved with increase in duration of sampling. Also, the treatments for cassava flour and starch with their interactions are significantly high ($P \leq 0.001$). However, there is no significant difference in the temperature of starch samples collected at 24 and 30 minutes of operation. This may be because it has come to steady state at that period earlier than that of cassava flour. The coefficient of variation for the two products shows strong and reliable samples.

Moreover, Table 4 shows that cassava starch has lower mean temperature but higher MRT and SME than cassava flour all parameters (PT, MRT and SME) varied inversely with duration of operation. However, in Table 5, for cassava flour the product temperature

decreased with increase in moisture content from 25 to 40% whereas for cassava starch, there was a polynomial trend. This difference observed between cassava starch and cassava flour might be due to the differences in their

carbohydrate and protein contents as shown in Table 1. This result agrees with previous studies on extrusion of starch - primarily based crops like maize and wheat (Zweytick, 2008).

Table 2: ANOVA for system parameters for cassava flour

Source of variation	DF	MS		
		PT	MRT	SME
MC	2	1672.62***	4.32***	14078.41***
Duration	4	5296.09***	29.55***	16287.59***
MC*Duration	8	38.87**	0.37**	2302.23***
Error	28	9.31	0.09	0.24
cv (%)		2.97	0.68	0.61
Mean		102.62	44.91	80.72

*, **, ***- significant at 0.05, 0.01 and 0.001 level of significance respectively N.B: DF = Degree of freedom

Table 3: ANOVA for system parameters for cassava starch

Source of variation	DF	MS		
		PT	MRT	SME
MC	2	1711.67***	190.53***	13670.58***
Duration	4	6639.63***	83.51***	e20598.12***
MC*Duration	8	59.58***	10.93***	1188.09***
Error	28	7.95	1.27	0.26
cv (%)		2.85	2.36	0.49
Mean		98.8	47.72	104.37

*, **, ***- significant at 0.05, 0.01 and 0.001 level of significance respectively N.B: DF = Degree of freedom

Table 4: Mean performances of the system parameters under different sampling time

Duration	Cassava Starch			Cassava flour		
	PT	MRT	SME	PT	MRT	SME
30	118.22a	51.64a	164.15a	124.56a	47.63a	140.00a
24	117.00a	49.7b	136.34b	118.11b	45.67b	100.84b
18	111.22b	47.48c	103.47c	109.22c	44.47c	77.19c
10	94.22c	45.79d	73.61d	98.22d	43.89d	57.43d
2	53.33d	43.98e	44.27e	63.00e	42.93e	28.14e

Table 5: Mean performances of the system parameters under different initial moisture content

MC	Cassava Starch			Cassava flour		
	PT	MRT	SME	PT	MRT(s)	SME
25	92.80b	51.56a	139.02a	114.40a	45.40a	107.62a
30	111.33a	47.07b	90.32b	99.47b	45.01b	87.16b
40	99.47b	44.52c	83.77c	94.22c	44.34c	47.38c

Means with the same letter are not significantly different and mean comparison is along each column

Effect of Extrusion Variables on Product Quality Attributes

Tables 6 and 7 show the effect and result of extrusion variables on product quality attributes whereas tables 8 to 11 show the mean performances. The analysis shows that PQ_MC, CP, WAI, MV, CPV and HPV varied reciprocally while ExR, WSI and MV varied directly with length of operation. Also, the treatments for cassava flour and starch with their interactions are significantly high ($P \leq 0.001$). Lo *et al.* (1998) gave a similar result with yellow corn maize. The moisture content of the extruded samples varied directly with expansion. This might be because PT reduced when sample moisture is increased. Thus, on increasing feed wetness of cassava, the fall in temperature created lower pressure within the dough leading to less flashing of moisture and reduced expansion.

Expansion is negatively correlated to compressive strength because with additional expansion, the extrudate becomes stuffed with porous structure composed of air pockets enclosed by laminal sheets of gelatinized starch and so results in reduction in strength. Also, moisture loss in cassava flour extrudates is above that of cassava starch. This distinction obtained between the moisture loss by cassava flour and its starch may be due to variations between their viscosities at high temperature/shear environment. The maximum value for the height happens wherever the polysaccharide is least i.e., starch. For higher concentration as contained in flour it decreased. This could also be due to the very fact that cellulose, being a significant element of cassava flour does not develop viscosity (Arambula, *et al.* 2002). Cassava starch therefore could not dry fast like cassava flour because of its higher viscosity.

Altan and Maskan (2016) reporting on the characteristics of extruded product made up of mixtures of cassava flour, opined that as the proportion

of cassava starch increased, the concentration of proteins,

lipids and fibre diminished, while the concentration of carbohydrates increased. Associated with the increase in carbohydrate and consequent increase in reducing sugars, WSI of the products increased, whereas WAI decreased. This may be the reason why the WAI of cassava flour is lower than that of its starch counterpart. In this study, all extruded products had more than triple the WAI of non-extruded samples. These results agree with those of Osungbade *et al.* (2016) who reported that heat processing of different kinds of flours results in higher water absorption capacity than in the raw flour. Protein denaturation, starch gelatinization and swelling of the crude fiber, which occurred during extrusion, could all be responsible for the increased WAI of extruded products.

Also, the rise was caused maybe by bigger shear degradation of starch throughout extrusion at higher temperature. Sebjo and Chang (2000) observed that beneath milder extrusion conditions (low temperature and high moisture content), the destruction of the organized structure of starch was solely partial, characterized by increase in the WAI and WSI. On the other hand, under additional forceful conditions (i.e., raised temperature and low moisture content), starch dextrinization most likely occurred, and indicated by decreases in the WAI and increases in the WSI. However, the trend of the mean performances of moisture contents are different (Table 11). This being that in contrast to its flour counterpart, starch could not transmit from the first fine nature to a moistened state at water content $\leq 29\%$. High WSI implies that the material can dissolve simply in water and thus are wasted as feed fish. However, with high WSI, sensible solutions will be formed. From Tables 8 and 9, the WAI and WSI for the two products are negatively correlated.

Table 6: ANOVA for product quality attributes of cassava flour extrudates

Source of variation	DF	MS							
		PQ_MC	ExR	CP	WAI	WSI	MV	CPV	HPV
MC	2	1284.56***	26.18***	222058.03***	22.74***	0.04***	76.03***	15.46***	0.64***
Duration	4	159.07***	24.45***	1658247.71***	7.89***	0.06***	10.04***	21.53***	6.08***
MC*Duration	8	10.45***	10.65***	255259.02***	0.29***	0.00***	2.94***	2.97***	0.20***
Error	28	0.01	0.02	17.01	0.00	0.00	0.01	0.04	0.00
cv (%)		0.33	4.02	0.46	0.58	3.04	1.83	9.10	3.56
Mean		23.35	3.38	896.80	5.75	0.27	5.59	2.09	0.93

*, **, ***- significant at 0.05, 0.01 and 0.001 level of significance respectively N.B: DF = Degree of freedom

Table 7: ANOVA for product quality attributes of cassava starch extrudates

*, **, ***- significant at 0.05, 0.01 and 0.001 level of significance respectively N.B: DF = Degree of freedom

	DF	MS							
Source of variation		PQ_MC	ExR	CP	WAI	WSI	MV	CPV	HPV
MC	2	654.63***	48.96***	6984333.69***	30.55***	0.26***	38.67***	172.68***	173.63***
Duration	4	104.32***	6.75***	104130.02***	3.02***	0.03***	15.14***	71.17***	9.35***
MC*Duration	8	7.66***	5.99***	789622.02***	0.48***	0.01***	3.65***	5.08***	0.88***
Error	28	0.04	0.04	18.41	0.02	0.00	0.02	0.02	0.02
cv (%)		0.74	7.58	0.41	3.01	1.87	2.68	2.95	5.07
Mean		26.05	2.47	1046.55	5.04	0.26	5.51	4.28	2.89

Table 8: Mean performances of the quality performance attribute for cassava flour starch at different duration of sampling

Duration	PQ_MC	EX_R	CP	WAI	WSI	MV	CPV	HPV
2	30.26a	1.32e	1550.22a	6.81a	0.38a	4.14e	4.76a	2.33a
10	24.47b	2.14d	1003.3b	6.54b	0.31b	4.90d	1.87b	1.00b
18	20.89c	5.45a	903.16c	5.65c	0.27c	6.00c	1.72b	0.57c
24	20.56d	4.17b	563.89d	5.20d	0.22d	6.78a	1.29c	0.49d
30	20.55d	3.79c	463.41e	4.54e	0.18e	6.15b	0.83d	0.28e

Means with the same letter are not significantly different and mean comparison is along each column

Table 9: Mean performances of the quality performance attribute for cassava starch at different duration of sampling

Duration	PQ_MC	EX_R	CP	WAI	WSI	MV	CPV	HPV
2	30.89a	1.33d	1183.39a	5.63a	0.22d	5.01 e	9.00a	4.42a
10	28.15b	2.27c	1098.36b	5.48a	0.21e	6.67 d	4.62b	3.28b
18	25.01c	3.75a	1071.92c	5.17b	0.26c	8.98 b	3.21c	2.72c
24	23.36d	2.64b	965.33d	4.66c	0.32b	10.45a	2.55d	2.25d
30	22.85e	2.35c	913.77e	4.23d	0.33a	7.89 c	2.02e	1.79e

Table 10: Mean performances of the quality performance attribute for cassava flour at different moisture contents

MC	PQ_MC	EX_R	CP	WAI	WSI	MV	CPV	HPV
25	30.89a	1.33b	1183.39a	5.63a	0.33a	6.76a	9.00a	0.85b
30	28.15b	2.27c	1098.36b	5.48a	0.27b	6.44b	4.62b	0.78c
40	25.01c	3.75a	1071.92c	5.17b	0.22c	5.99c	3.21c	1.17a

Means with the same letter are not significantly different and mean comparison is along each column

Table 11: Mean performances of the quality performance attribute for cassava starch at different moisture contents

MC	PQ_MC	EX_R	CP	WAI	WSI	MV	CPV	HPV
25	22.17b	1.11c	258.63c	6.04a	0.12c	3.93c	8.20a	6.81a
30	22.31b	4.52a	1437.55b	3.40c	0.37a	7.14a	2.32b	0.64c
40	33.68a	1.77b	1443.48a	5.67b	0.30b	5.47b	2.32b	1.23b

Means with the same letter are not significantly different and mean comparison is along each column.

HPV diminished with increase in moisture content from 25 to 30% and a rise at 40%. A HPV of 9.7 dPas was earned at 0 (zero) duration of operation (i.e. raw cassava starch). CPV varies reciprocally with duration of operation and reduces with increase in moisture content from 25 to 30% with a rise at 40%. A CPV value of 16.47 dPas was for the raw sample. Hence, it will be deduced that cassava starch is less stable than its flour, having the best distinction between its CPV and HPV values. This shows an improvement with the stability of the extruded products compared to the raw samples. Also, from previous studies, extrusion improved the stability of cassava products better than cereal products (Fayose and Huan 2012). Thus, when

starchy products are extruded at optimum level of temperature and moisture, it helps to reduce their retrogradation.

Conclusions

The response of cassava to food extrusion process from a domestically developed extruder has been well studied. The results show that PQ_MC, CP, WAI, MV, CPV and HPV varied reciprocally whereas ExR, WSI and MV varied directly with the duration of operation. Also, the treatments for cassava flour and starch with their interactions are significantly highly ($P \leq 0.001$). Extrusion processing improved the stability of the two products, however, cassava starch extrudate is less stable than its flour counterpart. The duration of sampling and water content of the products before extrusion are significant and interrelated. Database on extrusion of cassava that are beneficial to food and feed processing are established. Cassava is very responsive to extrusion cooking.

References

- Altan, A. and Maskan, M. 2016. Development of Extruded foods by utilizing food industry by-products. In Maskan, M. and Altan, A. (Eds.) (2016). *Advances in Food Extrusion Technology* pp. 121-168. CRC Press Boca Raton.
- Amani, N. G., Buleon, A., Kamenana, A. and Colona, P. 2004. "Variability in starch physicochemical and functional properties of yam cultivated in Ivory Coast. *Journal of the Science of Food and Agriculture*, 84 (15), 2086-2096.
- Official Methods of Analysis of the Association of

Official Analytical Chemists Approved Methods. 1995. *Official Methods of Analysis of the Association of Official Analytical Chemists*, Washington D. C. pp.710.

- Arambula, V. G., Gonzalez-Hernandez, J., Moreno, M. E., and Ordorica, F. C. A. 2002. Characteristics of tortillas prepared from dry extruded masa flour added with maize pericarp. *Journal of Food Science*. 67 (4), 1447-1452.
- Camire, M. E. 2016. Nutritional changes during extrusion cooking. In Maskan, M. and Altan, A. (Eds.) (2016). *Advances in Food Extrusion Technology* pp. 87 - 102. CRC Press Boca Raton.
- Chandrasekara, A. and Kumar, J. K. 2016. Roots and tuber crops as functional foods: A review on phytochemical constituents and their potential health benefits. *International Journal of Food Science*, Article 3631647, <https://doi.org/10.1155/2016/3631647>.
- Chang, K. C. and Halek, G. W., 2006. Analysis of Shear and Thermal History during Co-rotating Twin-Screw Extrusion. *Journal of Food Science* 56 (2) : 518 - 531 .
- Chessari, C. J. and Sellahewa, J. N. 2001. Effective process control. In Guy, R (2001) (Ed.) *Extrusion Cooking Technologies and Applications*. (pp. 83 - 105). Wood Head Publishing Limited and CRC press LLC, Cambridge, England.
- Chi-Chuang, G. C., and Yeh, A., 2004. Effect of screw profile on residence time distribution and starch gelatinization of rice flour during single screw extrusion cooking. *Journal of Food Engineering*. 63 (1), 21-31.
- Danshy M. Y., and Bovell, B. 2003. Physical Properties and Sixth Graders' Acceptance of an Extruded Ready-A Response Surface Analysis. *Journal of Food Engineering*. 38, 369-379. (no issue no)
- Enesi, R. O, Hauser, S., Pypers, P., Kreye, C., Tariku, M. and Six, J. 2021. Understanding changes in cassava root dry matter yield by different planting dates, crop ages at harvest, fertilizer application and varieties, *European Journal of Agronomy*, Volume 133, Article 126448, <https://doi.org/10.1016/j.eja.2021.126448>.
- Fayose, F. T., Ogunlowo, A. S. and Agbetoye, L. A. (2017). The design, fabrication and preliminary testing of an indigenous single screw extruder. *Journal of Engineering Science and Technology*, 12 (10), 2585 - 2598.

- Fayose, F. T. and Huan, Z., 2012. Effect of extrusion processing conditions of a locally developed extruder on the product temperature of selected starch crops. *Journal of Natural Sciences, Engineering and Technology*, 2 (2), 144 -155.
- Fellows P. J. 2009. *Food processing technology: principle and practice*. Elsevier Science. Amsterdam Netherlands. (A textbook)
- Guan, J. and Hanna, M. A. 2004. Functional properties of extruded foam composites of starch acetylate and corn cob fiber. *Industrial Crops and Production* 19, 255-269.
- Gujksa, E. and Khan, K. 1990. Effect of temperature on properties of extrudates from high starch fractions of navy, pinto and garbanzo beans. *Journal of Food Science* 55(2), 466-468.
- Guy, R., 2001. (Ed) *Extrusion Cooking Technologies and Applications*. Wood Head Publishing Limited and CRC press LLC, Cambridge, England. International Institute of Tropical Agriculture. Cassava (*Manihot esculenta*). IITA Crops News. Available at <http://www.iita.org/crops/new/cassava>.
- International Starch 2005. *Memorandum on Tapioca (Cassava) Starch*, International Starch Institute, Science Park Aarhus, Denmark.
- Lo, T. E., Moreira, R. G. and Castell – Perez, M. E. 1998. Modeling product quality during twin – screw food extrusion. *Transaction. of the American Society of Agricultural Engineers* 41(6), 1729 – 1738.
- McCarthy, K. L, Rauch, D. J. and Krochta, J. M. 2016. Rheological properties of materials during the extrusion process. In Maskan, M. and Altan, A.(Eds.) (2016). *Advances in Food Extrusion Technology* pp. 103 - 120. CRC Press Boca Raton.
- Nrema, G. C., Gumbe, L. O., Chepete, H. J., and Agullo, J. O. 2011. *Rural structures in the Tropics: design and development*. FAO.(A test book)
- Oke, M., Awonorin, S. O., and Workney, T. S. 2013. Expansion ratio of extruded water yam (*Dioscorea alata*) starches using a single screw extruder. *African Journal of Agricultural Research*. 8(9), 750-762.
- Okon A. 2017. Cassava glut: Farmers, processors squabble over prices. *The Punch Newspaper*. Available at <http://www.punchng.com/cassava-glut-farmers-processors-squabble-over-prices>.
- Olusegun, A. A., Stephen, A. A. and Folasade, B. I. 2016. Effect of extrusion conditions on cassava/soybean extrudates. *MOJ Food Process Technology* 3(1): 237-245.
- Osungbade, O. R., Gbadamosi, O. S. and Adiamo, O. Q. 2016. Effects of cooking and fermentation on the chemical composition, functional properties and protein digestibility of sandhwa (Hura crepitans) seeds. *Journal of Food Biochemistry* 40(6): 754-765.
- Research Program on Root Tuber and Banana. 2016. New technologies make cassava processing more efficient and sustainable. News, Consultative Group on International Agricultural Research <https://www.rtb.cgiar.org/news/new-technologies-make-cassava-processing-more-efficient-and-sustainable>.
- Sebio, L. and Chang Y. K. (2000). Effects of selected process parameters in extrusion of yam flour (*Dioscorea rotundata*) on physicochemical properties of the extrudates. *Food/Nahrung* 44 (2), 96 - 101.
- Seker, M. 2005. Residence time distributions of starch with high moisture content in a single-screw extruder. *Journal of Food Engineering* 67 (3), 317–324.
- Ume, S. I., Onwujiariri, U. J. and Nwaneri, T. C. 2020. Effect of cassava processing to the environment in South East, Nigeria - implication on adoption of cassava processing technology. *Sustainable Food Production*. 9, pp. 1 – 14, doi:10.18052/www.scipress.com/SFP.9.1 2020 SciPress Ltd, Switzerland
- Viduranga, Y. W., 2018. Public perception of biotechnology. In: Y.W. Viduranga, (Ed.) *Cassava*. IntechOpen, DOI: 10.5772/intechopen.70324. Available from: <https://www.intechopen.com/chapters/56558>.
- Yisa, M., 2009. Mechanization: way forward. Lead paper Presentation. 9th Nigeria Institution of Agricultural Engineers Conference 2009, Yola, Nigeria
- Zweyck G. (2008): *Wheat Crisps - Extrusion Cooking Technology*. In Margarida Vieira, Peter Ho Eds., *Experiments in Unit Operations and Processing of Foods* 5, 143-149; Springer, New York;