THE FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE, NIGERIA

Biotechnology for Healthy Nutrition and Productive Lifestyle

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Delivered by:

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Deputy Vice-Chancellor (Development),
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Other Academic and Professional Colleagues,
Distinguished Guests and Friends of the University,
Gentlemen of the Press,
Distinguished Ladies and Gentlemen,
Great FUTARIANS

1.0 INTRODUCTION

1.1 Preamble

"Unless the Lord had been my help, my soul had almost dwelt in silence" – Ps 94:17

Mr. Vice Chancellor Sir, the above verse of Scripture sums up my life experience and the strong upholding hand of my Lord and Saviour, Jesus Christ. Indeed, my academic and life pursuits are greatly hinged on His overflowing mercy, faithfulness and grace. It is therefore with a hearty and sincere appreciation to the Almighty God that I stand before you today to present the 120th inaugural lecture of the Federal University of Technology, Akure, Nigeria, titled, **"*Biotechnology for healthy nutrition and productive lifestyle*"**. This is the 44th lecture emanating from the School of Agriculture and Agricultural Technology (SAAT), and the 4th in the Department of Food Science and Technology. I find myself highly privileged to present before you all an account of my research endeavours as a Biotechnologist and Food Product Development expert.

1.2 Varied Perspectives of Biotechnology

Biotechnology is a term that has been given varied and scattered definitions depending on the peculiar preferences of different researchers. While some view it from the angle of technological inputs into biology or Biosystems engineering, others see it purely as molecular modifications and interactions of cells; yet others

consider the engineering of genes and enzyme kinetics as the key elements. However, all the definitions point to biotechnology as the deliberate manipulation of biological systems or their derivatives for improved productivity, yield and nutritional value. The Convention on Biological Diversity (CBD, 2000) defines biotechnology as "any technological application that uses biological systems, living organisms or derivatives thereof, to make or modify products or processes for specific use". It thus includes activities such as traditional food fermentations, waste treatment, drug development, fish farming and crop development. Food biotechnology has been defined as "the application of biological techniques to food crops, animals and microorganisms to improve the quality, quantity, safety, ease of processing and production economics of food. It thus includes the traditional manufacturing processes used for bread, beer, cheese and various fermented milk products" (IFST, 2008). Modern genetic modification (or manipulation or engineering) techniques have been developed that enable selected genes to be transferred within a species, or from one species to another, using molecular biology techniques including recombinant DNA technologies.

The application of modern biotechnology to food production presents new opportunities and challenges for human health and development. Recombinant gene technology, the most well-known modern biotechnology, enables plants, animals and microorganisms to be genetically modified (GM) with novel traits beyond what is possible through traditional breeding and selection technologies. It is recognized that techniques such as cloning, tissue culture and marker-assisted breeding are often regarded as modern biotechnologies, in addition to genetic modification. The inclusion of novel traits potentially offers increased agricultural productivity, or improved quality and nutritional and processing characteristics, which can contribute directly to enhancing human health and development. From a health perspective, there may also be indirect benefits, such as reduction in agricultural chemical usage, and enhanced farm income, crop sustainability and food security, particularly in developing countries.

Traditional biotechnology which has been effectively adopted and

adapted in Africa includes spontaneous and controlled fermentation; seed culture and/or back-slopping for product reproducibility; starter culture development; exploitation of prebiotics, probiotics and synbiotics; provision of appropriate conditions and environmental modifications for optimal enzyme action; bioresource domestication and elaboration; and traditional genetic improvement through the use of stressed culture/environmental conditions to get desirable mutants or variants. It is interesting to note that traditional biotechnology, as against modern biotechnology (Figure 1), has shown more relevance to rural populations, in terms of overall essence and ease of applicability. Adapting local technology or modifying processes without losing the scientific underlying principles has proved vital in sustaining health and productivity in Africa (Enujiugha and Akanbi, 2002).

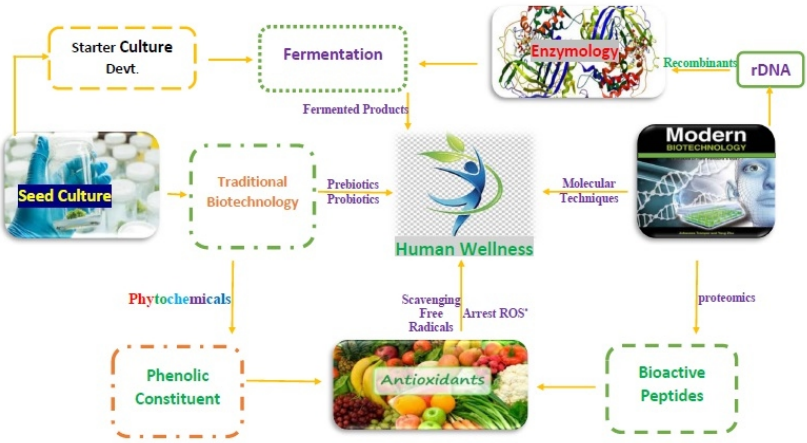

Fig. 1: The inter-play of traditional and modern biotechnology on human wellness

This is also important in achieving economic viability and at the same time improving food and household security among the diverse populations (Osundahunsi et al., 2016).
The key element in biotechnology involves the identification of

desirable traits and advantageous qualities in traditional ecosystems and biodiversity, and exploitation of those needed traits for the betterment of human populations. Harnessing the important innate nutrient composition and active phytochemical constituents (bioactive components) of local biodiversity starts with their delineation and classification using harmonized tools. Fortunately, the Food and Agricultural Organisation (FAO) of the United Nations has developed a software for the calculation of nutrient values and grouping of data for key factors under archival, reference and user databases.

2.0 HARNESSING THE POTENTIALS OF LOCAL BIORESOURCES

The key component of biotechnology application for addressing the many nutritional and health challenges in the third world is the exploitation of local biodiversity. This can only be possible if adequate information on these locally available bioresources are clearly delineated and properly researched, with a view to maximizing their potential nutritional and health benefits, as well as the best cultural and agro-ecological conditions for their exploitation. This was the drive when in the year 2008 I made significant contributions to *The Encyclopedia of Fruit and Nuts* on six neglected and underutilized edible fruits and nuts that have high medicinal values and have been recognized as potent nutrient sources, namely, African oil bean (*Pentaclethra macrophylla*), African breadfruit (*Treculiar africana*), conophor nut (*Tetracarpidium conophorum*), wild soursop (*Annona senegalensis*), African walnut (*Coula edulis*) and African apricot (*Mammea africana*) (Enujiugha, 2008). If local biodiversity and traditional bio-resources are adequately tapped and effectively utilized, there will be, as a consequence, great improvements in agricultural productivity (Enujiugha, 2017). The need for effective collaboration between all stakeholders and increased advocacy and enlightenment of local farmers to the rich natural endowments of their immediate ecosystems is, therefore, greatly underscored. Reliable and comprehensive data on food composition are essential for a diversity of purposes; namely, nutrition and health assessment,

formulation of appropriate dietary guidelines, nutrition education, food and nutrition training, epidemiological research, plant breeding, nutrition labeling, food regulations, consumer protection, agricultural goods and products, a variety of applications in trade, research, development and assistance (Sanusi et al., 2017).

2.1 The Food Composition Database of Indigenous Biodiversity

My work on the exploitation of local bioresources via the compilation of food composition database started early in my academic career. My first venture was to add value to locally available food crops towards increasing and encouraging their wider exploitation. This prompted me to seek to develop sweetened fruit wine from pawpaw (*Carica papaya*) in my undergraduate project work in 1986. By 1990, I had developed a peanut butter-like food paste and bread spread from African oil bean seed (*Pentaclethra macrophylla* Benth) grouped under the category of neglected and underutilized seeds. This formed the core of my M.Sc research work and dissertation. In 2001, the need for value addition to our local foods led to the application of thermal processing and aseptic packaging for starter culture-fermented African oil bean seeds in appropriate media under optimal conditions, as the main thrust of my PhD research work and thesis. All these activities were carried out at the Obafemi Awolowo University (formerly, University of Ife), Ile-Ife, Nigeria. In addition, as Research Scientist with Mail-In Oilfield Services between 1993 and 1995, I was saddled with the responsibility of collating data on both flora and fauna (terrestrial and aquatic) across the two main vegetation covers (mangrove and rainforest ecosystems) for the publishing of Niger Delta Environmental Survey (NDES). The pollution parameters that could indicate potential vulnerability of edible aquatic flora and fauna, and by extension impact negatively on human health, have been clearly outlined (Enujiugha and Nwanna, 2004).

Mr Vice Chancellor Sir, it was at the University of Chester in United Kingdom during the 2007 Chester International Food Science and Technology Conference that we realized, during interactions among African participants, that for a meaningful work in food composition, there was need for training and re-training of

participants, and that interdisciplinary cooperation and networking was important. And so in 2009, I participated in a three-week training workshop on food composition database management and local bioresource exploitation at the Food and Agricultural Organisation (FAO) regional office in Accra, Ghana, jointly sponsored by West African Health Organisation (WAHO), Bioversity International and International Network of Food Data Systems (INFOODS). This was followed up by various consultations at the ECOWAS Commission, Abuja, Nigeria and led to the publishing of a compact food composition database for selected West African foods (Stadlmayr et al, 2010). This work (Plate 1) became the first food composition table for West African Traditional Foods.

Plate 1: First Compositional Work on West African Foods

These data represented the average values of the collected compositional data and formed a subset of the archival database that was compiled from seven countries (Benin, Burkina Faso, Ghana, Guinea, Niger, Nigeria and Senegal) and domiciled in the FAO/INFOODS website. Altogether, data from more than 1,500 food items were compiled, out of which 173 foods (classified in 13 food groups) and 30 components were selected for the user database and tables.

At an interactive session during the International Scientific Symposium on "Biodiversity and Sustainable Diets: United Against Hunger" held in Rome at FAO Headquarters, from 3 to 5 November, 2010, as part of the World Food Day/Week programme, there was unanimous decision to expand the scope of food composition database for West Africa, to include compositional data from Mali and Gambia as well as expand authorship and insert some missing nutrient values. The result of this consultation of key stakeholders was the publishing of West African Food Composition Table (Stadlmayr et al., 2012) (see Plate 2), which extended and updated the number of foods and values of components through data derived from the Mali Food Composition Table 2004, unpublished data from Nigeria, as well as analytical data from scientific articles.

Plate 2: Revised and Expanded Food Composition Table for West Africa

These tables included 472 foods and 28 components in the user database, with greater emphasis given to inclusion of data on food biodiversity by incorporating cultivars/varieties and underutilized foods, as well as wild forest seeds and nuts. For these foods, the country of origin of the cultivar/variety was reported, next to the

food name. Analytical data were supplemented with data from other sources mostly from outside Africa, essentially to complete the missing values, especially for minerals and vitamins. It was intended to have no missing values but for some vitamins, especially vitamins A and E, data were not available and no sources were found from which to derive reliable data. In these cases, they were left blank.

During the AFROFOODS Sub-Regional Coordinators Meeting and Regional Workshop on "Food Composition, Dietary Diversity and Food Security in Africa" held in Abuja, Nigeria in 2011, there was a clear identification of an urgent need to affect teaming rural populations in the respective countries positively, by compiling database of foods peculiar to them in their own local names, and this gave rise to series of consultations among Nigerian participants on publishing a food composition table of wholly Nigerian foods. With funding from Nestle Nig. Plc and logistic support of Food Basket Foundation, further workshops, training programmes and consultations were held by the Nigeria Foods Database Network (NIFOODS) at the University of Ibadan (hosted by the Department of Human Nutrition and Dietetics) between 2012 and 2016, and this led to the publishing of a harmonized edition of the Nigerian Food Composition Table in 2017 (Sanusi et al., 2017) (see Plate 3).

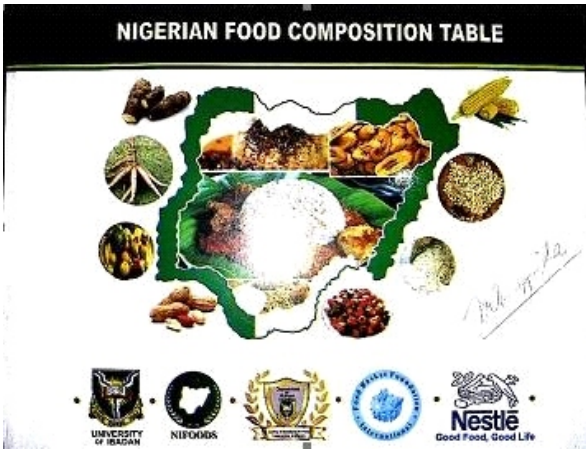

Plate 3: Food Composition Table for Nigerian Local Biodiversity

The emphasis here was to assemble original data on foods consumed in the hinterlands in Nigeria, and collated data were on sixteen (16) food groups with the inclusion of local names. In all these, I was fully involved as a major resource person. Currently, more consultations are ongoing to update the national and sub-regional food composition databases, with a view to including newly discovered foods and technology-driven novel foods.

2.2 My Research Works on Local Biodiversity and Traditional Foods

Mr Vice Chancellor Sir, my research adventure into the special area of unearthing and identifying the food and nutrient potentials of indigenous biodiversity has spanned many food groups broadly categorized into six, namely, underutilized legumes, oilseeds and nuts; cereals and pseudo-cereals; local conventional and unconventional beverages; fruits and vegetables; starchy roots and tubers; and oyster mushrooms. I will therefore assay to outline some of the discoveries made by my research group on the vast nutrient potentials of our local biodiversity.

2.2.1 Underutilised legumes, oilseeds and nuts

2.2.1.1 Composition and nutritional qualities of whole seed flours

The proximate chemical composition and energy values of some selected oilseeds and nuts (African oil bean, castor bean, locust bean, egusi melon and conophor nut), which are either fermented and used as seasonings and condiments, or eaten as cooked and prepared snacks, are presented in Table 1.

Table 1: Proximate chemical composition (g Kg^{-1}DM) and energy values (Kcal Kg^{-1} DM) of selected legumes and oilseeds (mean±s.e.m*)

Oilseed	Crude Protein	Crude fat	Crude fibre	Ash	Nitrogen free extractives (by difference)	Energy
Castor bean	201.8 ± 1.6	449.6 ± 2.0	31.4 ± 0.1	47.6 ± 0.4	129.5 ± 3.0	5789.2 ± 36.4
Conophor nut	227.5 ± 0.9	491.8 ± 1.1	55.4 ± 0.1	30.1 ± 1.0	140.9 ± 1.3	5900.0 ± 18.7
Locust bean	290.6 ± 1.2	261.9 ± 0.3	67.1 ± 2.5	25.0 ± 0.1	154.7 ± 6.7	4138.3 ± 34.3
'Egusi' melon	314.1 ± 7.2	439.3 ± 2.7	66.2 ± 0.5	47.9 ± 0.1	39.6 ± 0.4	5368.6 ± 54.7
Oil bean	206.3 ± 0.5	522.8 ± 0.6	90.7 ± 0.1	9.2 ± 0.0	26.9 ± 0.9	5637.8 ± 11.0

*s.e.m.= standard error of mean.

Although high in essential nutrients, their consumption and utilisation vary within the context of local preferences. Cowpea, for instance, is mainly utilised in the production of bean cake (akara), pudding (moinmoin) and porridge, which are delicacies among target populations. Pigeon pea, velvet bean, lima bean and sword (or jack) bean are cooked and eaten in form of porridge. Conophor nut is only utilised as a cherished boiled snack that is eaten along with boiled corn. Locust bean, castor bean, mesquite seed and African oil bean are consumed as fermented condiments and seasonings. Bambara nut is used in the production of a hard mash that is consumed as snack, or is fermented and used as a condiment in local soups and porridges.

The African oil bean tree *Pentaclethra macrophylla* Benth (*Leguminosae*, subfamily *mimosoidae*) is a large leguminous, nodule-forming multipurpose tree species occurring naturally in the humid lowlands and some parts of the sub-humid zones of West and Central Africa (Enujiugha, 2008). The edible part of the plant is the seed which can be consumed as roasted snack, or as fermented condiment in soups and porridges (Enujiugha and Olagundoye, 2001; Enujiugha et al., 2008). Enujiugha and Agbede (2000) examined the nutritional and antinutritional characteristics of African oil bean seeds and found that this underutilized food resource has high nutrient potentials to enrich local diets. The seed contains on dry matter basis, 33.41% crude protein, 48.5% crude fat, 6.28% crude fibre, 2.37% total ash and 8.93% carbohydrates. In the local areas where animal protein and conventional vegetable protein sources are scarce, the fermented African oil bean seed product "ugba" has been effectively utilized in the local diet as a meat analogue and protein source (Enujiugha and Akanbi, 2010; Enujiugha et al., 2002). This particular product is consumed by more than 40 million rural populations in the west coasts of Africa, especially in eastern parts of Nigeria (Enujiugha et al., 2002). Although the raw seed contains 0.4 HU/100g of hemagglutinins (lectins) and other antinutritional and toxic factors, the processing conditions it is usually subjected to (cooking, soaking and washing, fermentation) have been found to remarkably eliminate or

substantially reduce the concentrations of these factors to acceptable levels (Enujiugha, 2000, 2003a, 2005a; Enujiugha and Olagundoye, 2001; Enujiugha et al., 2004). Germination has also been employed as a relevant step in reducing the antinutrients in the seeds while at the same time increasing their nutritional and functional properties (Enujiugha et al., 2003).

Cooked conophor nut (*Tetracarpidium conophorum*) called ukpa or asala is a popular snack in southern Nigeria. The conophor plant (*Tetracarpidium conophorum* Mull. (Arg) Euphorbiaceae), commonly called the African walnut, is a perennial climbing shrub found in the moist forest zones of sub-Saharan Africa (Enujiugha, 2008). The proximate chemical composition of freshly harvested mature conophor nut showed that it contains on a dry weight basis, 29.09% protein, 6.34% fibre, 48.9% oil, 3.09% ash and 12.58% carbohydrates (Enujiugha, 2003b). The elemental concentrations in the raw conophor nut showed it has a high phosphorus content (465.95 mg/100g); cadmium and nickel were very low (0.01 and 0.38 mg/100g, respectively). A bitter after-taste is usually observed upon drinking water immediately after eating conophor nut and this could be attributed to the presence of alkaloids and other anti-nutritional and toxic factors. Enujiugha and Ayodele-Oni (2003) reported the presence of significant concentrations of oxalates, phytates and tannins in raw conophor nut, but hydrothermal treatment and soaking lead to improved bioavailability of nutrients, as some of these antinutritional factors usually leach into the processing water.

Oilseeds and legumes share one common quality, which is the reasonably high protein content. The protein contents of most legumes and oilseeds range between 200-400 g kg^{-1} DM and that contrasts with the low-protein starchy staples in tropical and sub-tropical countries (Enujiugha, 2005a). The nutrient potentials of some underutilized legumes and oilseeds are presented in Tables 2 and 3.

Table 2: Approximate nutrient contents in some underutilized legumes and oilseeds (% dry wt)

Legume/oilseed	Crude protein	Oil content	Crude fibre	Ash	Carbohydrate
Phaseolus vulgaris	17.75	1.13	-	4.79	76.33
Tetracarpidium conophorum	29.09	48.90	6.34	3.09	12.58
Pentaclethra macrophylla	33.42	50.15	7.64	4.02	4.77
Citrullus vulgaris	31.41	43.93	6.62	4.79	3.96
Parkia biglobosa	29.06	26.19	6.71	2.50	15.47
Sphenostylis stenocarpa	20.67	5.81	-	3.87	60.09
Mung bean	23.56	0.37	1.10	3.00	59.92
Lathyrus sativus	23.60	1.30	5.00	2.90	63.50

Table 3: Mineral contents of some less-common legumes and oil seeds (mg 10^{-2} g^{-1} dry wt)

	Na	K	Ca	Mg	P	Zn	Fe	Cu
Phaseolus vulgaris	-	554	66.6	43.8	496	7.51	6.88	1.01
Tetracarpidium conophorum	4.00	590	42.06	57.37	465.95	6.84	1.55	1.56
Pentaclethra macrophylla	40	91	30	30	112	40	30	-
Parkia biglobosa	29.0	400.0	150.0	212.0	285.0	3.0	12.0	-
Sphenostylis stenocarpa	5.38	6.19	8.35	12.07	218	6.92	5.11	5.85
Lathyrus sativus	60.5	1098	156	150.0	482	6.7	9.7	2.4

The amino acids profiles for some of these seeds are comparable to the FAO reference protein, although some are limiting in the sulfur amino acids (cysteine and methionine). The principal fatty acids are linoleic, linolenic and oleic acids. It has been reported that linoleic, α-linolenic and docosahexaenoic acids are essential to the well-being, growth and development of children, especially breast-fed infants during the first six months. This underscores the great potential of most of the underutilized crop seeds as weaning food ingredients. The seeds and nuts are also high in phosphorus and potassium; and a K/Na ratio of >1 is desirable since an average human diet is low in potassium and high in sodium.

2.2.1.2 Enriching the seeds through appropriate processing and preservation

Conventional and adaptable techniques for the processing of underutilized legumes and oilseeds has significantly helped in maximizing their nutrient bioavailability and enhancing their textural and sensory profiles (Enujiugha, 2005a; Enujiugha and Akanbi, 2002). Legumes generally contain lysine in amounts slightly lower than in beef and milk, but they are known to be generally low in cysteine and methionine which are the sulphur

amino acids. However, the problem with processing under-exploited legumes and oilseeds is the rigorous, energy-consuming operations involved in the traditional methods, namely, lengthy hydrothermal treatment and soaking and fermentation procedures. These processing operations considerably reduce the levels of anti-nutritional and toxic factors, but at the same time drastically affect their contents of some important nutrients. The loss of nutrients, especially vitamins and minerals is expected, although the fermenting microorganisms which are mainly bacteria species tend to contribute to the nutrient composition of the respective products. Lower nutrient contents have been observed with the traditional processing of some oilseeds (Enujiugha, 2005a). However, fermentation as a processing and preservation technique has been reported to enhance nutrient status and improve nutrient bioavailability through the reduction of antinutrient composition. For example, Nwanna et al. (2005) examined fungal fermentation of Bambara groundnut, and reported that *Penicillium* sp. and yeast fermentation brought about improvements in the nutritional quality of the underutilized legume seed.

Enujiugha et al. (2012a) and Olotu et al. (2014a,b) have critically examined the influence of combined γ-irradiation (an effective preservation method to curtail microbial infestation and spoilage) and cooking on the physicochemical properties as well as on the amino and fatty acid profiles of African oil bean seed. In the work of Enujiugha et al. (2012a), combination of γ-irradiation (5 kGy, 10 kGy) and cooking increased nutrient bioavailability in the seed and led to improvement in the functional properties. Combined treatment led to the retention of sodium, calcium, zinc and iron more than the single treatments, but the same process reduced magnesium from 0.52 mg/100g to 0.47 mg/100g and phosphorus from 0.43 mg/100g to 0.35 mg/100g. The reduction of all the antinutritional factors by combined γ-irradiation and cooking increased nutrient bioavailability and protein digestibility as these antinutritional factors are known to bind protein and other nutrients. Further work by Olotu et al. (2014a) revealed that the combined treatment retained essential amino acids valine, isoleucine, methionine, threonine, phenylalanine and leucine in the seed.

2.2.1.3 Composition and performance of seed oils

Talabi and Enujiugha (2014) extracted oils from some underutilized and neglected oilseeds (castor bean seed *Ricinus communis* L., African oil bean seed *Pentaclethra macrophylla* Benth, African locust bean seed *Parkia filicoidea* Welw, and "egusi" melon seed *Citrullus vulgaris* L.) and found their percentage oil yields as follows: castor bean 42.22±0.51%, African oil bean 43.75±0.85%, locust bean 20.68±0.71% and "egusi" melon 45.52±0.82%. These values are indicative of the high potentials of the seeds for viable commercial vegetable oil production. The results of refractive index for all the oil samples were within the range 1.452 – 1.464, which is a clear indication of their relative purity. Specific gravity values fell within the range obtained for other vegetable oils. Locust bean seed oil with high saponification value (358.69 mg/g) contained low molecular weight fatty acids and may not be useful in some non-edible processes like soap making. The acid values (1.80 -2.83 mg/g) were within the range commonly reported for most unrefined vegetable oils. It is expected that refining the oils would reduce their predisposition to rancidity. Some physical treatments have also been found to affect the quality of the oils. For example, γ-irradiation of *Pentaclethra macrophylla* seed at 10 kGy slightly raised the peroxide value but significantly ($p<0.05$) lowered the free fatty acid content of the seed oil (Enujiugha et al., 2012a). The same treatment also raised the content of linoleic acid (which is the principal fatty acid in the seed oil) from 53.63% to 78.17% of the total fatty acids (Olotu et al., 2014b).

Frying performance of crude melon (*Citrullus vulgaris*) seed oil, conophor nut (*Tetracarpidium conophorum*) oil and African oil bean (*Pentaclethra macrophylla*) seed oil was investigated by assessing the physicochemical changes of the oils during frying of plantain, yam and potato chips (Oyinloye and Enujiugha, 2017). The chips were fried in each oil for two minutes, packaged and stored at room temperature. Lipids were extracted from the stored chips at two-week intervals and analyzed for acid value, peroxide value, iodine value, saponification value and free fatty acids. Conophor nut oil had free fatty acid (FFA) values of 1.86 mg/g before frying and 10.66 mg/g after frying, while melon seed oil had

FFA values of 1.02 and 2.26 mg/g before and after frying respectively (Tables 4a,b).

Table 4a: Physicochemical properties of selected seed oils

Parameter	Soybean Oil	Melon seed oil	Conophor nut oil	AOB Oil
R.index	1.45[a]	1.48[a]	1.47[a]	1.47[a]
Specific Gravity (g/cm)	0.87[a]	0.91[a]	0.89[a]	0.97[a]
Viscosity (CP)	44.13[b]	46.63[a]	33.13[c]	36.23[d]
Smoke point (°C)	178.50[b]	184.00[a]	122.00[d]	163.00[c]
Flash point (°C)	288.00[b]	318.00[a]	156.00[d]	210.00[c]
Fire point (°C)	319.00[c]	336.00[a]	202.00[d]	287.00[c]
Acid value (mg/g)	3.37[b]	2.02[d]	3.70[a]	3.07[c]
Iodine Value (mg/g)	159.90[d]	177.70[c]	276.64[a]	206.00[b]
Peroxide Value (mg/g)	21.00[b]	9.40[c]	42.00[a]	7.00[d]
Saponification Value (mg/g)	153.24[c]	160.25[b]	120.31[d]	178.00[a]
Free fatty Acids (mg/g)	1.69[b]	1.02[d]	1.86[a]	1.54[c]
Unsaponifiable Matter (%)	2.42[a]	2.81[a]	1.42[b]	1.92[ab]
Ester Value (mg/g)	149.87[b]	158.23[a]	83.33[d]	147.33[c]

*Values with the same letter superscripts on the same row are not significantly different at $p < 0.05$
Legend: A.O.B Oil - African Oil Bean seed oil

Table 4b: Physicochemical properties of the oils after frying

Parameters	Soybean oil	Melon seed Oil	Conophor nut Oil	AOB Oil
R. index	1.47[a]	1.47[a]	1.47[a]	1.47[a]
Viscosity(CP)	42.57[d]	45.92[c]	57.21[b]	61.70[a]
Smoke Point (°C)	148.00[b]	142.00[c]	138.00[d]	160.00[a]
Flash Point (°C)	282.00[a]	220.00[c]	182.00[d]	250.00[b]
Fire Point (°C)	330.00[a]	300.00[c]	210.00[d]	310.00[b]
Acid Value (mg/g)	3.44[d]	4.49[c]	21.21[a]	12.34[b]
Iodine Value	456.84[b]	406.08[c]	492.37[a]	352.78[d]
Peroxide (mg/g) Value(mg/g)	30.00[c]	40.00[b]	60.00[a]	20.00[d]
Saponification Value (mg/g)	218.79[a]	75.74[c]	74.33[d]	183.73[b]
Free Fatty Acids (mg/g)	1.72[d]	2.26[c]	10.66[a]	6.20[b]
Ester Value (mg/g)	216.55[a]	71.25[d]	137.73[c]	171.39[b]

*Values with the same letter superscripts on the same row are not significantly different at $p < 0.05$
Legend: A.O.B Oil - African Oil bean seed oil

Melon seed oil fried products had the highest sensory ratings with general acceptability scores of 7.50, 7.57 and 6.60 for potato, plantain and yam chips respectively. Conophor nut oil fried products had the least general acceptability scores of 3.80, 4.20 and 3.42 for potato, plantain and yam chips respectively. Chips fried in conophor nut oil had a greater rate of accumulation of peroxide and free fatty acids over the 4 weeks of storage having peroxide values of 9.44, 35.73 and 11.96 mg/g for potato, plantain and yam fried chips respectively in the second week of storage. These increased to 13.93, 87.14 and 16.00 mg/g by the fourth week of storage. Chips fried in Melon seed oil had the least accumulation of peroxides with

peroxide values of 0.73, 19.22 and 10.32 mg/g for potato, plantain and yam fried chips respectively in the second week and 12.61, 23.21 and 14.00 mg/g in the fourth week. Among all three frying oils, melon seed oil was the most stable while conophor nut oil generally exhibited the least chemical stability during frying. Conophor nut oil fried products were least accepted while melon seed oil fried products were the highest rated. The results showed that melon seed oil and African oil bean seed oil were suitable frying oils while conophor nut oil was an unstable frying oil due to its poor physicochemical changes during and after the frying process.

2.2.2 Cereals and pseudo-cereals

Cereals contain water-soluble fiber (such as β-glucan and arabinoxylan), oligosaccharides (such as galacto- and fructo-oligosaccharides) and resistant starch, and thus have been suggested to fulfill the prebiotic concept (Enujiugha and Badejo, 2017). Fermented maize product, ogi, is a popular starchy porridge in the west coasts of Africa. Although consumed by adults as a breakfast cereal, its main use is as a weaning food for infants (Enujiugha, 2006). In parts of Africa to the south of Sahara, fermented ogi slurry could also be obtained from sorghum (*Sorghum bicolor*) or millet (*Pennisetum typhoides*), but maize (*Zea mays*) is the most common base for ogi manufacture. Ogi is commonly reconstituted with boiling water (to form a semi-solid gruel called akamu, or allowed to cool to form a steamed pudding called agidi or eko) (Enujiugha and Badejo, 2017) and consumed, either alone or with bean meal (moinmoin) or bean cake (akara) as accompaniment (Oluwamukomi et al., 2005a). Ogi is traditionally prepared by natural fermentation (steeping maize grains in water for 2–4 days at room temperature), followed by wet milling, sieving and souring of slurry (2–3 days rest at room temperature) (Enujiugha, 2006). Ojo and Enujiugha (2016) examined the chemical composition, physico-chemical properties, and acceptability of instant 'Ogi' from blends of fermented maize, conophor nut and melon seeds and found that conophor nut/melon/ogi flour with improved nutrient composition, sensory quality and pasting properties that is comparable to the traditional fermented maize 'ogi' flour can be obtained up to 80:10:10 ratio. However, increased supplementation with conophor

nut and melon seed flour increased the anti-nutrient contents. In another study (Ojo and Enujiugha, 2018), it was found that germination and co-fermentation improved the nutritional qualities of 30% *Kerstingiella geocarpa* substituted 'ogi'. In terms of consumer acceptance, the germinated samples had higher level of acceptance than the ungerminated ones but the germinated probiotic sample had the highest acceptability score. Therefore, germination and probiotic co-fermentation could be adopted as an improved treatment for commercial production of 30% *Kerstingiella geocarpa*-maize 'ogi'.

Apart from ogi, various other cereal-based fermented products and/or snack foods have found their way into an average African cuisine. Other maize-based products commonly consumed in rural areas include elekute (Oluwamukomi et al., 2005b; Lawal and Enujiugha, 2016), agidi (Akinola et al., 2015), aadun (Adeyanju et al., 2016; Akinola and Enujiugha, 2017), and kokoro (Adeyanju et al., 2019). The key efforts being made by researchers boil down to improving the nutrient content through amino acid complementarity and protein enrichment towards reducing the generally prevailing protein-energy malnutrition (PEM). Fortunately, positive results are achieved in this regard. Some pseudo-cereals, especially seeds of the *Amaranthus* family, have also been examined.

Esan et al. (2018a) carried out research on the biochemical and nutritional compositions of two accessions of *Amaranthus cruentus* (an underutilized and neglected pseudo-cereal) seed flour. The two accessions of *Amaranthus cruentus* (PI538319 and PI538326) showed high protein values of 15.5 and 16.1% (Table 5), while the values of essential amino acid recorded were 32.84 and 32.90 g/100g protein, respectively. Lysine, which is known to be deficient in most cereals, was found to be relatively high with values of 3.50 and 3.71 g/100g protein, respectively.

Table 5: Proximate composition of two accessions of *Amaranthus cruentus* (PI538319 and PI538326) flours

Sample	PI 538319	PI 538326
Crude protein (%)	15.5^{b}	16.1^{a}
Moisture content (%)	8.3^{a}	7.2^{b}
Total ash (%)	3.1^{a}	2.5^{b}
Crude fat (%)	8.0^{a}	7.8^{b}
Crude fiber (%)	3.9^{b}	4.1^{a}
*Carbohydrate (%)	61.2^{a}	62.3^{a}
Energy value (MJ kg^{-1})	16.0903	15.8554

*= Calculated by difference. Values followed by different letters in a row are significantly different ($p>0.05$).

The percentage ratio of the essential to non-essential amino acids was in the range of 42 – 45%. With reference to FAO/WHO (2007) standard, the chemical scores showed that most of the essential amino acids in the two accessions of *Amaranthus cruentus* were present in high amounts when compared with other grain sources. Thus, with the nutritional composition and amino acid profiles, it shows that this seed flour can fulfill the protein requirements of an adult human being. The percentage of bran fraction (embryo and seed coat which is smooth and thin) is higher in amaranth when compared with common cereals, which explains the higher level of protein and fat present in the seeds. The limiting amino acid in PI538319 was found to be the sulphur-containing amino acids (methionine + cysteine) while the first and second limiting amino acids in PI538326 were found to be isoleucine and sulphur-containing amino acids.

Esan et al. (2019) hydrolysed *Amaranthus cruentus* Pi538326 and *Amaranthus caudatus* PI595951 using three different digestive enzymes. The hydrolysates were sequentially hydrolysed using porcine pancreatin+pepsin; porcine pancreatin+pepsin+trypsin. The amino acid composition of the seed flours, protein isolate and hydrolysate were determined and the protein quality was evaluated.

Glutamic acid and aspartic acid were the most abundant amino acid in both the seed flours, protein isolate and hydrolysate respectively. The predicted protein efficiency ratio and the predicted biological value ranged from 1.52 – 2.57 and 14.78 - 77.56 respectively. Lysine, the essential amino acid limiting in cereals, is readily available in the seed flour and hydrolyzed samples. The first and second limiting amino acids in PI538326 seed flour are isoleucine and sulphur containing amino acids; and protein isolate are sulphur group of amino acids; while the protein hydrolysate samples are all in excess when compared with the FAO/WHO (2007) standards. In addition, the first and second limiting amino acids in PI595951 seed flour are the sulphur amino acid group and isoleucine; protein isolate is only limiting in sulphur amino acid group; and the sample hydrolyzed with porcine pancreatin+pepsin is limiting only in valine and other hydrolyzed sample with three enzymes is available in excess as against the standard. The seed flours, protein isolate and hydrolysate contained adequate essential amino acids required by growing school children and adults. It could also be used as a protein supplement in cereal based complementary diets.

2.2.3 Beverages

Studies have been carried out on the properties of tea (*Camellia sinensis*) and ginger (*Zingiber officinale*), both of which are noted for their remarkable health benefits. The consumption of tea flavonoid has been linked to lower incidences of chronic diseases such as cardiovascular disease and cancer. Ginger is also known to possess anti-inflammatory, antinausea, anticarcinogenic, and antioxidant effects. Studies carried out on the aqueous (Makanjuola et al., 2016) and ethanolic (Makanjuola and Enujiugha, 2018) extraction of ginger indicated that the influence of extraction temperature, powder concentration, and extraction time on the antioxidant properties is quite significant. Tables 6 and 7 show the regression model parameters for antioxidant prediction in both aqueous and absolute ethanolic ginger extracts, respectively.

Table 6: Regression parameters for antioxidant prediction in aqueous ginger extract

	Components[1)]	R^2	Q^2	RMSE
TFC				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.926	0.497	354.857
PCR	L*, b*, hue, chroma, pH, A610, hue index	0.818	0.284	456.251
PLSR	A610	0.713	0.702	443.533
TPC				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.866	0.526	42.516
PCR	L*, b*, A610, hue index	0.763	0.524	41.260
PLSR	A610	0.753	0.748	36.467
DPPH				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.967	0.324	6.744
PCR	L*, b*, hue, chroma, pH, A610, hue index	0.905	0.644	9.305
PLSR	b*, chroma, A610	0.818	0.672	9.993
ABTS				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.688	0.321	0.183
PCR	L*, b*, A610, hue index	0.595	0.260	0.152
PLSR	L*, A510	0.521	0.417	0.143
1/(Peroxide scavenging activity)[2]				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.445	−0.175	0.000849
PCR	L*, b*, A610, hue index	0.103	−0.184	0.000788
PLSR	–[2)]	–	–	–
1/(Iron chelating activity)[2]				
OLSR	L*, a*, b*, hue, chroma, pH, redox potential, A510, A610, A510/610, hue index	0.843	−0.267	0.000135
PCR	L*, b*, pH, A610, hue index	0.451	−0.219	0.000191
PLSR	–	–	–	–

TFC, total flavonoid content; TPC, total phenol content; DPPH, 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity; ABTS, 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging activity; RMSE, root mean square error; OLSR, ordinary least square regression; PCR, principal component regression; PLSR, partial least square regression.
[1)]The component column shows the predictors present in the different regression equations.
[2)]No suitable model was found because the antioxidant property had no positive Q^2 with any of the PLSR components.

Table 7: Regression model parameters for antioxidant prediction in absolute ethanolic ginger extract

	Components	R^2	Q^2	RMSE
Total flavonoid content				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.974	0.885	475.563
PCR	A510/610, A610, hue index, a*, chroma, A510/610, b*, A510	0.967	0.894	471.118
PLSR	A510	0.886	0.875	635.598
Total phenol content				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.854	0.466	60.747
PCR	A510/610, A610, hue index, a*	0.796	0.587	54.883
PLSR	a*	0.639	0.542	61.356
DPPH				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.734	−0.133	6.945
PCR	A510/610, A610, hue index, a*, chroma	0.444	−0.299	8.011
PLSR	–[c]	–	–	–
(1/ABTS)[2]				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.820	0.645	0.0697
PCR	A510/610, A610, hue index, a*, chroma, A510/610, b*, A510	0.747	0.292	0.0730
PLSR	A610, a*	0.410	0.027	0.081
Peroxide scavenging activity				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.886	0.571	6.350
PCR	A510/610, A610, hue index, a*, chroma, A510/610, b*, A510	0.770	0.361	7.973
PLSR	chroma, A510/A610, A610, A	0.318	−0.233	9.986
(1/iron chelating activity)[2]				
OLSR	L*, a*, b*, hue, chroma, A510, A610, A510/610, hue index	0.709	−1.303	0.0000157
PCR	A510/610, A610, hue index, a*, chroma, A510/610, b*, A510	0.698	−0.454	0.0000103
PLSR	–	–	–	–

OLSR ordinary least square regression, *PCR* principal component regression, *PLSR* partial least square regression. The component column shows the predictors present in the different regression equations, *RMSE* root mean square error
[c]No suitable model was found because the antioxidant property had no positive Q^2 with any of the PLSR components

The studies also indicated that the absorbance and colour properties of ginger extract could be exploited for the prediction and rapid estimation of its total phenolics and total flavonoids content. The multiresponse optimization condition for aqueous extraction of ginger powder antioxidant based on the experimental range studied was 96 °C, 2.10 g/100 mL, and 90 min. For the absolute ethanolic extraction, powder-to solvent ratio was more influential in the extraction process than extraction temperature and extraction time, especially for total flavonoids. The response surface graphs showing multi-response optimization conditions for aqueous and ethanlic extraction of antioxidants from ginger powder are shown on Figures 2 and 3

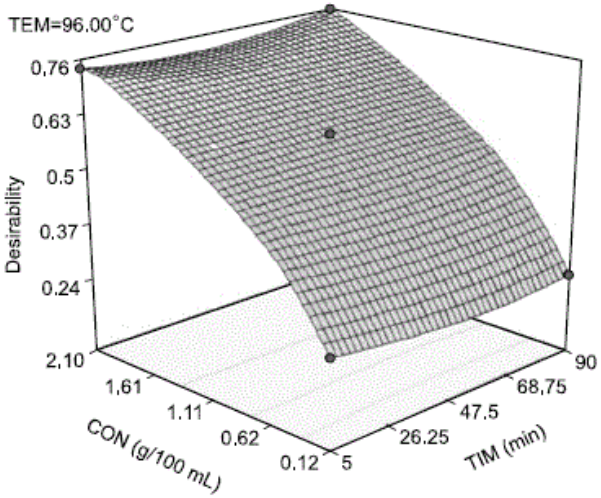

Fig. 2: Response surface graph showing multi-response optimization conditions for aqueous extraction of antioxidants from ginger powder. TEM, temperature; CON, concentration; TIM, time..

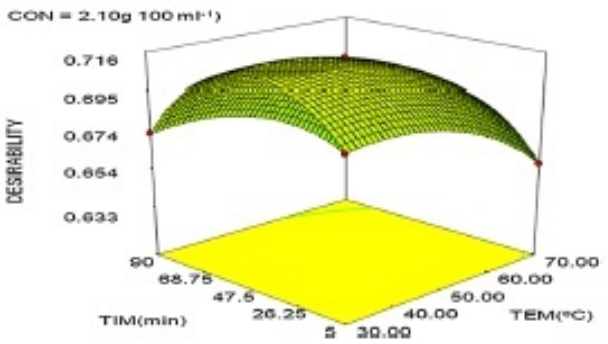

Fig. 3: Response surface graphs showing multi-response optimization conditions for ethanolic extraction of antioxidants from ginger powder

Combining tea and ginger at ratio of 2:1 has been reported to enhance consumer perception and acceptance of the beverage (Makanjuola and Enujiugha, 2017), and at the same time improve upon the health benefits derivable from its consumption (Makanjuola et al., 2015a,b,c). Extracts of tea-ginger blends exhibited synergistic effects in their ABTS and DPPH radical scavenging activity. Makanjuola et al. (2015a) investigated the influence of solvent on antioxidant content of tea, ginger, and tea + ginger blends. Under the investigated extraction conditions, water was the most effective extraction solvent to maximise peroxide scavenging and iron chelating activity of tea, ginger, and their blends. Aqueous ethanol was the most effective solvent to maximise ABTS radical scavenging activity and ethanol was the best solvent to maximise DPPH radical scavenging activity (Table 8).

Table 8: Antioxidant contents of tea, ginger, and their blends.

Solvent	Powder	Total flavonoid (mg CE L^{-1})	Total phenol (mg GAE L^{-1})	ABTS radical activity (mg TE L^{-1})	Peroxide scavenging effect (%)	Iron chelating effect (%)	DPPH radical activity (%)
Aqueous	Tea	725.0 c[1]	375.4 a	0.91 d	91.1 bc	90.4 f	12.3 f
Aqueous	Ginger	14.2 i	109.4 e	0.069 m	89.9 c	97.6 b	1.0 h
Aqueous	Tea-ginger 1:1	435.0 g	170.7 c	0.59 h	95.7 a	96.7 c	4.5 g
Aqueous	Tea-ginger 2:1	516.7 efg	219.8 b	0.77 g	92.4 b	96.1 d	4.1 g
Aqueous	Tea-ginger 1:2	297.5 h	169.5 c	0.48 j	91.1 bc	97.3 b	5.1 g
Aqueous ethanol	Tea	1558.3 a	137.7 d	0.94 c	76.4 h	82.0 i	5.7 g
Aqueous ethanol	Ginger	228.3 h	36.0 m	0.36 k	85.3 de	97.9 a	10.8 f
Aqueous ethanol	Tea-ginger 1:1	495.0 fg	60.5 k	0.95 b	78.4 g	89.4 g	43.8 e
Aqueous ethanol	Tea-ginger 2:1	558.3 ef	93.5 f	0.97 a	80.7 f	85.9 h	48.2 d
Aqueous ethanol	Tea-ginger 1:2	453.3 fg	70.6 h	0.79 f	83.9 e	93.2 e	42.6 e
Absolute ethanol	Tea	695.0 cd	87.6 g	0.89 e	76.4 h	37.8 m	74.6 b
Absolute ethanol	Ginger	453.3 fg	46.8 l	0.22 j	78.3 g	42.7 l	42.8 e
Absolute ethanol	Tea-ginger 1:1	803.3 bc	88.1 g	0.91 d	86.2 d	46.3 j	62.8 c
Absolute ethanol	Tea-ginger 2:1	886.7 b	65.6 i	0.89 e	78.8 g	45.6 k	86.7 a
Absolute ethanol	Tea-ginger 1:2	611.7 de	63.5 j	0.56 i	73.0 i	46.1 j	75.4b

Mean scores followed by same letter within a column are not significantly different (P>0.05). Results expressed as means of triplicate measurement.

Makanjuola et al. (2015b,c) investigated the multiresponse optimisation and prediction of antioxidant properties of both aqueous and ethanolic extraction of tea-ginger (2:1) powder for beverage production. Tables 9 and 10 show the response surface models and the comparative analysis of regression techniques for antioxidant prediction for both aqueous and ethanolic extracts, respectively.

Table 9: Response surface model for aqueous extraction of tea-ginger 2:1 powder

Source	Total flavonoid content (mg CE/L)	Total phenol content (mg GAE/L)	ABTS (mg TE/L)	Peroxide scavenging activity (%)	Iron chelating activity (%)	DPPH (%)
Transformation	Sqrt(TF)	Log_{10}(TP)				
INTERCEPT	−3.3900	2.5773	0.7858	36.9479	89.1034	11.1457
TEM	1.1710	1.7622E-3				
CON	11.0702	0.6350	0.05296	31.1367		
TIM	0.4244		4.2216E-3	−0.75464		
TEM*CON	0.2970					
TEM*TIM						
CON*TIM			−1.063E-3			
TEM^2	−9.4820E-3					
CON^2		−0.1726		−12.1169		
TIM^2	−4.2766E-3		−2.534E-5	8.5620E-3		
Model (p-value)	<0.0001	<0.0001	0.0023	0.0091		
Lack of Fit	0.4347	0.6804	0.2478	0.9832	0.5713	0.8670
R^2	0.9639	0.8873	0.6485	0.5721	0	0
Adj R^2	0.9472	0.8662	0.5547	0.4580	0	0
Pred R^2	0.9018	0.8106	0.1755	0.3273		
Adeq Precision	23.406	17.274	8.203	9.464		

TEM, temperature; CON, concentration; TIM, time; Adj R^2, adjusted R^2; Pred R^2, predicted R^2; Adeq Precision, adequate precision; Sqrt(TF), square root of total flavonoid; Log_{10}(TP), Log of total phenol.

Table 10: Response surface model for ethanolic tea-ginger (2:1) extraction

Source	TFC	TPC (mg)	ABTS	PSA	ICA	DPPH
Transformation	Square root	Square root				
INTERCEPT	-70.3393[a]	36.8798	0.9615	30.3143	57.8835	111.6115
TEM	3.1403	-0.08268	2.1437E-3	1.7701	0.3980	-0.9668
CON	30.5182	-7.7515	-0.01279	12.4191	-0.04034	-0.9648
TIM			-2.031E-4	0.1749		-4.353E-3
TEM*CON		0.2211		-0.2913	0.06233	-0.1244
TEM*TIM				-4.907E-3		
CON*TIM						-0.05581
TEM^2	-0.02700		-2.482E-5	-0.01724	-3.7205E-3	9.192E-3
CON^2						
TIM^2						
P-value Model	<0.0001	0.0051	0.0033	0.0008	<0.0001	<0.0001
Lack of fit	0.1577	0.3123	0.4551	0.6915	0.6082	0.1958
R^2	0.8982	0.5410	0.6298	0.7898	0.7815	0.9212
Adjusted R^2	0.8791	0.4550	0.5311	0.6928	0.7232	0.8848
Predicted R^2	0.8325	0.1271	0.1779	0.5397	0.6333	0.7396
Adequate precision	20.759	7.762	9.872	11.160	11.750	18.615

[a] *Regression coefficients are in actual factors.*

For the aqueous extraction, OLSR, PCR, and PLSR were able to provide predictive models for DPPH, TP, and TF of the tea-ginger extract ($P < 0.05$). The PLSR gave the most parsimonious model with an R^2 of 0.851, 0.736, and 0.905 for DPPH, TP, and TF, respectively. Results from the multi-response optimisation of ethanolic extraction revealed the optimum conditions as temperature of 50.16°C, concentration of 2.1 g/ 100 ml and time of 5 minutes with a desirability of 0.68. The PLSR gave the most preferable model among the three multivariate regression techniques investigated.

Badejo et al. (2017) developed beverage blends from gluten-free malted acha (*Digitaria exilis*) and tigernut (*Cyperus esculentus*) extracts, spiced with ginger extract. The radical scavenging abilities of the beverage blends were evaluated and the phenolic constituents were characterized by high-performance liquid chromatography with diode array detector (HPLC-DAD). The beverage blends showed good radical scavenging ability with 2,2-diphenyl-1-picrylhydrazyl (DPPH), however progressive increase in the proportion of tigernut extract in the blends resulted in significant decreases in radical scavenging by 2,2′-azino-bis- 3-ethylbenzothiazoline-6-sulphonic acid (ABTS) and ferric reducing antioxidant power (FRAP). Total flavonoid and total phenolic

content ranged from 0.24 to 0.50 mg rutin Eqv/mL and 0.20 to 0.30 mg gallic acid Eqv/mL, respectively. The beverages were found to be rich in phenolic acids (gallic acid, chlorogenic acid, ellagic acid and caffeic acid) and flavonoids (quercetin, kaempferol, quercitrin and rutin) with quercetin being the most dominant in all the blends. Progressive increase in the proportion of the tigernut extract in the beverages had positive significant ($P < 0.05$) effect on the flavour, taste, mouthfeel, appearance and overall acceptability. However, Babatuyi et al. (2019) evaluated the physicochemical, microbiological and sensory qualities of milk extract from three varieties of tigernut during storage and concluded that the attributes of tigernut extract produced and stored at ambient temperature (27±2 ℃) reduced with increase in storage days.

Ojo et al. (2017) carried out a comparative study on the effects of *Thaumatococcus daniellii* (Benn) Benth sweetener on the physicochemical and sensory properties of sorghum based kunun-zaki drink, and found that physicochemical composition of kunun-zaki varied with concentrations of *Thaumatococcus danielli* aril and sucrose. pH ranged between 3.90 and 4.90, total solid (4.95-13.49 %) and titratable acidity (0.78-0.39 %) for kunun-zaki sweetened with *Thaumatococcus danielli* while kunun-zaki sweetened with sucrose had pH (3.51-4.90), total Solids (4.95-7.43%) and titratable acidity (0.74-0.85), respectively (Table 11).

Table 11: Comparative study on the physicochemical properties of kunun-zaki with sucrose and *Thaumatococcus daninelli* aril

Sample	Concentration (g)	pH	Total solids	Titratable acidity
Sucrose	2.5	3.90^{cd}±0.10	9.15^{a}±0.22	0.93^{c}±0.04
	5.0	4.00^{cd}±0.00	10.23^{c}±0.14	0.82^{cd}±0.28
	7.5	4.15^{bc}±0.07	10.10^{cd}±0.14	0.78^{d}±0.02
	10.0	4.40^{b}±0.14	10.12^{cd}±0.16	0.81^{cd}±0.01
	12.5	4.40^{b}±0.35	11.85^{b}±0.32	1.39^{a}±0.14
	15.0	4.45^{b}±0.70	13.49^{a}±1.29	1.10^{b}±0.14
Thaumatococcus danielli	2.5	3.51^{e}±0.13	5.33^{gh}±0.16	0.74^{d}±0.29
	5.0	3.70^{cd}±0.01	5.81^{fgh}±0.12	0.77^{d}±0.10
	7.5	3.57^{e}±0.07	6.67^{ef}±0.14	0.82^{cd}±0.01
	10.0	3.75^{cd}±0.13	6.56^{ef}±0.15	0.85^{cd}±0.01
	12.5	3.97^{cd}±0.14	7.43^{e}±0.15	0.85^{cd}±0.04
	15.0	3.96^{cd}±0.14	7.23^{e}±0.66	0.83^{cd}0.07
control		4.90^{a}±0.14	4.95^{h}±0.11	0.80^{d}±0.01

Values with the same superscript down the column were not significant different ($p< 0.05$)

The study revealed that the addition of *Thaumatococcus danielli* aril to kunun-zaki could improve the nutrient status and consumer acceptability of the product. Ojo et al. (2019) investigated the chemical and sensory properties of kunun-zaki sweetened with serendipity berry (*Dioscoresphyllum cumminsii*) and enriched with defatted moringa seed flour. A constant defatted moringa seed flour value (0.6%) was added to each sample while serendipity berry and sucrose were added at varying proportions (0, 0.4, 0.8, 1.2, 1.6 and 2.0%) to a constant volume of 250 ml kunun-zaki. The results of the proximate composition, mineral element concentrations and sensory quality revealed that addition of serendipity berry to the millet-based kunun-zaki increased the protein content by 5.90-9.08% and reduced fat by 0.94-0.91%.

2.2.4 Fruits and Vegetables

Studies have been carried out on indigenous vegetables such as fluted pumpkin (*Telfeiria occidentalis*) and amaranth (*Amaranthus caudatus*) (Enujiugha et al., 2014), garden egg, igbagba (*Solanum macrocarpon*) (Famurewa and Enujiugha, 2003), okro (*Abelmoschus esculentus* L), marugbo (*Clerodendrum volubile*) and amaranth (Lawal et al., 2018), and snake tomato (*Trichosanthes cucumerina*) (Badejo et al., 2016); and on local fruits such as African star apple (*Chrysophylum albidum*) (Bobadoye et al., 2016), pumpkin (*Cucurbita mixta* and *Cucurbita maxima*) (Oyeleke and

Enujiugha, 2017, Oyeleke et al., 2019), wild soursop (*Annona senegalensis*) and African apricot (*Mammea africana*) (Enujiugha, 2008), and tomatoes (*Lycopersicon esculentum*) (Makanjuola et al., 2010a,b; 2012). The main thrust of these studies was to highlight the hidden potentials of these indigenous bioresources, vis-à-vis their high nutrient composition and remarkable bioactive properties.

Bobadoye et al. (2016) investigated the possible hypolipidemic and antioxidative effects of African star apple (*Chrysophyllum albidum*) juice in rats fed on high cholesterol and fatty diets. Twenty five male albino rats of the Wistar strain were divided into five groups of five each: a normal diet group, a high-cholesterol diet group, a high fat/cholesterol diet with 3 ml of African star apple juice group, a high fat/cholesterol diet with 6 ml of African star apple juice group, and a high fat/cholesterol diet with 9 ml of African star apple juice group. Blood serum, selected tissues and organs were collected and the serum lipid profile, organ histology and oxidative stress test were carried out at the end of the 28-day animal experimentation. The levels of total cholesterol, triglyceride, low density lipoprotein-cholesterol, very low density lipoprotein-cholesterol and artherogenic index obtained from rats treated with African star apple juice (3 ml, 6 ml and 9 ml) decreased significantly ($P \leq 0.05$), compared respectively to the high fat/cholesterol diet group (Table 12).

Table 12: Serum lipid profile of albino rats after 4 weeks consumption of experimental *C. albidum* diets (mg/dl).

Parameters	LFCD	HFCD	HFCD/3	HFCD/6	HFCD/9	US guideline
Cholesterol	109.81 ± 0.00^{d}	215.67 ± 3.19^{a}	182.77 ± 9.57^{b}	165.90 ± 5.53^{c}	169.74 ± 3.19^{c}	<240
Triglyceride	91.45 ± 0.00^{e}	187.48 ± 4.28^{a}	148.32 ± 0.00^{b}	128.15 ± 4.29^{c}	122.47 ± 4.29^{d}	<200
HDL-C	46.40 ± 2.97^{a}	20.10 ± 1.21^{d}	35.9 ± 4.20^{b}	26.40 ± 2.43^{c}	39.4 ± 3.21^{b}	≥10
LDL-C	45.12 ± 2.97^{d}	158.07 ± 3.50^{a}	117.21 ± 5.40^{c}	113.87 ± 6.48^{b}	105.85 ± 6.98^{b}	<160
VLDL-C	18.33 ± 0.00^{e}	37.65 ± 0.86^{a}	29.72 ± 0.00^{b}	25.76 ± 0.86^{c}	24.27 ± 0.86^{d}	
AI	0.93 ± 0.13^{e}	7.61 ± 0.50^{a}	4.09 ± 0.29^{d}	5.28 ± 0.62^{b}	3.31 ± 0.35^{c}	

Values in the table are expressed as mean ± SD for five Animals. Means in the same row with different superscripts are significantly different ($P < 0.05$).

Note: LFCD: Low Fat Cholesterol Diet; HFCD: High Fat/Cholesterol Diet; HFCD/3: High Fat/Cholesterol Diet+ 3 ml African Star Apple Juice; HFCD/6: High Fat/Cholesterol Diet+ 6 ml African Star Apple Juice; HFCD/9: High Fat/Cholesterol Diet+ 9 ml African Star Apple Juice; Cholesterol: Total Cholesterol; HDL-C: High Density Lipoprotein-Cholesterol; LDL-C: Low Density Lipoprotein-Cholesterol; VLDL-C: Very Low Density Lipoprotein-Cholesterol; AI: Atherogenic Index.

The results also showed that treatment with African star apple juice positively changed plasma antioxidant enzyme activities and lipid profiles in cholesterol-fed rats, and thus may have potential hypolipidemic and antioxidant effects, and by inference, the antiatherogenic properties in male rats. African star apple (*Chrysophyllum albidum*) juice could protect against oxidative stress linked atherosclerosis and decrease the atherogenic index, thereby supporting the local use of *Chrysophyllum albidum* in the management of atherosclerosis and hypertensive conditions.

Badejo et al. (2016) studied the changes in nutrient composition, antioxidant properties, and enzymes activities of snake tomato (*Trichosanthes cucumerina*) during ripening, and observed that the lycopene and β-carotene contents were especially high in the ripe pulp with values of 21.62±1.22 and 3.96±0.14 mg/100 g, respectively. The ascorbic acid content was highest in the pulp of unripe fruit with a value of 56.58±1.08 mg/100 g and significantly ($P<0.05$) decreased in the ripened fruits (Table 13).

Table 13: Antioxidant compositions of coat and pulp of *Trichosanthes cucumerina* at unripe and ripened stages

	Unripe		Ripened	
	Coat	Pulp	Coat	Pulp
Lycopene (mg/100 g)	10.82±0.96^{d}	12.64±0.44^{c}	18.28±0.91^{b}	21.62±1.22^{a}
β-Carotene (mg/100 g)	1.75±0.17^{d}	2.19±0.06^{c}	3.22±0.21^{b}	3.96±0.14^{a}
Phenolics (mg/GAE g)[1)]	0.81±0.06^{c}	1.85±0.13^{a}	0.97±0.08^{b}	0.74±0.11^{c}
Flavonoids (mg/RE g)[2)]	1.36±0.09^{c}	2.04±0.07^{a}	1.35±0.09^{c}	1.84±0.11^{b}
Ascorbic acid (mg/100 g)	39.32±0.88^{c}	56.58±1.08^{a}	32.36±1.77^{d}	51.09±0.61^{b}

Values are mean±SD of 3 replicates.
Different letters (a-d) within same row are significantly different (P<0.05) according to Duncan's multiple range test.
[1)]GAE: gallic acid equivalent.
[2)]RE: rutin equivalent.

The antioxidant potential of the fruits assayed using 1,1-diphenyl-2-picrylhydrazyl (DPPH), 2,2'-azinobis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) radical scavenging activities, and ferric reducing antioxidant power (FRAP) showed that, in terms of free radical scavenging capacity, unripe pulp> ripe coat> ripe pulp> unripe coat. There were decreases in the antioxidant enzymes (superoxide dismutase, ascorbate peroxidase, and glutathione reductase) activities, with the exception of catalase, as ripening progressed in the fruits (Table 14).

Table 14: Antioxidant enzymes activities in coat and pulp of unripe and ripened *Trichosanthes cucumerina*

	Unripe		Ripened	
	Coat	Pulp	Coat	Pulp
SOD	22.2±1.2^{a}	20.1±0.8^{b}	20.7±0.4^{b}	18.7±0.3^{c}
CAT	148.3±4.8^{d}	172.3±4.3^{c}	180.8±5.8^{b}	222.3±5.7^{a}
APX	443.5±11.5^{a}	404.2±8.7^{b}	257.8±10.7^{c}	193.7±8.3^{d}
GR	70.6±2.6^{a}	65.7±2.8^{b}	58.6±1.9^{c}	45.9±1.8^{d}

Values are mean±SD of 3 replicates.

Different letters (a-d) within same row are significantly different (P<0.05) according to Duncan's multiple range test. SOD, superoxide dismutase (U/g protein); CAT, catalase (nmol H_2O_2/g protein/min); APX, ascorbate peroxidase (nmol ascorbic acid/g protein/min); GR, glutathione reductase (nmol NADPH/g protein/min).

These decreased activities could have been the major cause of softening of the fruit during ripening. The study also showed that

Trichosanthes cucumerina is a fruit that is low in energy value but very rich in crude fibre, which is beneficial to humans as natural laxative.

2.2.5 Starchy roots and tubers

Roots and tubers refer to growing plants that store edible materials in subterranean roots, corms and tubers. Such agricultural products include yam, cassava, cocoyam, sweet potato, etc. Bobadoye and Enujiugha (2016) evaluated the glycaemic indices (GI) of some selected Nigerian boiled yam (*Dioscorea* spp) *in vivo* using healthy human volunteers based on fasting and postprandial glucose levels. Four different species of yam *Dioscorea* spp (*D. rotundata* (white yam), *D. alata* (water yam), *D. dumentorum* (trifoliate yam) and *D. cayenensis* (yellow yam)) obtained from the open market in Akure, Nigeria, were peeled, washed, cubed, weighed and boiled separately for 20 mins. Each of the yams was served as a meal in 50 g portions to ten healthy subjects (7 males and 3 females, average BMI=20.6 kg/m^2, average age=26 years). The subjects were required to go through the study protocol on five separate occasions (four tests for the test yam samples and one for the reference food i.e. glucose) after an overnight fast before being served the meals. Venous blood samples were taken immediately before (0 min) and 30, 60, 90 and 120 mins after consumption of the test foods. The blood glucose response was obtained by calculating the incremental area under the curve (IAUC) and the corresponding GI for each yam was determined and compared. The mean areas under blood glucose curves were 666.00, 646.41, 588.77 and 615.64 mol min/L for *D. rotundata*, *D. alata*, *D. dumentorum* and *D. cayenensis*, respectively, with corresponding G.I values of 106.92%, 103.78%, 94.52% and 98.83% (Table 15).

Table 15: Mean Values of Blood Glucose (mmol/L) in Subjects for the Yam Species

Dioscorea Spp	0min	30mins	60mins	90mins	120mins	Mean area under curve (mmol.min/L)	Mean peak rise (mmol/L)	Mean GI (%)
Rotundata	4.49±0.09	5.48±0.14	6.31±0.13	5.41±0.12	4.56±0.10	666	6.31	106.92[a]
Alata	4.46±0.11	5.30±0.12	6.23±0.08	5.27±0.09	4.44±0.10	646.41	6.23	103.78[a]
Dumentorum	4.23±0.11	4.73±0.12	5.86±0.23	4.66±0.22	4.19±0.12	588.77	5.86	94.52[a]
Cayenensis	4.30±0.10	5.03±0.08	6.39±0.20	5.04±0.16	4.03±0.27	615.64	6.39	98.83[a]

This study showed that all the four species of yams tested could be categorised as having high GI. The rate of glucose entry into blood and the duration of elevated blood glucose are known to induce many hormonal and metabolic changes that may affect health and disease parameters. The research findings clearly indicated that postprandial hyperglycaemia in regions where yams are major staples is expected. Gwer et al. (2018) carried out studies on the nutritional and in vitro glycemic properties of selected indigenous tubers (*Tacca involucrata*, *Dioscorea angawa* and *Dioscorea bulbifera*) which are usually boiled or roasted and consumed with or without sauce by the rural populations in the northern parts of Nigeria, especially in Benue state. These tubers were subjected to processing. A batch was processed into raw flours, another batch was boiled for 30 min and another batch boiled for 1 h after which the samples were dried at 60 °C for 48 h to obtain boiled treated flour samples. The flour samples were then analysed for proximate composition, minerals, amylose/amylopectin content, alpha amylase and alpha glucosidase using –standard methods. The results of the study indicated that boiling significantly ($P<0.05$) increased the carbohydrate content of the raw flour samples from 79 to 81%, 79 to 84% and 85 to 88% for *Dioscorea angawa*, *Tacca involucrata* and *Dioscorea bulbifera*, resspectively. Amylopectin content increased from (69.38±0.02%, 70.80±0.02%, 71.95±0.01%) in the raw samples to (76.56±0.05%, 74.50±0.01%, 73.32±0.01%) after 1 h boiling for *Dioscorea angawa*, *Dioscorea bulibifera* and *Tacca involucrata*, respectively. In vitro Alpha amylase increased its activity from (38.27±0.01 mg/g, 49.16±0.06 mg/g, 53.51±0.01 mg/g) in the raw samples to (70.29±0.5 mg/g, 65.93±0.01 mg/g, 118.76±0.03 mg/g) after 1 h boiling for *Dioscorea angawa*, *Dioscorea bulbifera* and *Tacca*

involucrata, respectively and in vitro alpha glucosidase activities of the tubers increased from (566.11±0.01 mg/g, 603.25±0.01 mg/g, 644.43±0.04 mg/g) in the raw samples to (822.03±0.07 mg/g, 992.14±0.01 mg/g 1014.12±0.01 mg/g) in samples boiled for 1 h. Boiling these tubers for 1 h increased the rate of activity of the in vitro enzymes involved in the breaking down of starch to simple sugars.

Isaac-Bamgboye et al. (2019) investigated the pasting properties of fermented and toasted African yam bean (*Sphenostylis stenocarpa*) seed-enriched cassava (*Manihot esculenta*) product (*pupuru*). Cassava flour was substituted with 5, 10 and 15% African yam bean seed flour, while 100% cassava flour served as control. The cassava product (*pupuru*) was prepared by spontaneous fermentation, roasting and drying of the cassava. The pasting properties of the *pupuru* samples were investigated using Rapid Visco Analyzer. The findings revealed that inclusion of African yam bean seed flour in pupuru at increasing substitution levels resulted in an increase in the viscosities and a decrease in pasting temperature and time.

2.2.6 Mushrooms

Mushroom is the fleshy, spore bearing fruiting body of a fungus, typically produced above ground on soil or on its food source and, like all fungus, mushroom is not a plant because it does not exhibit photosynthesis. Mushrooms represent one of the world's greatest untapped resources of nutritious food. Currently, there is significant interest in the use of edible mushroom extracts as dietary supplements because of their high content of bioactive compounds. Oyster mushrooms are a diverse group of saprotrophic fungi belonging to the genus *Pleurotus*. Bello et al. (2017a) examined the inhibitory effects of extracts of three species of oyster mushrooms namely, *Pleurotus sajur caju*, *Pleurotus ostreatus* and *Pleurotus florida* on two key saccharides-hydrolysing enzymes: α-amylase and α-glucosidase. Sorghum grains served as growth support in spawn production, while sawdust supplemented with rice bran served as cultivation substrate for the production of the oyster mushrooms species. The produced mushroom species were dried at 60 °C for 7 h and the resulting dried samples were subjected to analysis. The results revealed that the mushroom extracts inhibited

the hydrolysing enzymes in a dose dependent manner in the range *Pleurotus sajur caju* > *Pleurotus ostreatus* > *Pleurotus florida* (Figure 4a,b).

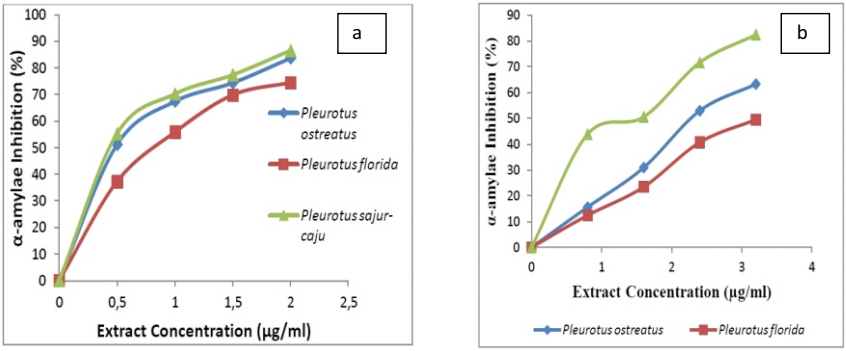

Fig. 4: α-amylase and α-glucosidase inhibition activities of aqueous extract of oyster mushroom species

Bello et al. (2019a) determined the moisture sorption isotherms of *Pleurotus ostreatus* at three different temperatures (10, 30 and 40 °C) and relative humidity range (6 to 88%), using standard static gravimetric method. Equilibrium moisture content of the samples were determine and the data fitted to the Guggenheim-Anderson-de Boer (GAB) equation to describe the moisture adsorption characteristics. From the data obtained for the mean relative percent modulus (%E) of 1.318 to 3.318, r^2 values of 0.997 to 0.998 and the standard error of estimate (SEE) values of 0.07 to 0.09 (Figure 5), there was a very good fit between the experimental moisture sorption and the predicted GAB sorption.

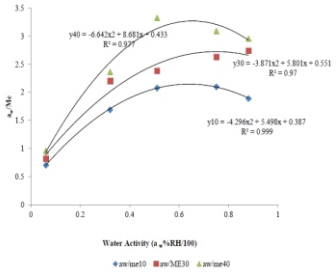

Fig. 5a: GAB model isotherm curve for *Pleurotus ostreatus* stored at 10, 30 and 40 °C at water activities of 0.05 to 0.9

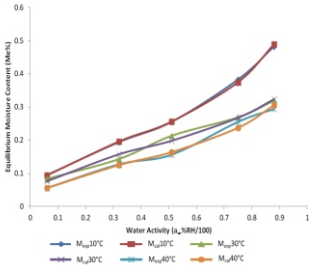

Fig. 5b: Experimental and GAB fitted data for *Pleurotus ostreatus* stored at 10, 30 and 40 °C at water activities of 0.05 tto to 0.9.

Hence GAB model could be used to predict the sorption behavior of *P. ostreatus* mushroom at the range of water activity used in the study. In another study (Satimehin et al., 2018), the drying behaviour of oyster mushroom (*Pleurotus ostreatus*) exhibited the characteristic moisture desorption behavior. The drying rate decreased with decreasing moisture contents and drying occur in the falling rate period, with internal diffusion in the mushroom. An increase in the drying temperature reduced the drying time and increased the drying rate. Drying air temperature of 60 °C was found to be better as it gave dried product with lower shrinkage, better colour and better crispness. Logarithmic model gave the best fit to the drying data, and thus considered to best predict drying characteristics of *Pleurotus ostreatus*.

2.3 Product Development Applications to Locally Available Bioresources

Enujiugha and Akanbi (2010) optimized the thermal processing variables for starter culture fermented African oil bean (*Pentaclethra macrophylla* Benth) seed product ugba in three media (brine, refined groundnut oil and tomato sauce) and at three temperatures (110℃, 116℃ and 121℃) were investigated. Thermal inactivation studies using *Bacillus stearothermophilus* 1518 spores showed that the z-values for the thermal processing were 10.5℃, 12.5℃ and 11.0℃ for brine-, oil- and sauce-canned samples, respectively. At 121℃ processing temperature, the D values of 2.2 min (brine), 3.5 min (oil) and 3.2 min (sauce) would give 5D process times of 11.0, 17.5 and 16.0 min, respectively, as the targeted F values, which are lower than the experimental F values obtained for the three media. Heat penetration studies showed that process times according to general method were in the range 39.3–42.7 min at 121℃, 45.5–49.4 min at 116℃, and 51.4–57.2 min at 110℃. Brine-canned samples had the shortest process times at 121℃. The results indicated that canning in brine at 121℃ for 35 min would appear to be the optimized condition for fermented African oil bean seed slices. Table 16 shows the process parameters at the three temperatures using the mathematical (or formula) method.

Table 16: Thermal process parameters at the three temperatures according to formula method

Parameter	Values for process parameters at 110℃			Values for process parameters at 116℃			Values for process parameters at 121℃		
	Brine	Oil	Sauce	Brine	Oil	Sauce	Brine	Oil	Sauce
Heating rate index f_h/min	27.83±0.03^{a*}	25.10±0.17^{b}	23.51±1.03^{b}	27.15±1.20^{a*}	21.04±1.15^{b}	22.50±0.90^{b}	23.25±0.17^{a*}	20.10±0.12^{b}	19.55±1.02^{b}
Heating lag factor J_h	1.13±0.12^{a}	0.88±0.11^{b}	1.07±0.16^{a}	0.98±0.03^{b}	1.23±0.02^{a}	1.20±0.05^{a}	0.76±0.04^{b}	0.88±0.02^{b}	1.63±0.01^{a}
Cooling lag factor J_c	1.97±0.06^{a}	1.50±0.02^{a}	1.33±0.09^{a}	2.22±0.12^{a}	1.38±0.03^{b}	1.27±0.15^{b}	4.84±0.06^{a}	1.75±0.05^{b}	1.59±0.10^{b}
Temperature deficit g/℃	0.43±0.05^{a}	0.39±0.02^{b}	0.44±0.04^{a}	0.95±0.03^{a}	0.91±0.10^{a}	1.12±0.03^{a}	1.73±0.02^{a}	1.53±0.06^{a}	1.32±0.01^{a}
Process time B/min	54.12±1.20^{a}	50.09±1.15^{a}	49.82±1.50^{a}	47.11±1.32^{a}	42.41±1.52^{a}	45.07±1.33^{a}	38.11±1.22^{b}	38.60±1.53^{b}	40.56±1.38^{a}

Note: Each value is expressed as the mean±s.d. of three determinations. *Values with the same letters in superscript along a row are not significantly different ($p>0.05$).

Results of storage and sensory studies showed that the products were still acceptable after six months storage period (Enujiugha and Akanbi, 2008).

Overall, thermal processing of the African oil bean seeds raised nutrient bioavailability, digestibility and functionality (Enujiugha and Akanbi, 2005a). Each processing step (cooking, soaking, fermenting, canning) brought about a decrease in levels of anti-nutritional factors analyzed. Oxalates, tannins and phytic acid were reduced from 2.79mg/g, 0.38g/100g and 2.11g/100g in the raw seeds to 0.81mg/g, 0.22g/100g and 1.16g/100g in the canned product, respectively. The thermal processing in lacquered metal cans did not significantly ($p<0.05$) affect the colour and fatty acids profile of the fermented product (Enujiugha et al., 2015).

Enujiugha (2000) investigated the possibility of producing a potential bread spread from African oil bean seeds, by drying the fermented product and milling to a paste, with a view to developing a nutritious, more shelf-stable and convenient replacement for the commercially available fermented "ugba". Employing a panel of 50 judges and scoring on a 7-point Hedonic scale, the acceptability of the developed food paste was found to be 80% as a condiment in a local porridge compared to 73% for the commercially available fermented product, and 78% as a breakfast spread on bread compared to 82% for peanut butter, revealing the fairly high consumer rating of the product. Fatty acid profile showed the principal fatty acid, linoleic acid, increasing from about 60% of the

total fatty acids in the raw African oil bean seeds to about 80% in the developed food paste.

Makanjuola et al. (2010a,b; 2012) examined the canning of two tomato cultivars (*Lycopersicon esculentum* Var. Roma VF and *Lycopersicon esculentum* var. Ibadan Local) without removal of the peels, with a view to reducing the high post-harvest losses previously reported by Enujiugha and Akanbi (2005b). Canned tomatoes are usually peeled, leading to substantial losses of carotenoids and ascorbic acid because these are present in higher concentrations in the peels compared to tomato juice or pulp. Makanjuola et al. (2010a) investigated the effect of cultivar, soak treatment and brine composition on physico-chemical and sensory properties of unpeeled whole canned tomatoes with a view to understanding the influence of these process conditions on the canned product characteristics. Results revealed that D-value of *Bacillus coagulans* at 100℃ in jars of whole tomato in juice was 2.8 min and a lethal treatment equivalent to $IS^{11.5}_{100}$ = 12.7 min was safe from a spoilage standpoint for the unpeeled whole tomatoes in $CaCl_2$ tomato juice (with a pH of 4.1 or less) in the ratio of 7:9 (Makanjuola et al., 2010b). Converted to experimental times, this lethality was achieved with a 22 minutes thermal processing in steam at 100℃ for a 370 mL jar used in the investigation. The pH, total solids, soluble solids and lycopene values were not significantly different ($P > 0.05$) for the two cultivars; Roma VF had higher ascorbic acid content and lower titratable acidity ($P < 0.05$). The sensory data reveals that the influence of varied processing conditions on the sensory characteristics of the canned unpeeled tomatoes is negligible. The study also revealed a high level of correlation of aroma, colour, and appearance of canned unpeeled tomatoes with the overall acceptability both for the whole (Table 17) and the halved (Table 18) tomatoes.

Table 17: Correlation coefficients among sensory scores and objective data for canned whole tomatoes

	Drained Weight	Brine volume	Tomato pH	Brine pH	Total solids	Aroma	Appearance	Color
Overall acceptability	0.318	-0.467	-0.227	-0.156	-0.717**	0.726**	0.878**	0.872**
Color	0.081	0.189	-0.514	-0.491	0.516	0.103	0.848**	
Brine turbidity	-0.022	0.109	-0.063	-0.061	0.175			
Lycopene	-0.328	0.315	-0.058	-0.021	0.478			
Ascorbic acid	0.097	-0.089	-0.846**	-0.883**	0.512			
Titratable acidity	0.310	0.488	-0.856**	-0.803**	0.801**			
Brine pH	-0.151	0.113	0.990**					
Tomato pH	0.178	0.170						
Brine volume	0.843**							

*Indicates significance at the 5% level
**Indicates significance at the 1% level

Table 18: Correlation coefficients among sensory scores and objective data for canned halved tomatoes

Coefficients	Drained weight	Brine volume	Tomato pH	Brine pH	Total solids	Aroma	Appearance	Color
Overall acceptability	0.309	0.343	0.521	-0.548	0.086	0.770**	0.878**	0.872**
Color	0.259	-0.273	-0.475	-0.498	0.210	0.605*	0.848**	
Brine turbidity	0.638*	-0.352	-0.615*	-0.697*	-0.313			
Lycopene	0.533	-0.494	-0.441	-0.482	-0.445			
Ascorbic acid	0.502	-0.325	-0.801**	-0.811**	0.329			
Titratable acidity	0.402	-0.441	-0.605*	-0.226				
Brine pH	0.782**	0.693*	0.944**					
Tomato pH	0.811**	0.563						
Brine volume	0.712**							

Indicates significance at the 5% level. **Indicates significance at the 1% level.

Enujiugha et al. (2006) developed dry condiment powders from fermented products of some underutilized legumes and oil seeds, namely, ugba from African oil bean seed, iru from African locust bean seed, okpeye from mesquite seed, and ogiri from castor oil seed. The freshly processed ugba, iru, okpeye and ogiri were dried at 60 ^{o}C for 5 days using air oven. The dried samples were then milled into fine powder using a combination of hammer and pin-disc mills. The dry milled products were stored at three separate temperatures

(10, 30 and 40 °C) and four different relative humidities using saturated salt solutions (RH 20, 30, 50 and 70%) for a period of 21 days. Both the initial and equilibrium moisture contents were determined on the products and the data obtained were used to construct moisture sorption isotherm curves. The results revealed that higher storage temperatures gave lower sorption capacities for the condiment powders. Also the rate of moisture absorption increased at the monolayer at all the storage temperatures considered. At ambient and higher storage temperatures, ogiri had the relatively longest shelf life, followed by okpeye, then iru and finally ugba. The products gave normal sigmoid isotherms, especially at ambient and higher temperatures (Figure 6a-d). As temperature increased at constant water activity (a_w), the moisture decreased, making the products less hygroscopic at higher temperatures. .

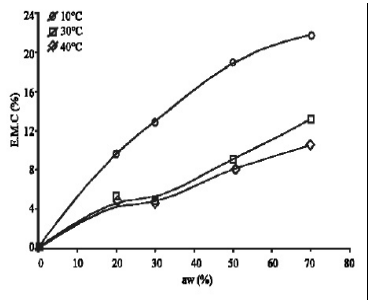

Fig. 6a: Moisture sorption isotherm of 'Ugba'

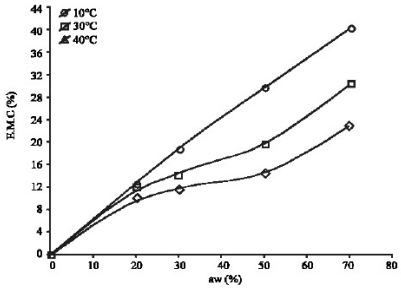

Fig. 6b: Moisture sorption isotherm of 'Iru'

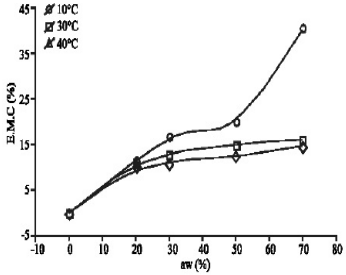

Fig. 6c: Moisture sorption isotherm of 'Ogiri'

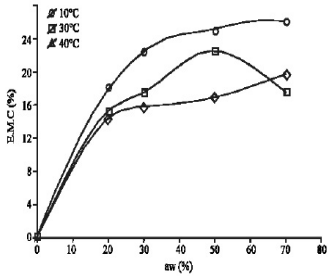

Fig.6d: Moisture sorption isotherm of 'Okpeye'

Olagunju et al. (2018a) developed value-added nutritious crackers (biscuits) with high antidiabetic properties from blends of acha (*Digitaria exilis*) and blanched pigeon pea (*Cajanus cajan*). Protein contents of the formulated crackers increased with increase in supplementation with pigeon pea flour. Glutamic and aspartic acids were the predominant amino acids while methionine and lysine significantly increased as a result of supplementation with pigeon pea flour. The biscuit exhibited good antioxidant properties indicated by its strong ability to scavenge hydroxyl, superoxide and DPPH radicals, and reduction of Fe^{3+} to Fe^{2+}. Acha-pigeon pea cracker (70:30) exhibited the highest inhibitory activity against potent digestive enzymes (α-amylase and α-glucosidase) responsible for breakdown and absorption of carbohydrate. It equally exhibited the lowest glycemic index (47.95% compared to 69.73% for 100% wheat cracker and 65.24% for 100% acha cracker), which may be relevant in lowering postprandial hyperglycemia. Foods with high glycemic index produce a higher peak in postprandial blood glucose and a greater overall blood glucose response during the first 2 h after consumption than foods with low glycemic index. It could therefore be inferred that the formulated crackers biscuits, especially acha-pigeon pea cracker (70:30), may be potential snacks for management of hyperglycemia and may serve as functional foods for the prevention of degenerative diseases.

3.0 CONTRIBUTIONS TOWARDS SUSTAINING HEALTHY NUTRITION

Mr. Vice Chancellor Sir, the problem of malnutrition among rural and diverse populations in Africa has provoked concerted efforts and elicited researches towards ameliorating its pervasive negative impacts. According to Enujiugha (2017), malnutrition has been viewed as the outcome of various processes in society whose causes may be immediate, underlying, or basic. The immediate causes are grouped into those related to food intake and those related to diseases. Basic causes are related to various more structural and environmental constraints related to social, political, economic, demographic, ecological and organizational factors. Underlying

causes at household and family levels include inadequate access to food, health services, water and sanitation as well as inappropriate maternal and child care practices (Ijarotimi and Enujiugha, 2008). I have over the course of my research endeavours addressed these problems through the exploitation of antioxidant potentials of local bioresources, utilization of indigenous foods as potential sources of industrial biocatalysts, the modification and saccharification of starch in local staples, production of protein isolates and hydrolysates, and the development of starters for indigenous fermentations. This was with a view to creating the required conditions for achieving healthy nutrition.

3.1 Researches on Antioxidant Properties of Local Bioresources

It is widely accepted that significant antioxidant activity of food is related to high total phenol content (Xu and Chang, 2007). Plant foods contain a large variety of phenolic derivatives, including simple phenols, phenylpropanoids, benzoic acid derivatives, flavonoids, stilbenes, tannins, lignans and lignins, and these compounds which are present naturally in vegetables, fruits, grains and pulses, possess the ability to reduce oxidative damages that are believed to cause many diseases including cancer, cardiovascular diseases, cataracts, atherosclerosis, diabetes, arthritis, immune deficiency diseases and ageing (Enujiugha, 2010, Enujiugha et al., 2014). The chemical reactivity and protein binding capacity of polyphenols and their oxidation products are responsible for their effects in biological systems. The antioxidant capacity of most plant food sources is usually associated with their bioactive components and phytochemical constituents. Although plant polyphenols such as tannins and flavonoids have problems of astringency and protein binding which have grouped them under the category of anti-nutrients (Enujiugha, 2005a; Enujiugha and Ayodele-Oni, 2003), they have been found useful as natural antioxidants in scavenging deleterious free radicals released in the body by fat metabolism (Enujiugha, 2010; Enujiugha et al., 2012b).

My research group has been able to evaluate the antioxidant properties of our indigenous biodiversity which includes African locust bean (Enujiugha, 2010), African yam bean (Enujiugha et al.,

2012b), African oil bean (Oyinloye and Enujiugha, 2019), fluted pumpkin and amaranth (Enujiugha et al., 2014; Esan et al., 2018b), tea and ginger (Makanjuola et al., 2015a,b,c), African star apple (Bobadoye et al., 2016), acha and tigernut (Badejo et al., 2017), snake tomato (Badejo et al., 2016), mushrooms (Bello et al., 2019b), among others. These studies show that extraction conditions (temperature and time) as well as extraction solvents play key roles in maximizing the antioxidant potentials of these local bioresources. The research works show clearly that our locally-available biodiversity are potential sources of antioxidants and can adequately be utilized to improve nutrition and health status, especially of vulnerable groups.

3.2 My Research Works on Biocatalysts

Enzymes, as biocatalysts, are important components of industrial bioreactors, which are needed to speed up the rate of reactions without being involved in the actual reactions. The three biopolymers or macronutrients in food, namely carbohydrates, proteins and lipids are normally hydrolysed in the human body to respective simple metabolisable molecules through the catalyzing action of specific enzymes (amylases, proteases and lipases). It could be asserted that the drivers of biotechnology are enzymes as they are involved, either directly or indirectly, in all molecular reactions and kinetics. They are also the key factors in all genetic transactions, including recombinant DNA technique of genetic engineering.

3.2.1 Alpha- and beta-amylases

Amylases are among the most important industrial enzymes that have a wide variety of applications ranging from conversion of starch to sugar syrups, to the production of cyclodextrins for the pharmaceutical industry. Amylases include α-amylase (1,4 α-glucan glucohydrolase, EC 3.2.1.1), β–amylase (1,4 α–glucan maltohydrolase, EC 3.2.1.2) and glucoamylase (1,4 α-glucan glucohydrolase, EC 3.2.1.3). Enujiugha et al. (2002) examined the role of plant and bacterial α–amylases in the fermentation of African oil bean seed, and reported that the enzymes are responsible for the breaking down of the complex carbohydrates to simple sugars both in stored, unprocessed dormant seeds and in the actual fermentation. The specific activities of the purified enzyme from raw and

fermented seeds were 0.037 ml^{-1} min^{-1} and 0.88 ml^{-1} min^{-1} respectively. The α-amylase from fermented seeds was more thermostable with optimum activity at 70 °C, compared to the optimum temperature of 60 °C obtained for the raw seed enzyme. The assayed α-amylases were stable over a wide range of pH (3.0–7.0), with optimum activity found at pH 6.0 and pH 5.0 for raw and fermented seeds respectively. The results show that the α-amylase of *Pentaclethra macrophylla* complements the microbial amylases in the mainly bacterial fermentation of African oil bean seeds to 'ugba', a highly nutritious food condiment and cherished snack. While the α-amylase in the raw seeds was basically the plant enzyme, that isolated from the fermented seed product was a combination of plant and microbial α-amylases.

Abu et al. (2014) purified and characterized β-amylase from *Bacillus subtilis* isolated from fermented *Parkia biglobosa* seed product. Purification was achieved using ion exchange DEAE column and gel filtration (Sephadex G-200) chromatography (the enzyme was purified 18.76 -fold and the molecular weight was 42.2 kDa). The optimum production of β-amylase was at temperature, pH and time of 37 $^{\circ}C$, 7.0 and 24 h, respectively. The results showed that purified β-amylase had more enzymatic activity than crude samples from *Bacillus subtilis* whereby the activity of crude enzyme was 3.21 mM/min/mL while the purified enzyme had an improved activity of 21.46 mM/min/mL. Optimum temperature and pH values of the purified amylase were found to be 50 °C and 5.0, respectively. pH stability of the enzyme ranged from 4.0- 9.0. At pH 5.0 and 7.0 it retained 70% and 60% of its activity after 5 h of incubation. Temperature stability ranged between 40 $^{\circ}C$ and 70 $^{\circ}C$ but most stable at 50 $^{\circ}C$ retaining 64% of its activity after 1 h of incubation. The enzyme exhibited maximum activity on soluble starch and sucrose, among other carbohydrate substrates. EDTA, Cu^{2+} and Fe^{2+} inhibited its activity while Ca^{2+} and K^{+} enhanced it up to 30%. The Lineweaver-Burke plot of the purified β-amylase activity of *B. subtilis* indicates that the β-amylase enzyme had apparent Km and Vmax values for the hydrolysis of soluble starch of 17.74 mg/mL and 14.09 U, respectively. The study revealed that β-amylase from *B. subtilis* can be exploited for starch conversion biotechnologies.

3.2.2 Proteases

Oludumila et al. (2015) extracted, purified and characterized proteases from *Aspergillus niger* isolated from yam peels. The enzyme was purified 16.60-fold, had a yield of 10.96 and the apparent molecular weight was 46.90 kDa. Purification was achieved using ion exchange DEAE column and gel filtration (Sephadex G-200) chromatography. The optimum production of protease was at temperature, pH and time of 37 ^{o}C, 7.0 and 42 h, respectively. The results showed that purified protease had more specific activity than crude enzyme from *Aspergillus niger* (the specific activity of crude enzyme was 0.51 U/mg, while the purified enzyme had an improved specific activity of 8.51 U/mg). Optimum temperature and pH values of the purified protease were found to be 50 °C and 10.0, respectively. pH stability of the enzyme ranged from 3.0 to 12.0. At pH 3.0 and 10.0 it retained 70% and 60% of its activity after 5 h of incubation, respectively. Temperature stability ranged between 30 ^{o}C and 90 ^{o}C but most stable at 50 ^{o}C retaining 94% of its activity after 1 h of incubation. The enzyme exhibited maximum activity on casein, among other protein substrates. EDTA, Cu^{2+}, Fe^{2+}, Mg^{2+}, and Ca^{2+} inhibited its activity while Na^{+} enhanced it. The study showed that industrially important protease can be produced from *Aspergillus niger* isolated from yam peels and such other food wastes.

3.2.3 Lipases

Lipases (glycerol ester hydrolases E.C. 3.1.1.3) in oilseeds help to hydrolyze the ester bonds of storage triacylglycerols. Acetone powders (acetone-insoluble residues obtained by extraction of the oilseed homogenates with chilled acetone) have been found effective in oil hydrolysis with preferential cleavage of fatty acids esterified at the sn-1,3 positions of the triacylglycerols. Oilseed lipases have great potential for commercial exploitation as industrial enzymes. Enujiugha et al. (2004) examined the activity as well as substrate specificity of lipases (glycerol ester hydrolases E.C. 3.1.1.3) in *Pentaclethra macrophylla* dormant (ungerminated) seeds, and observed that the oil bean lipase was effective on triacylglycerols with short-chain fatty acids (especially lauric oils). The optimum conditions for lipolysis were found to be 30 ^{o}C and 60

min incubation time, with a pH optimum near neutrality. The presence of Ca^{2+} increased activity by 64% while sodium chloride and mercuric chloride inhibited activity by 36% and 28.5%, respectively. On addition of EDTA, an inhibition in activity of 28% was observed. The *Pentaclethra* seed lipase could be exploited commercially in industrial processes, especially with the current focus on oilseed lipases as convenient replacements for microbial lipases in biotechnological applications.

Crude lipase from conophor nut (*Tetracarpidium conophorum*) was isolated and assayed via quantification of the free fatty acids liberated by the hydrolysis of the oilseed triacylglycerols (Enujiugha, 2009a). Optimum pH and temperature for the enzyme activity of the conophor nut lipase were pH 8.0 and 30 °C with substantial lipolysis at 80 °C, underscoring the thermostability of the enzyme. Ca^{2+} and Hg^{2+} enhanced the enzyme activity, while Na^{+} and EDTA caused various degrees of inhibition. The study concluded that conophor nut lipase could prove useful in industrial biocatalytic hydrolysis. The preliminary characterization also inferred that the conophor nut lipase could prove useful in processes that require lower cooling costs and minimal corrosion problems.

3.2.4 Phytases

Phytases (myo-inositol hexakisphosphate phosphohydrolases) hydrolyse phytic acid to less phosphorylated myoinositol derivatives, releasing inorganic phosphate. Phytases can be grouped into different classes depending on pH (acidic or alkaline), catalytic mechanisms (histidine acid-phosphataselike phytase, purple acid phosphatase-like phytase and β-propeller phytase), and specificity of hydrolysis (3-phytase, 6-phytase and 5-phytase. Enujiugha (2005b) isolated crude phytase from selected locally available bioresources, namely, African oil bean (*Pentaclethra macrophylla*), locust bean (*Parkia biglobosa*) and conophor nut (*Tetracarpidium conophorum*), and subsequently characterized the enzyme with respect to activity and substrate specificity. The crude phytases were isolated and assayed via estimation of inorganic orthophosphate liberated by the hydrolysis of phytic acid using a method based on colorimetric measurement of phosphomolybdate in acetone. The phytase activities and corresponding protein concentrations for the

three underexploited oilseeds were 0.720 μmL^{-1} and 16.85 mgmL^{-1} for *P. macrophylla*; 0.078 μmL^{-1} and 10.65 mgmL^{-1} for *T. conophorum*; and 0.082 μmL^{-1} and 14.00 mgmL^{-1} for *P. biglobosa*, respectively. This implies that the *Pentaclethra* seed phytase has comparatively higher activity with higher protein concentration in the enzyme molecule, followed by the *Parkia* seed phytase and lastly the *Tetracarpidium* seed phytase. The optimum temperatures for the phytase activity were 50 °C for oil bean and conophor seeds and 60 °C for locust bean seed. The optimum pH was 5.0 for oil bean phytase, 4.0 for conophor nut phytase, and 7.0 for locust bean lipase, respectively. The results show that locust bean phytase was more thermoactive with an alkaline pH optimum, conophor nut and oil bean seed both have acid phytases in their cotyledons.

Sanni et al. (2019) purified phytase from *Aspergillus fumigatus* isolated from African Giant Snail (*Achatina fulica*). The crude phytase was subjected to ammonium sulphate precipitation, DEAE Sephacel and Sephacryl S-200. Approximately 45%-fold purification was achieved with an overall recovery of 15%. The purified phytase had optima temperature and pH activity at 40 °C and pH 6, respectively with a marked activity of 83% and 78% at pH 8.0 and 9.0, respectively. It retained over 80% of its initial activity after 6 h at pH 4.0−7.0 with a 48% remaining activity at 50 °C after 1 h incubation time. Vmax and Km were determined to be 35.7 μmol/min and 7.2 mM respectively. The phytase activity was enhanced in the presence of Ca^{2+}, Cu^{2+} and Fe^{2+}, but was greatly inhibited by Zn^{2+}, Hg^{2+}, Al^{3+}, sodium dodecyl sulphate (SDS) and urea. The results showed that phytase produced from A. fumigatus may contribute significantly to the phytate degrading enzyme system in African giant snail and may serve a useful commercial purpose.

3.3 Studies on Starch Modification and Saccharification

Starch is a key ingredient in many food applications because it functionally contributes to thickening, stabilization, texturization, gelation, encapsulation and shelf-life extension, thus improving quality and texture in addition to controlling the acceptability of food products. However, starches in their native form are

incompatible with industrial food applications because of low shear stress, increased viscosity leading to thickening during heat treatment, thermal decomposition and high degree of retrogradation. Starch modification is an efficient way to improve physicochemical and functional properties of native starches in order to meet the needs of specific industrial processes, particularly where the native starch cannot provide optimal performance. Acetylation, which entails esterification of starch polymer with acetic anhydride, imparts a desirable thickening capability, reduces gelatinization temperature, increases viscosity and freeze-thaw stability and reduces retrogradation rates, thereby significantly enhancing starch utilization in various food applications. Olagunju et al. (2020) investigated the influence of acetylation on physicochemical and morphological characteristics of pigeon pea starch (modification was done by esterification with acetic anhydride to obtain 0.05, 0.09 and 0.14 degree of substitution) and found that acetylation decreased the heat transition temperatures and enthalpy of gelatinization. The study showed that integrated band intensities of all three characteristic FTIR peaks increased linearly with increasing degree of substitution (Figure 7).

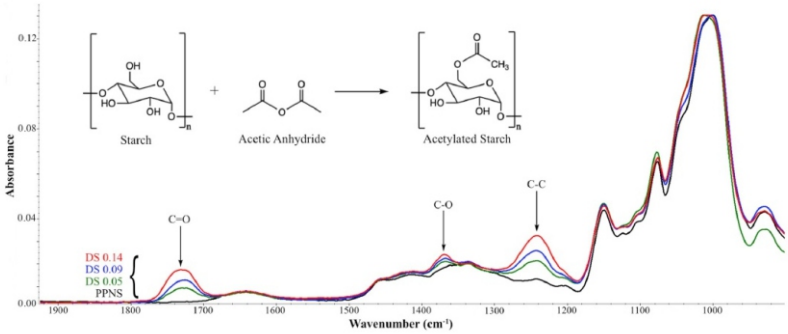

Fig.7: Three absorption bands in the FTIR spectra of acetylated pigeon pea native starch provide quantitative evidence of linearly increasing acetylation with increasing volumes of acetic anhydride treatment. Bands are assigned to functional groups introduced with acetylation. PPNS: Pigeon pea native starch; Pigeon pea acetylated starches with DS ¼ 0.05, 0.09, 0.14.

SEM imaging showed that acetylation did not lead to any observable change in starch granule shape and size; however, there was a significant rupture of starch granules at 0.14 degree of substitution. Acetylated pigeon pea starch exhibited improved functional properties including better water and oil holding capacities, better whiteness index, lower gelatinization temperatures, significantly lower retrogradation tendency and lower glycemic index. This makes it a potential ingredient for use in food applications as thickener, stabilizer or filling agent.

Pele et al. (2018a,b) investigated the effect of pH and temperature on the activities of alpha-amylase in cassava starch liquefaction and in maltodextrin production from breadfruit starch, respectively. For cassava starch, the optimum condition of hydrolysis was determined by using a pure culture of a thermostable alpha-amylase for liquefaction, and the activity of the enzyme determined at varying pH, temperature and time. A 3x3x3 completely randomized experimental design comprising three pH values (pH 6.0, 6.5 and 7.0); three temperatures (65, 70 and 75 °C) and three time ranges (40, 50 and 60 min) were employed for liquefaction. Results showed that sample dry weight decreased with increasing value of pH, temperature and time. The optimal reducing sugar and dextrose equivalent were 17.84% and 14.74 DE, respectively at pH 6.5, 70 °C and 60 min (Pele et al., 2018a). For the breadfruit starch, sample dry weight significantly decreased with respect to increased value of pH, temperature and time, while reducing sugar and dextrose equivalent significantly increased with respect to increased time. The optimal reducing sugar and dextrose equivalent were 14.88% and 12.30 DE, respectively at pH 6.5, 70 ^{o}C and 60 min (Pele et al., 2018b). The maltodextrin obtained in the study has potential to serve as a substrate to initiate saccharification reaction in the production of glucose syrup.

3.4 Protein Isolates and Hydrolysates

The role of protein isolates and hydrolysates in human nutrition has in the past decades assumed a prominent research focus. Protein functionality and molecular significance with regard to enhancing human nutrition have been variously reported (Aderinola et al., 2018; Oyewole et al., 2017). Olagunju et al. (2018b) hydrolysed

pigeon pea protein isolate using food grade enzymes (alcalase, pancreatin, pepsin + pancreatin). Alcalase is a broad-spectrum protease that liberates peptides with hydrophobic amino acids such as phenylalanine, tyrosine, tryptophan, leucine, isoleucine, valine and methionine. Pancreatin is a serine protease which displays carboxypeptidase activity. It is a mixture of enzymes characterized by tryptic, chymotryptic and elastase type with active sites that include peptide bonds formed by histidine, serine and aspartate. Pepsin is a gastrointestinal protein hydrolysing enzyme with broad range of substrate specificity. It is an endopeptidase and the predominant cleavage sites are phenylalanine and leucine. In the particular work carried out by Olagunju et al. (2018b), the resulting hydrolysates were fractionated by membrane ultrafiltration and evaluated for their antioxidant activities. Fraction with molecular weight <1 kDa had the highest peptide yield (36.97%) for pepsin + pancreatin hydrolysates, whereas fraction 1–3 kDa showed the highest yield (28.84%, 37.27%) for alcalase-derived peptide and pancreatin-derived peptide, respectively (see Figure 8).

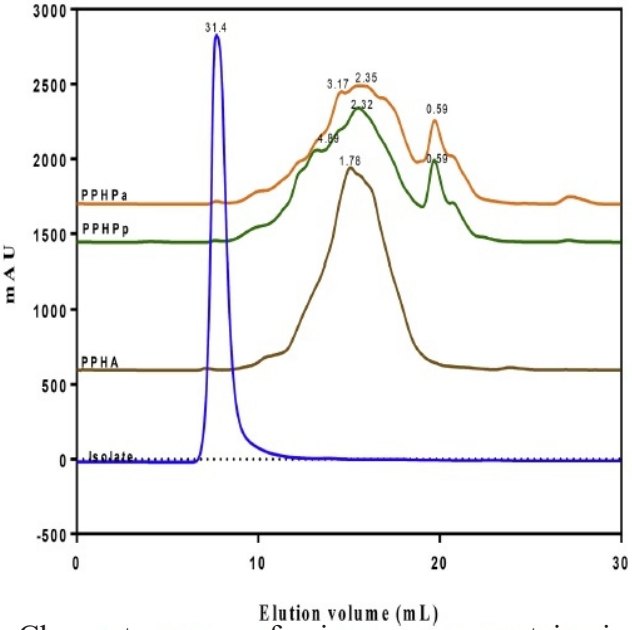

Fig. 8: Chromatograms of pigeon pea protein isolate and hydrolysates after passage through a Superdex Peptide 12 10/300 GL column. PPHA: Alcalase-hydrolysed protein; PPHPa: Pancreatin-hydrolysed protein; PPHPp: Pepsin-pancreatin- hydrolysed protein.

The high molecular weight peptides exhibited better radical scavenging activity (DPPH) and reducing property (FRAP) than the low molecular weight peptides. However, the low molecular weight fractions (< 5 kDa) were able to inhibit the progression of lipid peroxidation during the first four days of incubation for most of the peptides. Olagunju et al. (2018c) examined the ACE/renin inhibitory activities of the pigeon pea hydrolysates and their effects on systolic blood pressure of spontaneously hypertensive rats. It was observed that as inhibitors of ACE and renin, the multifunctional capacity of the pigeon pea peptides provides an opportunity to formulate functional foods and nutraceuticals with potential role in the prevention and treatment of chronic diseases. Pepsin-pancreatin-hydrolyzed pea protein exhibited strong antihypertensive effect, showing an instantaneous systolic blood pressure lowering effect

(−26.12 mmHg) within 2-h post-oral administration (Figure 9)

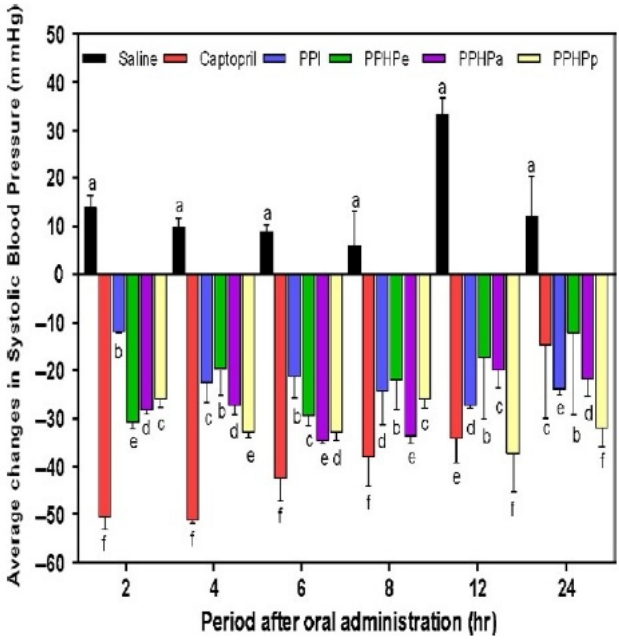

Fig. 9: Average changes in systolic blood pressure of spontaneously hypertensive rats after oral administration of pigeon pea isolate and hydrolysates at 100 mg/kg body weight. Values are mean ± SD; Bars with different letters are significantly different ($p < 0.05$). PPI: Pigeon pea protein isolate; PPHPa: Pancreatin hydrolyzed pigeon pea protein; PPHPe: Pepsin hydrolyzed pigeon pea protein; PPHPp: Pepsin-Pancreatin hydrolyzed pigeon pea protein

Pigeon pea protein hydrolysate (especially from pancreatin digest) could therefore, be a promising source of bioactive peptides and potential ingredient for formulation of functional foods against oxidative stress and hypertension.

Aderinola et al. (2018; 2019a,b,c,d; 2020) investigated the quality attributes of moringa (*Moringa oleifera*) seed protein fractions, isolates and hydrolysates as potential functional food ingredients, with respect to their antioxidant and/or antihypertensive properties.

Moringa oleifera seed protein isolate (ISO) was subjected to enzymatic (alcalase, pepsin and trypsin) hydrolysis to obtain alcalase isolate, pepsin isolate and trypsin isolate hydrolysates (AIH, PIH, TIH), respectively (Aderinola et al., 2018). Generally, the hydrolysis process produced hydrolysates with improved antioxidant and ACE-inhibitory properties when compared to the isolate. Table 19 shows the amino acid composition of the *Moringa oleifera* seed protein isolate and enzymatic hydrolysates.

Table 19: Amino acid composition of *Moringa oleifera* seed protein isolate and hydrolysates.

AA	ISO	AIH	PIH	TIH
ASX	6.27	6.87	6.86	7.44
THR	3.35	3.63	3.70	4.10
SER	3.19	3.33	3.32	3.34
GLX	25.70	22.03	24.90	23.02
PRO	5.90	6.05	4.71	5.01
GLY	5.98	6.77	8.43	8.08
ALA	4.41	4.83	4.83	5.04
CYS	3.42	2.93	2.31	1.50
VAL	4.46	5.09	4.52	4.93
MET	1.93	1.85	1.58	1.37
ILE	3.00	3.27	3.05	3.10
LEU	6.33	6.70	5.99	6.22
TYR	2.27	2.44	2.22	2.59
PHE	5.35	5.62	5.60	6.56
HIS	2.95	3.08	3.07	2.98
LYS	1.29	1.46	2.51	2.49
ARG	13.19	13.19	11.95	11.35
TRP	0.99	0.86	0.45	0.91
AAA	8.61	8.92	8.26	10.05
BCAA	13.79	15.07	13.56	14.25
HAA	38.07	39.64	35.26	37.22
PCAA	17.43	17.73	17.53	16.81
NCAA	31.97	28.90	31.76	30.46
SCAA	5.35	4.77	3.90	2.87
EAA	42.85	44.75	42.42	44.00

ISO, protein isolate; AIH, alcalase hydrolysate; PIH, pepsin hydrolysate; TIH, trypsin hydrolysate; HAA: hydrophobic amino acids e alanine, valine, isoleucine, leucine, tyrosine, phenylalanine, tryptophan, proline, methionine and cysteine; PCAA: positively charged amino acids e histidine, lysine; NCAA: negatively charged amino acids e ASX(asparagine þ aspartic acid) and GLX: (glutamine þ-glutamic acid); AAA: aromatic amino acids- phenylalanine, tryptophan and tyrosine; SCAA: sulphur containing amino acids- cysteine and methionine; BCAA e branched chain amino acids e leucine and isoleucine; EAA: essential

amino acids e threonine, valine, methionine, isoleucine, leucine, phenylalanine, histidine, lysine, arginine and tryptophan.

Further studies on the *in vitro* antihypertensive and antioxidative properties of trypsin-derived (Aderinola et al., 2019a) and alcalase-derived (Aderinola et al., 2019b) *Moringa oleifera* seed globulin hydrolysate and its membrane fractions revealed that the hydrolysis produced potent bioactive peptides and peptide fractions with high antioxidative and antihypertensive properties. Aderinola et al. (2019c) extracted *Moringa oleifera* seed meal proteins using salt, water and alkaline precipitation to obtain globulins (GLO), albumins (ALB), and iso-electric precipitated (ISO) isolates and subjected them to comparative antioxidant action via 2, 2-diphenyl-1-picrylhydrazyl (DPPH), hydroxyl radical scavenging activity (HRSA), ferric reducing antioxidant power (FRAP) and inhibition of metal ion chelation assays. The albumin fraction in particular showed considerable inhibitory potentials against the DPPH (53.02%) and hydroxyl radical (44.21%). None of the samples, however, had any significant metal chelating ability since the only sample (globulin) with activity had less than 5% metal chelation activity. Aderinola et al. (2019d) fractionated alcalase-derived *Moringa oleifera* seed protein hydrolysate by membrane ultrafiltration using 1, 3, 5, and 10 kDa molecular weight cut-off membranes. Results showed that membrane separation led to decreased free radical (DPPH, hydroxyl) scavenging but enhanced ferric reducing antioxidant power and metal ion chelation properties. The 1–3 kDa peptide fraction was the most active against angiotensin converting enzymes (ACE) and renin with 6.70% and 24.62% increases, respectively when compared to the hydrolysate. Oral administration (200 mg/kg body weight) to spontaneously hypertensive rats (SHR) resulted in significant decreases in systolic (SBP), diastolic (DBP) and mean arterial (MAP) blood pressure for the hydrolysates and peptide fractions (Figure 10) when compared to the negative control (phosphate-buffered saline, pH 7.2)..

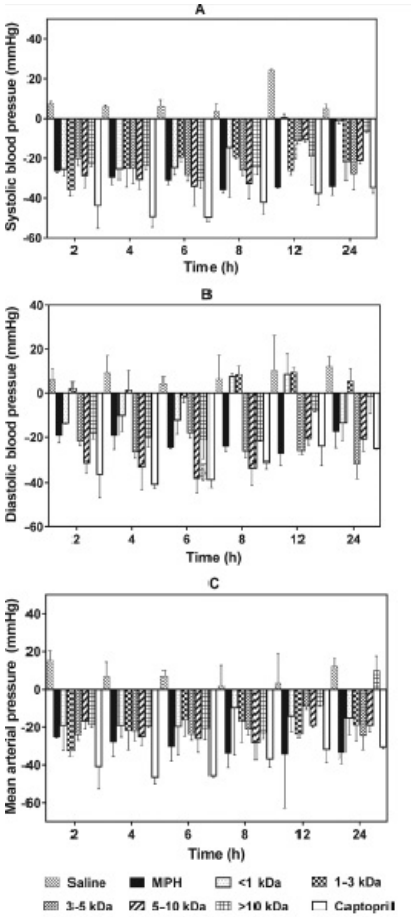

Fig. 10: Effects of *Moringa oleifera* seed protein hydrolysate (MPH) and its peptide fractions on blood pressure of spontaneously hypertensive rats: (A) systolic, (B) diastolic and (C) mean arterial.

Captopril (20 mg/kg body weight) was used as positive control. The 1–3 kDa peptide fraction also showed the greatest (–35 mm Hg) reduction in SBP along with fastest (2 h) reduction of MAP in the SHR. The hydrolysate produced the most persistent SBP reduction with up to –34 mm Hg after 24 h. However, the longer peptides (>10 kDa) were the most effective (–78 beats per min) in reducing SHR

heart rate. The results suggest that the alcalase-hydrolysed *M. oleifera* seed peptides could function as potential ingredients for the formulations of functional foods and nutraceuticals with antihypertensive benefits.

3.5 Starter Culture Development and Applications

Fermentation involves the action of desirable microorganisms, or their enzymes, on food ingredients to make biochemical changes, which cause significant modifications to the food. It preserves and enriches food, improves digestibility, and enhances the taste and flavour of foods. Fermented foods are a common feature in African diets, constituting between 70-85% of the daily per capita food consumption. Such fermented food products are obtained from different substrates, including roots and tubers, legumes and oilseeds, fruit and vegetables, and cereals. However, African fermentations face great challenges in lack of reproducibility and obvious disregard for hygiene and safety standards. The problem of reproducibility has been tackled via the introduction of starter cultures and process optimization. Enujiugha et al. (2008) investigated the development of bacterial starter for the spontaneous fermentation of cooked and detoxified African oil bean seeds into ugba, a local nutritious condiment. It was observed from the research findings that African oil bean seed fermentation is a bacterial mixed culture and alkaline fermentation. The results show that the three organisms involved, namely, *Bacillus subtilis, Bacillus licheniformis* and *Pseudomonas fluorescens* produce a synergistic action in the fermentation. However, further studies using the bacterial isolates as single and mixed starters showed that *B. subtilis* and *B. licheniformis* appeared to be actively involved in the fermentation, while *P. fluorescens* only aided conditions for the mainly alkaline fermentation.

Enujiugha (2009b) isolated and characterized various types of microorganisms from fermented products of locust bean seeds (*Parkia biglobosa*), castor bean seeds (*Ricinus communis*), African oil bean seeds (*Pentaclethra macrophylla*) and mesquite seeds (*Prosopis africana*). The fermented products, namely, iru, ogiri, ugba and okpei, respectively, are mainly used as condiments in soups, sauces and porridges among consuming populations in

Nigeria. The following organisms were isolated from the respective fermented oil seed samples. Iru-*Staphylococcus aureus, Staphylococcus saprophyticus, Bacillus subtilis and Bacillus cereus.* Ogiri-*Lactobacillus fermentum, Bacillus subtilis, and Micrococcus varians*. Okpei-*Bacillus subtilis, Bacillus cereus and Lactobacillus brevis.* Ugba-*Bacillus subtilis and Micrococcus roseus*. The isolates were used to ferment freshly prepared oilseed samples, with subsequent evaluation of the desirable quality characteristics of texture, color and aroma. *Bacillus subtilis* was found to give the products with acceptable quality attributes. The other organisms were mainly contaminants in the traditional spontaneous fermentations. Further studies on the production of poly-γ-glutamic acid (γ-PGA) during the fermentation of locust bean seed into iru using *Bacillus subtilis* (isolated and identified using molecular characterization) as a single starter in comparison to spontaneous (or wild) fermentation (Oyedokun et al., 2016) revealed that *B. subtilis* was the main organism in the fermentation. The production of γ-PGA was at maximum on the third day of fermentation, after which it steadily decreased, indicating that 72 h was optimum fermentation period.

Enujiugha and Badejo (2002) examined the alteration of cultural environment of *Bacillus subtilis* as a single starter culture in a batch fermentation of African oil bean seeds. The controlled laboratory fermentation of prepared seed slices was preceded by subculturing of the *B. subtilis* isolate under combinations of different temperature conditions (0 °C, 20 °C, 37 °C and 50 °C), acidic environments (pH 4, pH 5, pH 6 and pH 6.8) and different salt concentrations (5%, 10%, 15% w/w NaCl) using Plate Count Agar. Isolates from the different cultural environments were used as single starters in the fermentation, and the products were evaluated for desirable quality characteristics and overall acceptability. It was found that *B. subtilis* did not show any observable growth at very high and very low temperatures. Equally, very low pH and very high salt concentrations negatively affected the growth of the isolates. Overall, the organism grown under a combination of 5% w/w NaCl concentration, pH 6.8 and 37 °C was found to give the best rated product.

Adepehin et al. (2018) investigated the microbial diversity of three sourdoughs produced from composite gluten-free flours using 16S rRNA gene clone libraries. Finger millet-pearl millet (FP), Pearl millet-sorghum (PS) and Finger millet-sorghum (FS) sourdoughs were produced. Pearl millet (*Pennisetum glaucum*), finger millet (*Eleusine coracana*) and sorghum (*Sorghum bicolor*) are gluten-free cereals known to be rich sources of energy and used in the production of fermented foods. Eleven aerobic bacteria and twelve lactic acid bacteria (LAB) were randomly selected from the sourdoughs after 48 h of fermentation, while yeast was not detected in any of the products. The LAB population and pH ranged from log 7.70 CFU g^{-1} to log 10.52 CFU g^{-1} and pH 3.8 to 4.2, respectively. The findings showed that well-developed sourdough could be produced from these composite flours by spontaneous fermentation. This study enhanced the corpus of existing knowledge on the microbial diversity of gluten-free sourdough and provided a basis for the possible application of *Pediococcus* spp. and *Weisella* spp. as starter cultures in fermented products. Microbial diversity in the composite gluten-free sourdoughs were mainly LAB (*Pediococcus acidilactici, Pediococcus pentosaceus, Weissella confusa*) and two strains of *Bacillus* spp. (*Bacillus licheniformis* and *Bacillus subtilis*) (Figure 11).

Presumptive micro-organisms strains	**FP**	**PS**	**FS**
Bacillus subtilis strain QD9	■	■	■
Pediococcus acidilactici strain KTNA3010M	■	■	
Bacillus licheniformis strain TS_16	■	■	
Bacillus licheniformis strain DSM 13			■
Pediococcus pentosaceus strain WiKim20		■	■
Cronobacter sakazakii strain BDCSS014		■	
Weissella confusa strain bcpcaqj1		■	■

Fig. 11: Bacteria strains identified through the culture-dependent method in the two laboratory produced sourdoughs. The black and white boxes indicate the presence and absence of strains, respectively

These arrays of organisms found in the cereal blends have strong potential to inhibit the growth of pathogenic organisms, improve nutritional parameters and increase the shelf-life of sourdough-based baked products.

Adisa et al. (2019) enumerated the bacterial and fungal isolates responsible for the fermentation of millet sourdoughs, evaluated the antimicrobial safety of the sourdough starters and the quality of bread produced thereafter. The individual flours were spontaneously fermented in the ratio 1:1 (w/v) for 48 h. At the end of the fermentation, the microbial consortium of the sourdough meals obtained were determined and also screened for antagonistic activity against selected pathogens. All the sourdough starters revealed strong clearance zones against the selected food borne pathogens with values ranging from 5.00 to 16.1 mm. *Lactobacillus fermentum* and *Candida* spp. dominated the pearl millet fermentation, while *Lactobacillus plantarum* and *Saccharomyces cerevisiae* dominated the finger millet and fonio (both black and white varieties) fermentations. A further research (Adisa et al., 2020) revealed the strong probiotic potentials of the yeast species involved in the millet sourdough fermentation.

4.0 RELATING BIOTECHNOLOGY TO PRODUCTIVE LIFESTYLE

The advent of modern biotechnology meant a great diversion from the traditional lifestyle to accommodate the many benefits that the new discipline has offered to human populations. Africa was known for monotonous diets based on starchy roots, tubers and protein-deficient cereals as main staples, with focus on the supply of energy. Such diets engender drastic reductions in productivity and human capacity development, because the required nutrient index for effectiveness and efficiency is far from being achieved. The current focus on exploiting the bioactive potentials and medicinal values of local vegetables, fruits and nuts has impacted heavily on diet preferences among rural dwellers (which comprise more than 80% of the population), and ultimately affected biodiversity and sustainability of local diets (Enujiugha, 2017). The desire for year-round availability of our local bioresources and the need to sustain

the changing consumer lifestyles and food consumption patterns has driven research into various non-conventional processing and preservation techniques, functionally dynamic and environmentally friendly packaging, and the consumption of products hitherto regarded as wastes.

4.1 Utilisation of Probiotics and Prebiotics in Daily Diets

Probiotics are defined as live microorganisms in foodstuffs which, when consumed at certain levels in nutrition stabilizes the gastrointestinal tract microflora thereby conferring health benefits on the consumer (FAO/WHO, 2002). It has been reported that populations of 10^6–10^7 colony forming units (CFU)/g (or CFU/mL) in the final product are established as therapeutic quantities of probiotic cultures in processed foods (Ukeyima et al., 2010), reaching 10^8–10^9 CFU, provided by a daily consumption of 100 g or 100 mL of the particular food source. At the point of consumption, the level of probiotics in the food should be ≥ 10^6 CFU/mL (see Table 20).

Table 20: Conditions, organisms involved and examples of

Conditions for a food product to be classified as probiotic	- Must have live organisms ≥ 10^6 cfu / ml - Organisms are members of LAB family - The organisms are resistant to gastric acidity and bile salts - No negative nutritional effects on the human body
Microorganisms used as probiotics	- *Lactobacillus casei, L. acidophilus, L. brevis, L. lactis, L. plantarum, L. fermentum, L. delbrueckii* var. *bulgaricus* - *Bifidobacterium breve, Bf. animalis, Bf. Lactis, Bf. bifidum, Bf. longum, Bf. adolescentis* Other organisms (*Lactococcus lactis, Enterococcus faecium, Enterococcuc faecalis, Pediococcus acidolactici, Streptococcus salivarus* var. *thermophilus, Saccharomyces boulardi*)
Examples of probiotic foods	- Dairy-based foods: yoghurt, cheese, nunu - Non-dairy-based foods: ogi souring water, fufu liquor, fermented raffia palm sap

Probiotics offer remarkable potential for the prevention and management of various infective and
noninfective disorders. They are reported to play key roles in the suppression of gastrointestinal infections, antimicrobial activity, improvement in lactose metabolism, reduction in serum cholesterol, immune system stimulation, antimutagenic properties, anticarcinogenic properties, anti-diarrheal properties, and improvement in inflammatory bowel disease (Enujiugha and Badejo, 2017). Products, which were traditionally disposed as

wastes, such as ogi souring water and fufu liquor, have found their way into local cuisine due to their high concentrations of probiotics and other beneficial microorganisms. While past studies have shown that portable water supplies (both for domestic and industrial uses) in most developing countries are polluted at the treatment sites and along distribution systems at points of abstraction or use by consumers (Enujiugha et al., 1994), the high bacteriocin production (especially nisin) by probiotics and their high acidity offer great advantages for the safety of processed food products. Some of the factors that may influence the survival and activity of a probiotic product when entering the consumer's gastrointestinal tract may include: (1) the physiologic state of the probiotic organisms added, given by the logarithmic or the stationary growth phase; (2) the concentration at the time of consumption, as several studies have revealed that some commercial products do not sustain adequate populations of viable probiotic bacteria during their shelf-life; (3) the physical conditions during product storage, since some probiotic microorganism have shown viability during frozen shelf-life because they are held at lower temperature and subject to less temperature abuse; (4) the physico-chemical properties of the product to which the probiotics are added: pH, water activity; carbon, nitrogen, mineral and oxygen content affect the performance of these bacteria in many food environments and particularly in fermented foods; and (5) the possible interactions of the probiotics with the starter cultures (probiotics have been included as both starter and nonstarter cultures in fermented dairy products), with regard to bacteriocin production, antagonism, and synergism (Enujiugha and Badejo, 2017). Initial assessment of strains for use as probiotic cultures using such assays as acid and bile tolerance, can provide useful information for predicting their performance during gastric transit, and selection of strains based on tolerance to certain stresses, such as acid may also be useful predictors of technological performance in fermented foods.

The theoretical basis for selection of probiotic microorganisms includes safety, functional (survival, adherence, colonization, antimicrobial production, immune stimulation, antigenotoxic activity and prevention of pathogens) and technological aspects

(growth in milk, sensory properties, stability, phage resistance, viability in processes) (see Figure 12)

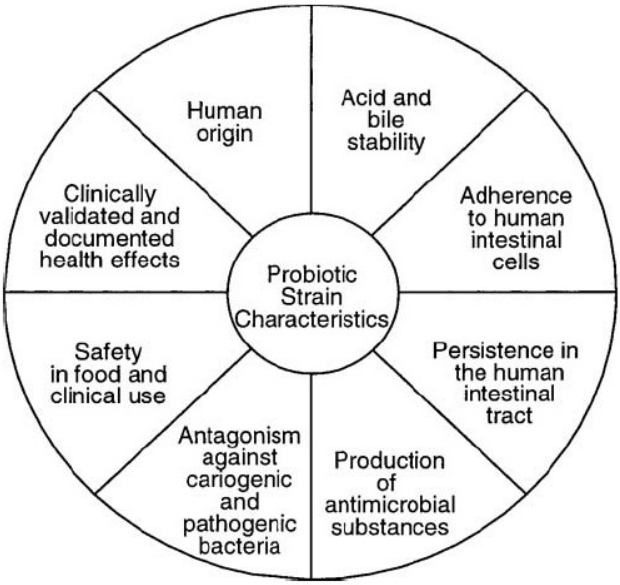

Fig. 12: The theoretical basis for selection of probiotic microorganisms

The adhesion to mucosal surfaces by probiotic microorganisms is an important ability for the colonization of the human gastrointestinal tract, prevents their elimination by peristalsis and provides a competitive advantage over pathogens. Adhesion provides an interaction with the mucosal surface facilitating the contact with gut associated lymphoid tissue mediating local and systemic immune effects (Enujiugha and Badejo, 2017). Thus, only adherent probiotics have been thought to effectively induce immune effects and to stabilize the intestinal mucosal barrier. Auto-aggregation appeared to be necessary for the adhesion of probiotic strains to intestinal epithelial cells and co-aggregation abilities may form a barrier that prevents colonization by pathogens. According to Ukeyima et al. (2010), probiotic organisms are expected to possess the following characteristics: (1) easy reproducibility; (2) ability to survive the

environmental conditions of the location where they are active; (3) genetically stable without plasmid transfer; (4) the absence of allergic, toxic, mutagenic or carcinogenic reactions, with neither its fermentation products nor its cell components being deleterious after consumption by the host; (5) ability to remain viable during processing; and (6) ability to adhere to and colonize the location where they are active.

4.2 Nutrient-Rich Edible Packaging Materials

Great importance is placed on packaging, especially in its ability to inform and persuade consumers. According to Makanjuola and Enujiugha (2015), consumers tend to be traditionally and culturally affected by size and a combination of size and touch in their choice of pre-packaged foods. However, the increasing awareness of the implications of some packaging materials to human health (especially, high and low density polyethylene) means that consumers are beginning to change their views on packaging to reflect the changing lifestyle of recourse to edible, medicinal and neutraceutical packaging regimes. The need to protect consumer health, as well as environmental concerns, has led to exploitation of natural food grade materials in food packaging. Such biodegradable films extend shelf life by acting as selective barriers against moisture and oxygen. Edible films can be used for versatile food products to reduce loss of moisture, restrict absorption of oxygen, lessen migration of lipids, improve mechanical handling properties, provide physical protection, and/or offer an alternative to the commercial packaging materials (Enujiugha et al., 2013). Composites and mixtures of these films have shown more remarkable functionality in terms of barrier properties and food freshness preservation, when compared to individual biopolymer-based films. An example is the combination of proteins and lipids to form biodegradable edible films and coatings, whereby the low water vapour resistance of protein films is compensated for by the water-repelling properties of the inorporated lipids (Enujiugha and Oyinloye, 2019).

Protein-lipid films present an interesting dimension to current packaging trends. Protein films are known to have excellent oxygen barrier properties and remarkable mechanical strength, but have

weak water vapour resistance ability when compared to other polymer-based films. However, edible protein films in combination with lipids result in better functionality, particularly as touching barrier properties. The mechanism by which proteins interact with lipids is significant in determining the properties of the resultant composite films and relies heavily on surface hydrophobicity (Enujiugha and Oyinloye, 2019). At the cellular level, membranes contain a large variety of lipid species that differ in the structure of their lipid head groups and in the length and saturation of their hydrophobic acyl chains. However, it is the behavior of protein molecules during denaturation whereby the hydrophobic core is exposed and their interfacial stabilizing ability that define the nature and properties of protein-lipid composite films in food systems (Enujiugha and Oyinloye, 2019).

The properties of protein-lipid films include the physical properties (color and opacity; solubility, as total soluble matter; film thickness; moisture content), the mechanical properties (tensile strength; Young's modulus; elongation at break), barrier properties (water vapour permeability; oxygen permeability) and molecular properties (surface and total sulfhydryl groups; electrophoretic patterns; protein content; concentration of saturated and unsaturated fatty acids) (see Table 21). .

Table 21: Comparison of physical and mechanical properties of selected protein-lipid films

Properties	*Amaranth flour*	*Pistachio globular protein—stearic acid*	*Hake protein—thyme oil*	*Egg white—Oleic acid*
Thickness (mm)	–	–	0.023 ± 0.005	0.103 ± 0.005
Tensile Strength (MPa)	1.20 ± 0.10	7.80 ± 0.10	5.61 ± 1.56	5.71 ± 0.20
Elongation at break (%)	39.0 ± 1.1	62.0 ± 2.0	146.3 ± 45.3	89.2 ± 1.6
Young's Modulus (MPa)	14.8 ± 0.8			
Water vapour Permeability ($gmmh^{-1}m^{-2}$ KPa)	0.4 ± 0.02	55.497 ± 6.09	$4.0E^{-11}$ ± 0.1	8.3 ± 0.2
Oxygen Permeability ($cm^3\mu mm^{-2}d^{-1}$ KPa)	33.7 ± 7.4			
Moisture content (%)	17.0 ± 0.6	34.76 ± 3.562		73.3 ± 0.6
Solubility (%)	39.9 ± 2.5	42.504 ± 3.251		45.7 ± 0.6
Opacity	20.3 ± 0.1	22.5 ± 0.1	14.9 ± 0.5	
L^{α}	78.3 ± 1.0		93.65 ± 0.25	95.85 ± 0.14
a^{α}	0.4 ± 0.1		−1.73 ± 0.14	−1.40 ± 0.12
b^{α}	18.9 ± 0.2		5.90 ± 0.64	6.00 ± 0.34
ΔE	24.1 ± 1.2		4.74 ± 0.66	

Properties such as tensile properties, water vapour resistance and gas permeability are usually affected by film structure and the nature of protein-lipid interactions.

4.3 Studies on Protein Supplementation and Complimentary Diets

Children in most developing countries, particularly those in low-income classes, are weaned on cheap, readily available starchy foods. This can be attributed to several factors including poor nutritional education, decline in household incomes and the unavailability of nutritious commercial formulae (Ijarotimi and Enujiugha, 2008). This has led to the continued research on locally sourced cheap protein-rich foods and their incorporation into traditional staples. Fermented maize product, ogi, is a popular weaning and breakfast cereal in sub-Saharan Africa, and is limiting in certain important amino acids, especially lysine and tryptophan. Also, during the processing of ogi, chemical constituents such as protein, soluble sugars and minerals are reduced in quantity and quality. Loss of protein content of maize during the production of ogi ranges between 5% and 10% depending on the method of manufacture. Attempts are currently being made in the developing world where maize is a major staple to supplement it with certain unconventional legumes and oilseeds that contain adequate amounts of the limiting amino acids.

Oludumila and Enujiugha (2017) evaluated the physicochemical and rheological properties of formulated complementary diet from blends of maize, African yam bean and pigeon pea flour. The blends considered were 90:5:5, 80:10:10 and 70:15:15 for maize, African yam bean and pigeon pea, respectively, which were compared with 100% maize gruel and a commercial weaning diet, Nutrend. The results showed that the complementary blend with ratio 70:15:15 (maize:African yam bean:pigeon pea) contained 24.29% protein, 4.05% ash, and 58.49% carbohydrate while 100% maize (ogi) had 10.52% protein, 4.2% ash and 73.02% carbohydrate in comparism with commercially produced diet, Nutrend, which had 21.64% protein, 3.58% ash and 61.35% carbohydrate. Overall the 70:15:15 ratio had higher proximate and mineral composition, and better antioxidant and pasting properties compared to the 100% maize gruel (ogi).

Enujiugha (2006) evaluated the quality of ogi from a composite mixture of maize (*Zea mays* L.) and oil bean seed (*Pentaclethra macrophylla* Benth) flours. Maize was substituted with oil bean seed at ratios of 90 : 10, 80 : 20, 70 : 30 and 60 : 40 maize/oil bean, with 100% maize ogi flour as control. The results show that protein content increased with increased oil bean seed substitution, reaching 33.25% dry weight at 60 : 40 ratio (Table 22).

Table 22: Proximate chemical composition of the ogi flours (g $10^{-2}g^{-1}$ DM)*

Ogi flour samples	*Ash content*	*Crude protein*	*Crude fat*	*CHO*	*Crude fibre*
100% maize ogi (control)	0.6 ± 0.1	10.5 ± 0.6	4.6 ± 0.3	79.3 ± 1.5	1.0 ± 0.2
Maize:oil bean (90:10)	1.1 ± 0.3	19.3 ± 0.5	5.6 ± 0.2	72.6 ± 0.9	1.5 ± 0.1
Maize:oil bean (80:20)	1.7 ± 0.4	22.8 ± 1.2	11.4 ± 0.7	63.8 ± 0.5	1.8 ± 0.4
Maize:oil bean (70:30)	3.1 ± 0.3	24.5 ± 0.8	12.9 ± 0.5	61.1 ± 1.2	2.0 ± 0.1
Maize:oil bean (60:40)	5.6 ± 0.5	33.3 ± 0.2	17.7 ± 2.1	55.9 ± 1.7	2.0 ± 0.3

CHO = carbohydrates.

*Values are means of triplicate determinations (±SD).

The mineral composition also showed marked improvement with increased substitution. On the other hand, tannins and oxalates increased with higher content of oil bean seed. However, the level of phytic acid was lowered with higher oil bean substitution. Pasting characteristics showed that higher oil bean seed substitution meant marked depreciation in the ease of cooking, and the peak viscosity was lowered (Table 23).

Table 23: Amylograph pasting characteristics of the different ogi samples

	Ogi flour samples (% maize:oil bean)				
	100 : 0	*90 : 10*	*80 : 20*	*70 : 30*	*60 : 40*
Gelatinization temperature (°C)	72.55	70.5	80.5	82.5	85.0
Peak (maximum) viscosity, V_m (BU)	480	440	380	310	240
Viscosity at 95°C, V_a (BU)	95	100.5	104	209	240
Viscosity at 95°C after 15 min, V_r (BU)	375	320	240	110	100
Viscosity at 50°C, V_e (BU)	520	500	530	530	650
Consistency ($V_e - V_a$) (BU)	225	299.5	426	321	410
Stability during cooking ($V_m - V_r$) (BU)	105	120	140	200	140
Setback ($V_e - V_m$) (BU)	40	60	150	220	410
Gelatinization time (m_g) (min.)	17	18	18.5	21	22
Time to reach peak viscosity (m_n) (min.)	42	40.9	40.9	30.8	28
Ease of cooking ($m_n - m_g$) (min.)	25	22.9	22.4	9.8	6

Results of sensory evaluation show that colour and flavour were significantly ($P < 0.05$) affected by increased substitution of oil bean seed beyond 20% substitution level, while the resultant ogi gels were still acceptable in terms of mouthfeel and overall acceptability at ≤ 20% substitution level. The study indicated that the quality attributes of ogi can be enhanced at ≤ 20% oil bean seed substitution of the ogi mass, with higher nutrient content and lower content of anti-nutritional factors, suggesting that defatted African oil bean seed flour has the potential as a source of protein and mineral supplement in traditional maize-ogi production.

Oluwamukomi et al. (2003) carried out the nutritional, physicochemical and sensory evaluation of sorghum and cowpea–based weaning formulation and observed that increasing legume (cowpea) supplementation brought about increased nutritional quality of the resultant formulation. The problem of cowpea oligosaccharides (raffinose, stachyose and verbascose) which are strongly associated with flatulence could be taken care of by the prolonged soaking of the legume seeds before milling, drying and formulation. The sorghum tannins (polyphenols) which are associated with astringency and protein-binding were effectively removed by steeping, and fermentation.

4.4 Using Bioresources in Composite Flour Formulation

Awolu et al. (2017) and Olorunfemi et al. (2018) investigated the effect of the addition of *Moringa oleifera* seed and African oil bean (AOB) seed flours on the minerals, antinutritional compositions, antioxidants and Angiotensin-1 converting enzyme (ACE) inhibitory potentials of wheat based composite flour. The mineral composition of the composite flour was optimized using optimal mixture design of response surface methodology (RSM) by varying the independent variables as; wheat flour (50-90 g/100g), *Moringa* seed flour (5-25 g/100g) and AOB flour (5-25 g/100g). The results of the optimisation indicated that run 11 (50% Wheat/25% *Moringa* seed/25% AOB flours) had overall highest Fe, Ca and Mg contents while run 1 (81.20% Wheat/8.68% *Moringa* seed flour/10.12% AOB seed flour) had the highest Zn, P and Na contents. Overall, the composite flour blend consisting 81.2% wheat flour, 8.68% *Moringa* seed flour and 10.12% African oil bean flour showed

antioxidant properties that was over 200% higher than the control (100% wheat), with lower antinutrients content and more than 50% higher ACE. Therefore, a composite flour consisting wheat, *Moringa* seed and AOB seed flours in ratios 81.2%:8.68%:10.12% will be suitable in the production of cake of high antioxidant characteristics with a high ACE inhibition potential which might serve as a very good antihypertensive functional food product.

In a study by Gbadamosi et al. (2011), wheat flour (WF) was substituted with African oil bean seed flour (AOBF) at 0, 5, 10, 15 and 20% in cookies, and the chemical and functional properties of the flours and their blends as well as the physical and sensory attributes of the cookies were determined. The flour blends had higher fat, ash and protein than the 100% wheat flour. The level of these nutrients improved as the amount of AOBF in the blend increased. Gross energy also increased as AOBF increased in the blend, WF having 398.91 and AOBF 676.01 kcal/100 g. All the composite cookies were as acceptable as the 100% wheat cookie, with the 5% AOBF substitution being rated better than the 100% wheat cookie. Except for the 'sleeping oil' appearance exhibited by wheat flour substitution levels of 15 and 20%, all levels of substitution produced cookies of acceptable quality. The study showed that cookies fortified with African oil bean flour at the 5% substitution level gave a product that compared well and above the all-wheat cookies, thus making this ratio (95% WF: 5% AOBF) the best of all the substitution levels.

Bello et al. (2017b) examined the nutrient composition and sensory properties of biscuit from mushroom-wheat composite flours. *Pleurotus sajur-caju* (PSC) mushroom was dried, processed into flour and used to substitute wheat flour as composite flour. The composite flour was at 0, 5, 10, 20 and 30% level of mushroom addition, the resulting mixtures were then used to produce biscuits. The proximate composition, minerals, physical (spread ratio, weight, thickness) and sensory properties of the composite biscuit were evaluated. The protein content increased from 13.04% in the control (100% WF) to a range of 13.41% - 15.55%. in the biscuits; crude fibre increased from 2.10 to 2.16 - 2.93 %.; ash content increased from 1.52% to a range of 1.87 - 3.85%, while crude fat and

carbohydrate reduced from 21.71 to 19.05 - 20.58% and 61.63 to 58.62 - 61.58% respectively. As the ratio of mushroom level increased, the mean, thickness, diameter, weight as well as the spread ratio increased. The results of mineral composition indicated that potassium, calcium, sodium, and phosphorous were the predominant mineral elements present in the mushroom/wheat biscuits. There was an increase in the mineral content of the biscuit with increase in the level of mushroom flour addition, which indicates that mushroom is a good source of minerals. There was no significant difference in the overall acceptability of the control (100% WF) and 5% mushroom substitution samples. Based on the nutritional composition and sensory evaluation, the consumption of the mushroom-wheat flour biscuit at 5-10% mushroom flour inclusion is therefore recommended as a supplementary, low fat, but high fibre snack food.

5.0 CONCLUSIONS

Mr. Vice Chancellor Sir, during the course of this lecture I have been able to highlight the potentials of biotechnology as a useful tool for tackling nutrition-related challenges and sustaining active and productive lifestyles. I have outlined the research efforts made by my team to harness the nutrient potentials of our indigenous bioresources and highlight their contributions towards solving the problem of protein-energy malnutrition. I was in the forefront of efforts to collate and galvanize our local foods into usable compendium, both at national and sub-regional levels for easy accessibility by all users. Happily, this has yielded fruit in the publishing of the respective food composition tables.

I have also in this lecture outlined all my major research efforts towards achieving healthy nutrition though effective utilization of locally-available biodiversity. Plant bioactive compounds, especially the antioxidative constituents, have been found useful in combating many degenerative and age-related diseases. Also, the utilization of protein isolates and hydrolysates (bioactive peptides) from local bioresources for their antioxidant, antihypertensive and immune-modulating properties have been established. The antidiabetic properties of some of our local bioresources both in raw

and processed forms have also been greatly underscored.

It is obvious that the advent of biotechnology has positively influenced dietary preferences and consumption patterns, and this has culminated in productive lifestyles, especially among the rural populations. Foods that are now being embraced were hitherto considered wastes and byproducts to be discarded. The concept of prebiotics and probiotics has been generally embraced because of their bowel modulating and antidiarrheal properties. Also, the introduction of graded substitution of protein-rich substrates into the traditional African starchy staples has helped to alleviate many nutrition-induced health challenges. Apart from increasing the protein content of our local diets, the balancing of amino acids through effective complimentarity has indeed made the exploitation of the diverse cultivated and wild bioresources very attractive.

The problems associated with the exploitation of the indigenous biodiversity, such as the high concentrations of antinutritional and toxic factors are known to be solved via the various steps involved in their processing and preservation (hydrothermal treatment, soaking, washing fermentation and drying). The introduction of hurdle technology (such as combining irradiation with cooking) has a positive effect on nutrient retention and flavor enhancement.

The introduction of edible packaging through the application of appropriate technologies, has helped to nutritionally enrich our pre-packaged consumer goods, while at the same time providing an alternative to the non-biodegradable synthetic materials such as high and low density polyethylene. The utilization of environmentally-friendly protein-lipid films, which can easily be formed at the rural subsistence level, from locally available grain legumes is a great step towards effective and efficient bioresource exploitation.

6.0 RCOMMENDATIONS

Arising from this lecture, concrete actions are required from all stakeholders to jointly advance and appropriate the advantages of wider and increased exploitation of our local biodiversity to achieve the noble goal of longevity and productivity. I will like to therefore make the following recommendations:

i. There is need for increased advocacy for the cultivation of those important bioresources that are germane for sustenance of healthy nutrition and productivity. For example, despite the great nutrient and medicinal potentials of conopnor nut (*Tetracarpidium conophorum*), there is till date no known cultivated plantation of this underutilized oilseed plant. What we have currently is that this audacious and persistent climber defies farmers to twin around cocoa and kolanut trees in their respective plantations. This unsavoury culture of neglect of our useful biodiversity could be curtailed by concerned government agencies via the creation of conducive agronomic environments for farmers.

ii. Local farmers should be adequately financially empowered to venture into domestication of the varied wild species scattered across the African agro-ecological landscape. Farmers need incentives to be able to venture into the cultivation of unconventional and neglected species, through the provision of funds and other forms of support such as equipment and fertilizer supplies.

iii. To increase bioresource exploitation, there is need to invent ways to add value to these crop plants by diversifying the existing consumption forms through adaptation of new and emerging processing techniques. For example, the only known use of African locust bean (*Parkia biglobosa*) is as a fermented condiment; application of value-addition to this local bioresource by exploring other uses would invariably increase its cultivation and utilization.

iv. There should be proper documentation and archiving of the innate nutrient potentials of our local foods, especially foods as eaten since raw foods may not accurately depict actual nutrient profile accruing from the consumption of such foods. The current food composition tables centre mainly on raw unprepared foods because of the complexity of knowing which components are contributing particular nutrients.

v. Town-gown relationships should be encouraged and strengthened such that products of research in the universities, especially in the area of functional and bioactive properties of

foods, would be well disseminated to consumers and other stakeholders. To this end, government should increase funding of research and formulate appropriate policies to encourage the dissemination and application of research results in the interest of rural populations

vi. Creating awareness of current research outputs through structured nutrition education programmes should be undertaken by government at all levels. If our teeming rural populations are well-informed about the nutrient and bioactive profiles of the divers bioresources, there would be as a consequence drastic reduction in incidence of nutrition-related diseases.

vii. Inter-disciplinary and inter-department research collaborations should be encouraged in our universities. Effective community-based research cannot be successful without involving experts in the different disciplines and from different departments. There is therefore need to design and re-structure academic and research curricula that would be all-encompassing to accommodate other disciplines in any particular research activity.

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