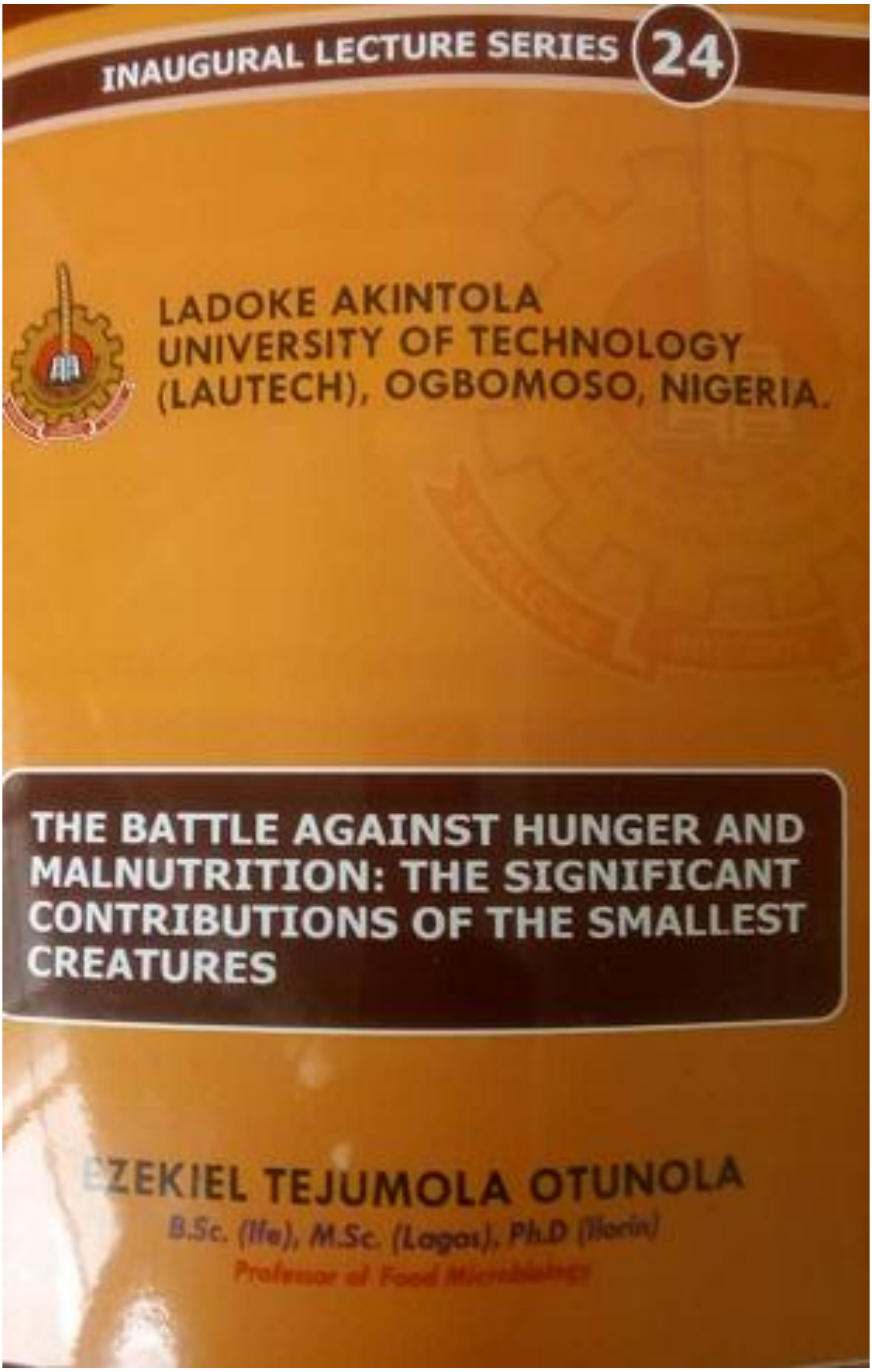
INAUGURAL LECTURE SERIES 24

LADOKE AKINTOLA UNIVERSITY OF TECHNOLOGY (LAUTECH), OGBOMOSO, NIGERIA.

THE BATTLE AGAINST HUNGER AND MALNUTRITION: THE SIGNIFICANT CONTRIBUTIONS OF THE SMALLEST CREATURES

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B.Sc. (Ife), M.Sc. (Lagos), Ph.D (Ilorin)
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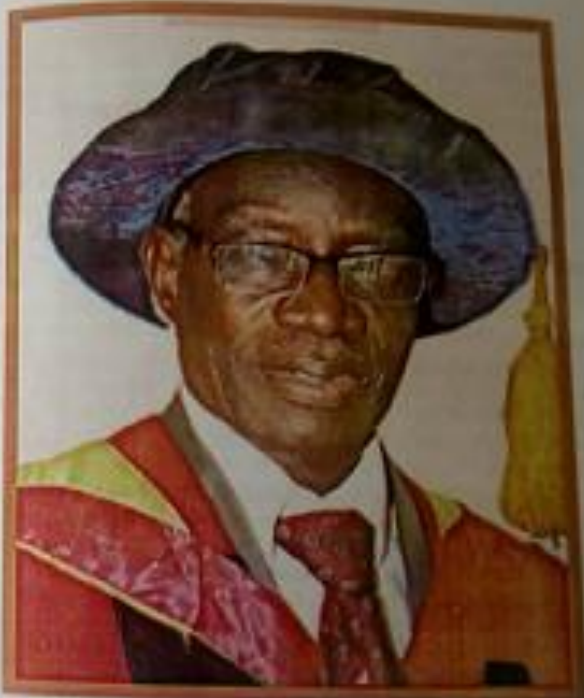

EZEKIEL TEJUMOLA OTUNOLA
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Courtesies

The Vice- Chancellor,
The Registrar,
Other Principal Officers of the University,
Provost of the College of Health Sciences,
Deans of Faculties and Post Graduate School,
Distinguished members of the University Senate,
My Academic Colleagues.
The Congregation and other staff,
Special Guests, Friends and well-wishers,
Gentlemen of the Press,
Great Ladokites,
Ladies and Gentlemen,

Preamble:

I give glory, honour and adoration to the almighty God for His grace that has been sufficient for me all my life, and for making today a special day of reality. I also wish to express my profound gratitude to the Vice-Chancellor of this great University, Professor Adeniyi S. Gbadegesin and his management team for this great and unique opportunity to deliver this 24th inaugural Lecture of this great citadel of learning. From records, it is the fifth in the Faculty of Engineering and Technology and the third in the Department of Food Science and Engineering. For this I also wish to greatly appreciate the Dean, Faculty of Engineering and Technology, Professor Kazeem A. Adebiyi, for this special privilege, and the support of the Acting Head, Department of Food Science and Engineering, Dr. (Mrs.) Oluyemisi .E. Adelakun.

From the Beginning Mr. Vice-Chancellor Sir, kindly permit me to start this lecture with a very brief review of my early life, especially as it concerns my educational pursuits. Please permit me further, and once again, to express my immense gratitude to God for His grace that has always been sufficient for me. It is by His grace that I had the opportunity of even a primary education at all, considering the prevailing situation then. The financial challenges were daunting. Typical of many polygamous homes, the responsibility of paying our school fees fell on our mothers when our father could no longer cope. My dear mother, determined to make me have a sound education, engaged in petty businesses, including local food processing. I recall vividly that I also had to support her by hawking some of her products such as 'agidi' a stiff fermented maize porridge wrapped in leaves, okro, plantain, vegetables and a few other farm produce after school hours. In addition, I had to engage in labour activities on other peoples' farms just to augment the payment of school fees, buy books and uniform when the need arose. It was a really tough time, but indeed, by that special grace of God, survival and success followed.

Advancement to the senior primary school brought along the desire to go to 'college' even when the purpose and activities in 'college' were not yet fully understood. This desire was strongly spurred by the presence of the mathematical set and science notebooks brought by two cousins, who came on holidays from 'college' The contents of the mathematical set, and the 'wonderful' drawings of apparatus on the graph pages of science notebooks were too attractive for me to ignore. Noticing my curiosity, these two cousins were magnanimous enough to explain and teach me how to use these components. Before they went back to school, I was excited to have been drawing concentric circles and constructing angles. This might sound trivial now, but, if we remember that up to the mid-sixties, post primary schools were not common sights, and particularly in my area of the defunct Northern Nigeria. From that point in time, the desire to go to 'college' grew stronger by the day, but always dampened by the thought of the challenges of school fees.

Further Developments

The grace of God surprisingly manifested again by the fact of an award of scholarships that accompanied my admission into secondary school. The scholarships, which covered all tuition, started with the unique entrance examination award in the first year, and followed by the defunct Northern Nigerian Government Scholarship award for subsequent years. Moreover, again by that marvelous grace of God, my maternal uncle graciously took over the financial responsibilities of other needs such as boarding, books, uniform etc. That appeared to mark the end of my financial worries as they concerned my educational pursuits. By that special grace of God again, my undergraduate stay at the University of Ife (Now Obafemi Awolowo University) was funded by a generous Federal Government Scholarship that covered tuition, boarding, feeding, and even with a book allowance. My postgraduate studies, by that grace of God also, at both Masters and Ph.D levels, were also funded by the Kwara State Government Scholarships

After obtaining my first degree from the University of Ife (Now Obafemi Awolowo University) Ile Ife, I participated in the mandatory National Youth Service. Thereafter, I had a short stay of about three months at the Federal Ministry of Health, as a Food Inspecting Officer. It is on record that it is that section of the Federal Ministry of Health where I worked that later metamorphosed into the National Agency for Food and Drug Administration and Control (NAFDAC). I left the Federal Ministry of Health and joined the services of the Kwara State College of Technology (Now Kwara State Polytechnic), Ilorin as lecturer III in September, 1975. There, I rose through the ranks to the post of a Chief Lecturer in October, 1993. There, in addition to teaching, research and other academic activities, I also had some administrative responsibilities.

My long desire to join the University system became realised when, by that special grace of God again, in 1993, I met Professor I. A. Adeyemi who came to organize the National Conference and Annual General Meeting of the Nigerian Institute of Food Science and Technology at Ilorin. He graciously co-opted me into the Local Organizing Committee (LOC) and that gave me the unique opportunity to discuss my desires with him. That meeting was highly blessed as it marked the beginning of my movement to the University system, and particularly to the Ladoke Akintola University of Technology, Ogbomoso. I started on part-time basis, but in September, 1995, I joined fully as a lecturer. It was also a rare privilege to take over the leadership of the Department of Food Science and Engineering from Prof. I. A. Adeyemi, who, just before then, became the first Deputy Vice-Chancellor of the University, in September, 1995. I have thus risen from that position of Lecturer I in 1995 to the post of a Professor in October, 2004. Since joining the services of LAUTECH, I have been involved in the teaching of various courses at both undergraduate and postgraduate levels and research.. I have also supervised many students at undergraduate, Masters and Ph.D levels. Moreover, I have also been involved in several administrative responsibilities and membership, and in a few cases, chairmanship of standing and ad-hoc committees of the University. I have also served various Local and National organizations in various capacities.

My research activities have centered mainly on the interaction of microorganisms with our foods, both positively and negatively, but with greater emphasis on the positive transformation microorganisms can bring to our foods. This focus has involved, on many occasions, interactions and collaborations with colleagues in and outside the Department, Faculty of Engineering and Technology, as well as other institutions at national and international levels. In this regard please permit me to appreciate my colleagues in Food Engineering, through whose collaboration, my horizon has been broadened in terms of how microbial interactions can affect the physico-chemical, processing and engineering properties of foods.

No matter how rosy, there is no life without its own peculiar challenges. My family and I have therefore had several challenges in life, many of them, including periods of severe hunger, life threatening. However, this marvelous grace of God had always been sufficient for me.

Hunger in the World

Hunger is so severe in the world today such that virtually all regions of the world suffer hunger in one form or the other. According to the recent estimate, about 1 billion people in the world are hungry and do not have enough food to lead a healthy and active life. Moreover of the 7.6 billion people in the world, one in ten suffers chronic malnutrition (FAO 2017). Unfortunately, the vast majority of the hungry and malnourished people live in the developing countries. Africa follows Asia very closely in terms of countries harbouring the larger populations of hungry and malnourished people. Furthermore, according to Global Hunger Index (GHI), sub-Saharan Africa, and particularly West African countries, (Plate 1), feature very prominently in the number of hungry and malnourished people (IFPRI, 2016; Rosen *et al*., 2016; (FAO, 2018)

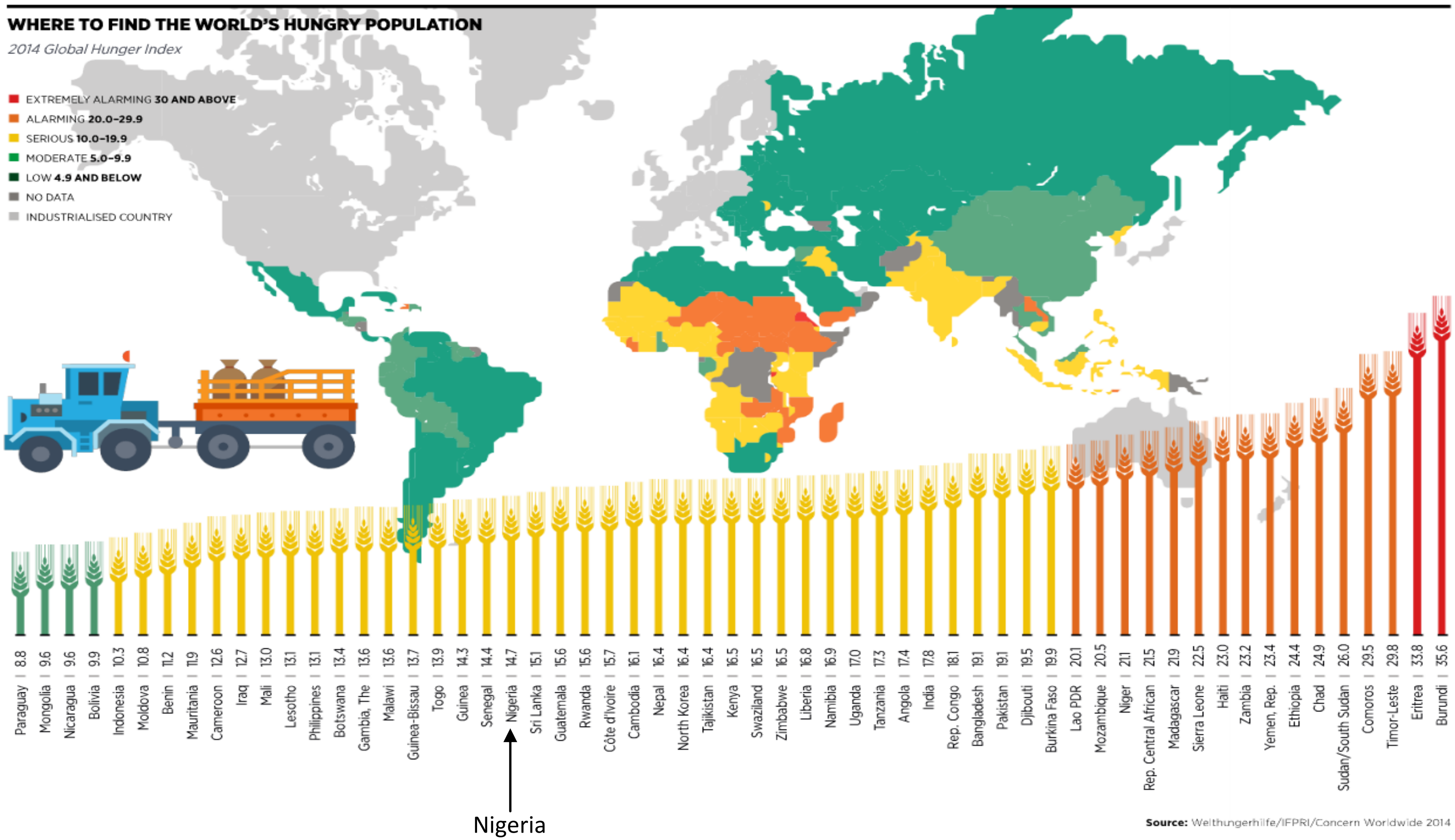

Plate 1: Global Hunger Index Estimates
Source: IFPRI, 2016

One of the greatest challenges inhibiting food and nutrition security in the world is the exponential rate of population growth and the consequent alarming increases in population. This makes the food supply system to find it extremely difficult to meet the food demands of these teeming populations around the world. It is unfortunate and an irony that 80% of the world alarming population resides in the poorest developing countries, including those in sub-Saharan Africa, where about 23% of the people remain hungry and undernourished (IFPRI, 2016; FAO, 2017)

Among the top causes of hunger in the world, food wastages at pre and post- harvest levels rank very high, following population, poverty, climate change and conflicts. About one-third of food produced in the world is wasted (FAO, 2016). Some prominent factors that contribute to this unfortunate situation include inadequate infrastructural facilities that could otherwise facilitate the use of preservative and post-harvest processing technologies. Yet many developing countries have, and can further develop, traditional preservative technologies that rely less on these modern technological advancements. If Sub-Saharan Africa and other developing countries, and even the developed ones to some extent, must break the vicious cycle of hunger, poverty and disease, all potential remedial measures available must be fully harvested rapidly and effectively.

The potentials of the traditional food processing techniques in many developing countries, if properly harnessed, could play a significant role in achieving food and nutrition security. This is because many of these traditional technologies do not require very sophisticated equipment and have far less energy requirements. One of the most promising of these is the traditional fermentation technology, a variety of which abounds in many developing countries, and has played very prominent roles since ancient times.

Microorganisms and our Foods

Microorganisms are generally defined as living organisms that cannot be seen with the unaided eye. They are so small, such that they can remain undetected in an environment until the assistance of a microscope, with magnifications much higher than that of a magnifying lens, is enlisted. Millions of their individual cells, each of which is capable of an independent life, performing all life activities, can aggregate into a colony the size of a very small dot.

Scientists believe that microorganisms had existed more than 3 billion years before the existence of man, (Willey *et al*., 2013), probably preparing the earth for man and other living organisms, especially in terms of food supply. The involvement of microorganisms in food supply for man and other living organisms has been in existence since life started. Their critical roles in the recycling of elements have been well known over the years (Fig. 1). It is generally believed that without microorganisms there will be no life.

Microorganisms are also prominently involved in the decomposition of the dead bodies of plants and animals thus releasing their chemical components into the soil by which plants get their essential nutrients. Many microorganisms are also involved in the enhancement of soil fertility in terms of nitrogen fixation, reclamation of alkaline user lands, and use as bio-fertilizers. They are also involved in biological control of pests as microbial pesticides. Microbial bio-fertilizers and bio-pesticides are known to be far less harmful than the synthetic chemicals traditionally used as fertilizers and pesticides.

There are however some negative impacts associated with the interactions of microorganisms with our foods. Many of them are notorious for their food spoilage and food poisoning activities. Devastating losses due to food spoilage by microorganisms are common knowledge, while very severe and some of the very fatal cases of food poisoning have been constantly reported all over the world over the years. It is interesting to note however that in many cases, it is the microorganisms themselves, either the same species or another, that are responsible for viable solutions or remedies for such incidences. This may be in form of the production of antibiotics, vaccines and other chemicals, produced by the same species or a related microorganism. Some of these chemicals act by completely eliminating or inhibiting the growth of the causative microorganisms.

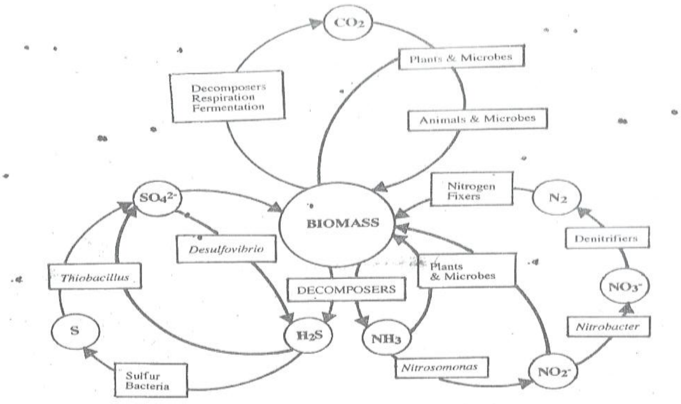

Fig. 1: Micro-organisms and the carbon, nitrogen and sulphur cycles
Source: (Adam and Moss, 2005)

Mr. Vice-Chancellor Sir, perhaps one of the most significant consequences of microbial interactions with our foods is through their fermentative activities, which also constitutes the focus of our research, and consequently the main thrust of this inaugural lecture.

Food Fermentation

In the strict physiological or biochemical sense, fermentation is generally defined as a process in which energy is derived from organic compounds without the involvement of oxygen as a final electron acceptor. The end products many include lactate, ethanol, and some other by products. In the food and industrial world however, fermentation has come to assume a wider definition as any process in which there is rapid multiplication or mass production of microbial cells, regardless of the final electron acceptor i.e. whether oxygen is involved or not. It is in this context of a broad definition that the concept of fermentation will be used in this lecture.

From the process of fermentation many amazingly useful food products are produced all over the world. In fact every country in the world has its own unique varieties of fermented foods such that the origin of fermented foods is sometimes used as the basis of classification. In many cases, they are also so much interwoven with the traditions and cultures of the different peoples of the world (Camp-bell Platt, 1994; Steinlcraus, 1998). Fermentation results in the transformation of the constituents of the food material into new useful forms. Foods are complex mixtures of various substances including carbohydrates, proteins, fats and several vitamins and mineral elements, as well as lots of indigestible materials. In most cases, toxic and ant-nutritional substances are also contained in foods. Water is also a major component of foods. The observable products of food fermentation depend largely on the particular raw food, its composition and the microbial flora it carries, except in the case of controlled fermentation where starter culture may be used. It also depends largely on the intrinsic and extrinsic factors of the raw food material.

Microorganisms Involved in Food Fermentation

As mentioned earlier, fermented foods are products of the transformation of foods by the action of microorganisms. Such products are expected to have desired characteristics that have to do with texture, taste, flavour, mouth feel, and other organolephic attributes. They are also expected to be nutritionally rich and safe for consumption. Where the products develop undesirable characteristics and are unsafe for consumption, then spoilage can be implied. Various types of microorganisms, belonging to a variety of genera, species and strains are usually involved in food fermentation, each with its unique biochemical processes. Each of them has its unique biochemical pathway of metabolism, although some may use a combination of two, depending on the prevailing intrinsic and extrinsic factors. The main ones are:

- Lactic acid bacteria (LAB)
- Acetic acid bacteria
- Propionic acid bacteria
- Species of *Bacillus* (for alkaline fermentation)
- Yeasts
- Molds

There are two major groups of lactic acid bacteria: namely; homofermentative and heterofermentative ones. The homofermentative ones produce lactic acid mainly as the end product of carbohydrate metabolism, while the heterofermentative ones produce a mixture of carbondioxide, ethanol and lactic acid in equimolar amounts. Each group has its own unique pathway of carbohydrate metabolism. While the homofermentative (LAB) employs the Embden Meyerhoff Panas (EMP) mainly, the hetero fermenters follow the phosphoketolase pathway (PP) mainly (Fig 2).

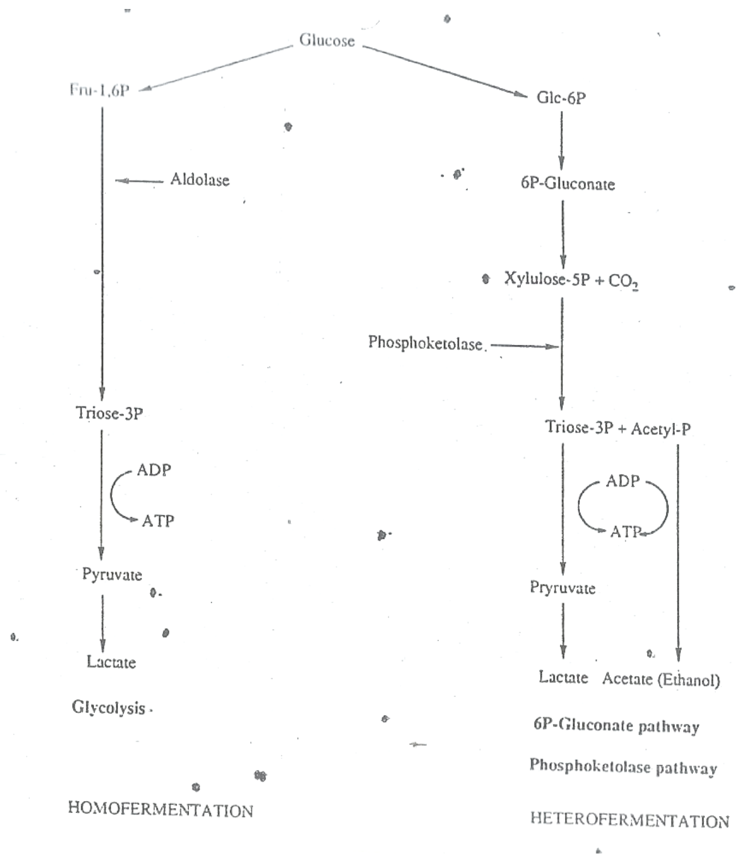

Fig. 2: EMP pathway and Phophoketolase pathway
Source: Adam and Moss, (2005)

The yeasts follow mainly the EMP pathway. While yeasts transform carbohydrates into ethanol, the acetic acid bacteria convert the alcohol formed by yeasts into vinegar, a solution of acetic acid. In each case, several minor substances are also produced which may have implications on the main end product. For instance acetoin and diacetyl are flavouring substances produced by LAB, in addition to the main products of lactic acid, carbondioxide and ethanol from pyruvate.

It may be of interest to note that many of these products of fermentation have anti-microbial properties that eliminate or at least, suppress the growth of undesirable microorganisms, while they themselves are tolerant to such conditions. For example, LAB and yeasts generally produce acids and alcohol respectively. While low pH and high alcohol concentrations may be well tolerated by LAB and yeasts, molds and other fermenting microorganisms, the growth of undesirable ones, mainly food spoilage and food poisoning ones are suppressed.

Advantages of Food Fermentation

Quite a number of benefits accrue as a result of the transformation of foods by microorganisms to fermented products. Some are enumerated below:

- **Enhancement of nutritional status**
  In most cases, the nutritional status of the food material is enhanced. This may be in terms of the increase in protein quality and quantity as exemplified by increase in the amount of essential amino acids. The more complex carbohydrates and proteins may also be made to become more digestible.

Development and enhancement of desirable sensory attributes

In all cases of food fermentation, the desirable sensory attributes are enhanced. For instance, textural properties are modified, due to the liberation of appropriate enzymes by the fermenting microorganisms that break down complex structural materials such as hemicelluloses, celluloses, pectin etc, and desirable flavours as imparted by lactic acid, diacetyl, acetoin etc.

- **Synthesis and release of micronutrients**

  During the process of fermentation, many microorganisms are capable of synthesizing quite a number of vitamins, thus improving the vitamin contents of the fermented product. Typical examples include the synthesis of some B complex vitamins by LAB, yeasts and molds during the fermentation of predominately carbohydrate foods. Moreover, many mineral elements that are otherwise locked up in the raw food materials are released and made available as a result of fermentation, thus increasing the variety and quantity of bio available mineral elements.

- **Availability of varieties of foods**

  The process of fermentation by microorganisms can lead to the production of more varieties of foods from the same raw material, thus increasing the utilization and economic value of the raw material. Typical and familiar example is the several products obtained from the fermentation of cassava tubers, which include gari, lafun, fufu etc.

- **Elimination and/or reduction of toxic constituents**

  The process of fermentation has been found to be very effective in eliminating toxic and anti-nutritional substances found in foods. Again, a typical example is the removal of cyanide from cassava by fermentation into gari, lafun and other products. Other examples include the reduction of phytate, oxalate, tanins and flatulence factors (oligosaccharides) from cereals and legumes. In most cases, the offensive substance is either completely eliminated or reduced to a tolerable level.

- **Suppression of toxin production**

  Various studies have demonstrated that toxin synthesis by food poisoning microorganisms is usually substantially suppressed during food fermentation. For example, the synthesis of botulinal toxins by *Clostridim botulinum* is inhibited. Botalinal toxins are very deadly neurotoxins produced by *C. botulinum*. The synthesis of this toxin has been demonstrated to be inhibited by the presence of lactic acid bacteria (LAB), which synthesize lactic acid from carbohydrate foods. The lactic acid antagonises the growth and synthesis of the toxin (Jay, 2005). Moreover, lowering of pH to less than 4.5, as occurs in fermented foods, prevents toxin formation (Taraka, 1982). Furthermore, spore germination by the toxin producing microorganism is also inhibited by the low pH of fermented foods, and this may partially explain why yoghurt, a fermented milk product hardly harbours botulinal toxin. Similarly, mycotoxin production by molds is appreciably prevented in fermented foods (Sighn, 2004)

- **Preservative effects / increase in shelf-life**

  Food fermentation imparts preservative effects and subsequently increases the shelf-life of the products. Food preservation by fermentation has been practiced since ancient times, even before the scientific knowledge of the process became known. Although the mechanism is not yet fully understood, a few of the ways by which fermentation exerts preservative effects on foods are enumerated below:

- The production of organic acids such as lactic acid, acetic acid, propanoic acid etc lowers the pH of the environment, which makes it difficult for some microorganisms, especially bacteria, which thrive best around the neutral pH, to grow
- Many of the fermenting microorganisms take advantage of the lowered pH, which favours them, to become predominant and suppress the growth of food spoilage and food poisoning ones.
- The organic acids, hydrogen peroxide and some antibiotics produced during fermentation also interfere with the metabolic pathways of food spoilage and food poisoning microorganisms that may be present in the unfermented food.
- Another important mechanism in the lowering of the oxidation reduction (redox) potential of the medium to a level unfavourable to food spoilage and food poisoning microorganisms (Adams & Moss, 2005).

➢ **Low cost nature**
Fermentation is known to be a relatively low cost food processing technique. This is usually in terms of low energy requirement and usually does not require sophisticated equipment or technology. It also drastically reduces cooking time, thus saving a lot on energy cost. All these make it easy to practice, especially in rural communities of the developing countries.

➢ **Conversion** of otherwise inedible materials into edible and beneficial forms e.g 'iru' production

➢ **Transformation** of food and agricultural wastes into useful forms, and even sometimes into edible forms that are quite different from the initial unfermented material or fermentation product. This in turn has positive implication for waste management and reduction of environmental pollution.

Our Research Contributions

As mentioned earlier in this lecture, our main focus of research has remained with fermented foods. But before embarking on this main research focus, I had earlier worked on the characteristics of some bodies of water, with a view to determining their suitability or otherwise, for drinking, domestic and industrial purposes. This was borne out of the realization that food processing at local and industrial levels rely heavily on the available water supply.

In line with this, I had cause to work on the characteristics and quality of water along the coastal areas of Lagos and Accra, Ghana. Here, an unconventional material, *Gyphea gasar*, (an edible oyster from the coastal areas) was used as an index, but later correlated with the conventional indices of coliforms, faecal coliforms and, faecal streptococci. This study confirmed the relatively heavy pollution with faecal matter in the coastal area of Lagos; while the waters form East and West Tema in Ghana were, on relative basis, far less polluted. It was observed further that the oysters from Lagos accumulated and retained for long, large populations of bacteria in their tissues, far in excess of what obtained in the surrounding waters (Otunola *et al*., 1983). The accumulated bacteria were also found to be resistant to the lethal effects of low and freezing temperature storage (Fig.3).

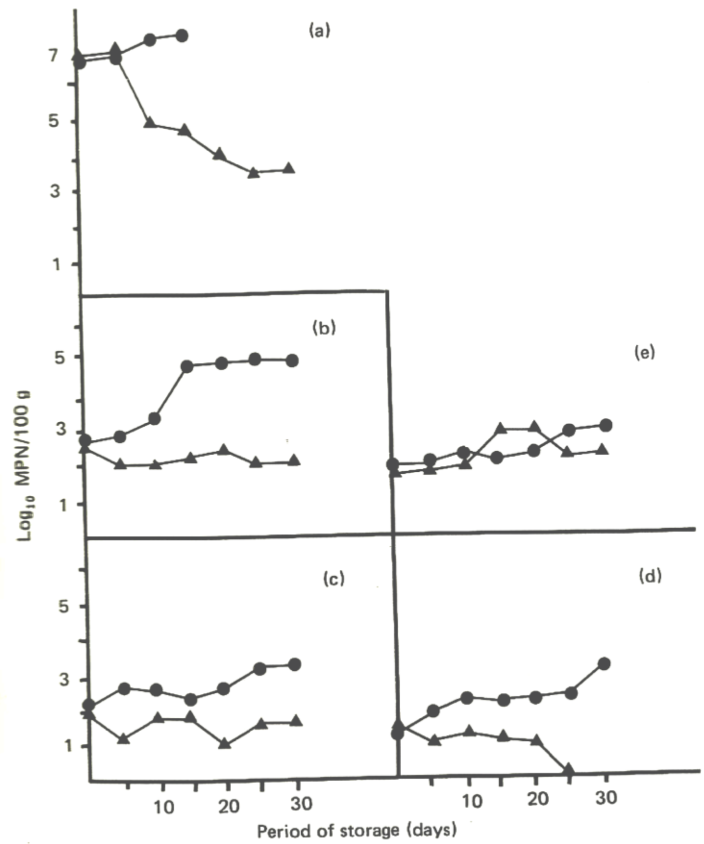

Fig. 3: Comparison of (a) total aerobic viable bacterial plate counts, (b) coliform bacteria, (c) *E. coli,* (d) faecal coliform and (e) *Clostridium* contents of oyster *G. gasar* stored at different temperatures for 30 days ●, 15^{o}C; ▲, - 5^{o}C
Source: (Otunola *et al*; 1983)

Later studies attributed this to the high protein and far contents of the oyster tissues, which are known to confer protective effect on bacteria against the lethal effects of high and freezing temperatures (Adams and Moss 2005; Frazier and Westhoff, 2005).

In a related study, the various sources of water that served the Polytechnic community of Kwara State Polytechnic, Ilorin were also found to be heavily contaminated with human and faecal matter from domestic activities. This was indicated by the high populations of coliforms and fecal coliforms in all the sources as indicated in Table 1 (Otunola and Giwa, 1994). This was considered a serious health hazard and adequate measures were subsequently taken by the Polytechnic authority to reduce the health risks associated with this.

Table 1: Feacal Coliforms (*E.coli*) MPN/100ml of sample from from Mogaji, Bolapa and Ojulogbo streams.

Sample No.	Date	MOGAJI	BOLAPA	OJULOGBO
1.	20/3/87	55	1800 +	1800 +
2.	24/3/87	1800 +	1800 +	1800 +
3.	27/3/87	900 +	1800 +	1800 +
4.	24/4/87	1800 +	1800 +	1800 +
5.	28/4/87	1800 +	1800 +	1800 +
6.	2/5/87	1800 +	1800 +	1800 +
7.	10/5/87	1600 +	1800 +	1800 +
8.	14/5/87	***	1800 +	1800 +
9.	20/5/87	1800 +	1800 +	1800 +
10.	22/5/87	1800 +	1800 +	1800 +
11.	3/6/87	1800 +	1800 +	1800 +
12.	14/6/87	1800 +	1600 +	1800 +

Source: Otunola and Giwa (1994)

Further work on the effect of sources of water on the characteristics of 'ogi' processed from them revealed that stream water, with its unique microbial flora, resulted in 'ogi' with the best quality characteristics in terms of protein contents, tritratable acidity, pH, % lactic acid, populations of lactic acid bacteria (LAB) and sensory attributes as illustrated in Tables 2,3,4 (Otunola and Ogunrombi, 1998). The performance of stream water was superior to those of well and the cleaner tap and distilled water, suggesting the significant role of the indigenous microflora on natural fermentation processes.

Table 2: Effect of processing water source on the proximate composition of ogi

Processing water source	Moisture (%)	Protein (%)	Fat(%)	Fibre(%)	Ash (%)	Carbohydrate (%)
Distilled	10.00	8.13	0.58	0.02	0.30	80.97
Stream	10.10	11.88	0.19	0.11	0.28	77.44
Rain	10.00	6.88	0.35	0.01	0.31	82.55
Well	10.00	6.78	1.08	0.01	0.30	81.89
Tap	10.00	10.62	0.85	0.04	0.30	78.96

Source: Otunola and Ogunrombi 1998

Table 3: Effect Of Processing Water Sources on the pH And Titratable Acidity Of 'Ogi'

Processing water source	pH	Titratable acidity (% Lactic acid)
Distilled	4.21	0.102
Stream	3.60	0.120
Rain	4.02	0.093
Well	3.72	0.109
Tap	3.75	0.104

Source: Otunola and Ogunrombi (1998)

Table 4: Effect of Processing Water Sources on the Lactic acid Bacterial (LAB) counts during steeping, souring and final ogi product

Processing water source	LAB counts (× 10^2 cfu per ml or p g of ogi)			
	Before steeping	After 72 hrs steeping	Souring	Ogi
Distilled	0.00	23	42	0.21
Stream	0.50	78	92	0.13
Rain	0.00	90	98	0.18
Well	2.0	115	120	0.23
Tap	0.00	31	69	0.25

Source: Otunola and Ogunrombi,(1998)

Subsequent studies were focused on;

- cereal fermentation and bio- enrichment
- roots and tubers fermentation and bio-enrichment
- legume fermentation and bio- enrichment
- production of analogues of conventional foods as novel food development from locally available raw materials.
- development of starter cultures especially for the fermentation of legumes as well as roots and tubers.

In all these, our aim was to do the same things better, or find new ways of doing the same things, all with a view to obtaining better products in terms of quantity, quality, varieties and improved shelf-life.

CEREAL FERMENTATION AND BIO-ENRICHMENT

Throughout the world, cereals are a major staple where they constitute a significant source of dietary nutrients. They are however known to be deficient in a number of essential amino acids and vitamins (Banigo and Muller, 1972; Adeyemi *et al*., 1987; Steinkraus 1998), though very rich in carbohydrates. Fermentation, as studied by various workers, has been proved to have the capability to enhance the nutritional status of cereal based foods and also reduce the levels of anti-nutritional factors contained in them. A great variety of fermented foods have also been produced from cereals, depending on the particular part of the world and the peoples' culture (Campbell-Platt, 1994).

Of all fermented foods of cereal origin, bread appears to be the most prominent. Bread, which has been baked since ancient times, is consumed in all parts of the world, though with varieties peculiar to each country. Despite its popularity, bread is still a predominantly carbohydrate food; produced by fermentation of the carbohydrate contained in wheat flour by yeasts. Like all fermented cereal foods, it is still highly deficient in many nutrients, though the fermentation process might impart slight improvements. Moreover, the health concerns about allergic reactions to gluten in wheat has spurred the research for alternatives, especially in terms of partial substitution to a considerable level as appropriate. For this reason, some of our studies centered on the partial substitution of wheat flour with selected fermented legumes, with a view to improving the nutritional status and reducing the level of gluten thereby reducing the risk of allergic reactions. In one of such studies (Otunola *et al*., 2006), tempeh produced in our laboratory, was added to wheat flour in various proportions. Substantial improvements were observed at the end of the fermentation period (Tables 5 and 6)

In a related study, bambara groundnut was also fermented, by a modification of the procedure for tempeh production, to obtain a tempeh analogue, and then used to partially substitute wheat in bread baking (Olanipekun, 2014). The resulting products in each case ranked very close to whole wheat bread, especially up to 20% level of substitution, with respect to the physical attributes of the bread loaves. Furthermore, bread baked with 10% tempeh or fermented bambara groundnut gave the best physical attribute, while in terms of sensory attributes, the loaves with up to 20% tempeh or fermented bambara groundnut ranked best and closest to unsubstituted whole wheat bread. All the bread loaves, regardless of the level of substitution and the fermentation time had enhanced nutritional status in terms of the quantities of protein, vitamins and mineral elements (Tables 5 and 6) the values of which increased with increases in the proportion of fermented tempeh or bambara groundnut analogue. In a similar study, 5% substitution level with fermented bambara groundnut gave biscuits with the best quality attributes (Otunola *et al*., 2007).

Table 5 **:** Proximate Composition of Bread loaves from Wheat- Fermented Soybean Flour Mixes

Content	Level of substitution with fermented soybean (%)					
	0	5	10	20 20	30	40
Moisture content(%)	14.25± 0.41	13.79 ± 0.45	13.03 ± 0.38	12.23± 0.33	12.18 ± 0.22	12.14 ± 0.43
Protein (%)	4.8 ± 0.20	8.5 ± 0.80	9.9 ± 0.80	11.1 ± 0.90	11.0 ± 0.90	13.0 ± 0.00
Fat (%)	1.4 ± 0.14	1.8± 0.16	2.6 ± 0.29	2.9 ±0.16	3.0±0.00	3.33± 0.16
Ash (%)	1.0±0.16	0.2± 0.02	0.51±0.08	0.9 ± 0.08	1.0± 0.10	1.1 ± 0.16
Carbohydrate by difference (%)	78.55 ± 3.07	75.71 ± 1.65	73.97 ±0.99	72.87 ±1.15	71.92±2.58	70.46 ± 1.51

Source: Otunola *et al*., (2006a)

Addition of 9% oven dried tempeh to pre-gelatinized and malted maize portions also resulted in products with enhanced nutritional attributes (Table 7) in terms of increased contents of protein, B vitamins and selected mineral elements as well as acceptable organoleptic properties (Otunola *et al*, 1998). The physical and pasting characteristics of the products (Fig. 4-) also indicated that they could be classified as instant food products (Otunola *et al*., 1998).

Table 6: Vitamins and Mineral Elements Contents of Bread loaves from Wheat- Fermented Soybean Flour Mixes

Content	Level of substitution with fermented soybean (%)					
	0	5	10	20	30	40
Calcium (mg/100g)	30 ± 1.60	33 ± 0.80	35 ± 1.60	55±2.50	65 ± 2.50	79 ± 3.90
Phosphorus (mg/100g)	50 ± 1.60	56± 2.90	60 ± 1.80	67 ± 1.60	67 ± 1.60	74 ± 2.00
Iron (mg/100g)	0.9 ± 0.22	1.0 ± 0.00	1.31±1.73	1.5 ± 0.25	2.61 ± 0.33	3.9 ±0.22
Vitamin B1 (mg/100g)	0.15±0.02	0.16±0.01	0.17± 0.03	0.19±0.05	0.20 ± 0.04	0.21±0.06
Niacin (mg/100g)	0.09±0.01	0.10±0.02	0.11 ±0.01	0.17 ± 0.01	0.18±0.02	0.21± 0.01
Riboflavin (mg/100g)	0.05±0.01	0.11±0.01	0.12±0.01	0.24±0.02	0.26±0.01	0.30±0.04

Source: Otunola *et al*., 2006

Similar addition of tempeh to maize 'ogi' to obtain 'agidi,' a stiff maize porridge commonly eaten by the people of South West Nigeria, also led to increases in the nutritional components (Table 7). The sensory and physco-chemical properties (Table 8) especially syneresis, gel strength and some pasting characteristics were however negatively affected, indicating that the shelf life of 'agidi' would deteriorate faster as the level of substitution with tempeh increased (Otunola *et al*., 2006).

Table 7: Vitamins and Mineral Elements of Maize-Tempeh mixes

Vitamins/Mineral (mg/100g)	Formulation		
	A	B	C
Thiamine	6.24a	6.10a	6.00a
Riboflavin	3.17a	3.47b	3.52b
Pyridoxine	5.92a	5.52a	5.42a
Nicotinamide	1.63a	1.65a	1.67a
Calcium	98.00a	99.00ab	100.00b
Iron	42.88a	43.98a	44.98a
Phosphorus	29.07a	30.52ab	31.25b

Source: Otunola *et al*, (1998)

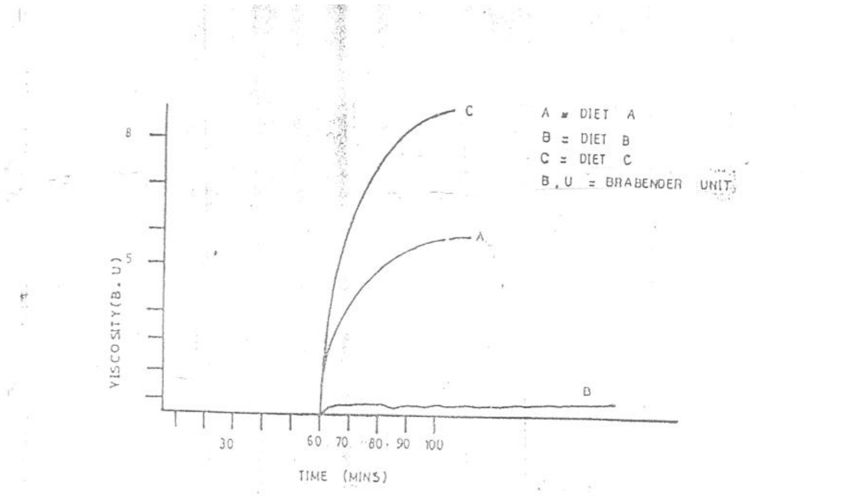

Fig 4: Brabender Amylograph Pasting viscosities of Pre-gelitinized Maize-Tempeh mixes
Source: Otunola *et al* (1998)

Table 8: Sensory attributes of 'Agidi' from 'Ogi-Tempeh' flour mixes

	A_0	B_{10}	C_{20}	D_{30}	E_h
Colour	6.44a	6.33a	5.33a,b	5.22b	4.11c
Aroma	5.67a,b	6.0a	5.33b,c	4.89a,d	4.44d
Texture	6.33a	5.33b	5.33b	4.44c	4.22c
Taste	5.89a	5.33a	5.33a	4.22b	3.89b
O.A	6.53a	5.00b,c	5.11b	4.56c	4.00c

Source: Otunola *et al* (2006b)

Partial substitution of maize 'ogi' with baobab fruit flour resulted in slight decreases in protein, fat and fiber but increases in ash with increasing proportions of baobab fruit powder (Adejuyitan *et al,* 2012). Substantial increases in many vitamins and mineral elements were also recorded. Sensory evaluation of the gruels obtained from the flour mixes indicated equal ratings in terms of taste, colour and mouth feel. The product with 50% baobab fruit powder was rated highest in terms of overall acceptability.

In another study by Sunny-Igweji *et al*., (1998), oncom, a fermented peanut presscake that is very popular in Indonesia and some other Asian countries, was produced in our laboratory and used to supplement maize flour in the production of 'tuwo'. The contents of crude protein, ash, fibre and fat increased significantly with increased proportion of fermented peanut presscake. The carbohydrate contents however showed a reverse pattern. Sensory evaluation indicated the highest preference for the non-substituted product. Up to 30% of oncom nevertheless ranked very close to the unsubstituted product.

'Kenkey', a fermented stiff maize based cake is a popular food in Ghana, but in recent times, has increased in popularity in Nigeria and many West African countries. Like all similar cereal based foods, kenkey is also highly deficient in many essential nutrients, especially in high quality protein. The little protein contained even lacks many of the essential amino acids. In an attempt to improve the nutritional status of 'kenkey', tempeh, a fermented soy bean food, was produced and added in varying proportions to maize flour, and each mix used to prepare kenkey meal. Results indicated significant increases (Table 9) in the levels of protein, fat, fibre and ash, as well as tested minerals and vitamins (Otunola *et al*., 2004). Sensory evaluation however indicated low levels of acceptability except for the sample with 10% tempeh that ranked close to unsubstituted product in terms of overall acceptability. It was the opinion of the authors that, to be able to enjoy the nutritional benefits of tempeh addition, appropriate flavouring and colouring agents could be incorporated.

An earlier study had indicated that addition of tempeh to maize in the production of kenkey may not result in substantial changes in the physico-chemical properties (Table 10) mainly because most of the parameters investigated such as gel strength, syneresis and pasting characteristics did not show significant differences in their values (Otunola *et al*; 2003).

Another possible way of enhancing the nutritional status of cereal based foods is by co-fermentation with fruits and vegetables. While fruits and vegetables may not be important sources of protein, they are however rich in vitamins and mineral elements, which can be imparted to the cereal food products.

Table 9: Proximate composition of kenkey-like products from the flour mixes

Level of substitution with fermented soy bean (%)	Contents (% db)					
	Moisture	Crude protein	Fat	Crude fibre	Ash	Carbohydrate
0	4.67 ± .06	4.67 ± .06	1.50 ± .33	1.46 ± 0.6	2.09 ± .11	83.93±.61
5	5.78±.60	5.78±.60	2.48±.24	1.660±.15	3.02±.01	80.84 ± .97
10	6.36 ± .41	8.88 ± .00	3.27 ± .05	1.63 ± .13	3.05 ± .90	76.81 ± .60
15	8.98 ± .90	8.98 ± .90	5.77 ± .24	1.68 ± .10	3.12 ± .08	68.10 ± 1.54
20	12.79± .30	12.79 ± .30	7.47 ± .06	1.71 ± .02	3.15 ± .45	73.43 ± .060

Source: Otunola *et al*., (2004)

In a study by Adeyemi and Soluade (1993) on pawpaw – ogi, there was no increase in protein and fat contents of the products of the mixtures. Increasing proportions of pawpaw however significantly increased the ash content, which was subsequently reflected in the contents of the mineral elements, especially sodium, potassium and calcium. Similar increases were recorded with regards to vitamins especially vitamin C (Adeyemi and Soluade, 1993).

Table 10: Pasting Characteristics of Flour Mixes for Kenkey Production

	Level of substitution with fermented soybeans				
	0%	5%	10%	15%	20%
Pasting Temperature (^{0}C)	89	89	90	92	91
Gelatinization time (Mn) in min	38	38	40	39	38
Temperature at Peak Viscosity	95	95	95	95	95
Peak Viscosity (Vp) during heating (B U)	20	10	15	18	10
Time to reach peak Viscosity (Mg) in min	42	48	43	42	42.5
Viscosity (V) at 95^0 C (B U)	20	10	15	18	10
Viscosity after 30 min holding at 95^{0}C (Vr) (BU)	18	10	18	22	15
Viscosity on cooling to 50^{0}C (Ve) (B.U)	48	19.5	28	39	35
Ease of cooking (Mn-mg)	4	10	3	4	4.5
Stability of Starch (Vp – Vr)	2	0	-3	-4	-5
Set back value (Ve – Vp)	23	9.5	13	21	25
Gelatinization Index(Ve – Vr)	30	9.5	10	17	20

Source: Otunola *et al*., (2003)

In a similar study in which sorghum was co-fermented with pineapple, slight increases in protein contents with increase in the proportion of pineapple slurry were recorded. This was attributed to the high sugar contents of pineapple which fastened the rate of fermentation, thereby rapidly increasing the biomass, which eventually resulted in increased in protein and ash contents. Earlier reports by Steinkraus (1998) confirmed that the faster the rate of fermentation, the greater the biomass accumulation. The addition of pineapple slurry however appeared to have significant effects on the pasting characteristics as virtually all the parameters investigated reduced drastically with increases in the proportion of pineapple, although the pasting time and temperature did not vary significantly. Sensory evaluation however indicated that the higher the proportion of pineapple slurry, the higher the acceptability with regards to all the attributes tested. This is not unexpected since the sugary taste of pineapple will significantly impact on the taste and other attributes of the products. In an earlier study maize co-fermented with pawpaw resulted in a product with increase of about 1.5% protein when equal amounts of maize and pawpaw were involved. Further incorporation of groundnut slurry gave a product with over 100% increase in protein. Of all the formulations, mixture of ogi, pawpaw and groundnut slurries had the highest ratings, while maize ogi only had the least, with regards to all the attributes tested (Table 11). All mixtures had substantial increases in mineral and vitamin contents.

Table 11: Proximate composition of maize-groundnut-pawpaw- ogi samples

SAMPLE	% protein	% fat	% fibre	% Ash	% moisture	% CHO
A	7.64^{0}	1.83^{0}	0.85^{0}	2.06^{0}	18.36^{0}	69.28^{0}
B	15.15^{0}	3.95^{0}	1.84^{0}	4.41^{0}	15.05^{0}	59.62^{0}
C	9.23^{0}	2.27^{0}	0.77^{0}	3.58^{0}	16.65^{0}	67.51^{0}
D	17.40^{0}	4.64^{0}	2.10^{0}	5.10^{0}	14.87^{0}	55.92^{0}

Key :A – Maize – Ogi Sample ; B – Maize – Groundnut Sample ;
C – Maize – Pawpaw Sample D – Maize- Groundnut – Pawpaw – Ogi Sample

ROOTS AND TUBERS FERMENTATION

In many parts of the world, roots and tubers constitute significant aspects of the diets of the people. They are also mainly starchy foods, although many of them are also rich in micronutrients. Apart from cassava, many of the available roots and tubers are generally regarded as foods for the poor and hence severely underutilized for food purposes. Instead some of them are utilized more in the pharmaceutical and chemical industries, mainly because of the properties of their starches.

Just like the case of their cereal counterparts, fermentation has played significant roles in the food utilization of many of the roots and tubers. In fact, without fermentation as occurs in cassava products processing, many of them would have been inedible due to their contents of toxic and anti - nutritional factors. Typical of these are the cyanide and oxalate contents of cassava and cocoyam respectively.

With regards to roots and tubers fermentation, what readily and justifiably comes to mind is the traditional fermentation processes of cassava that lead to various fermented products such as ‘gari’, ‘lafun’, ‘fufu’, pupuru etc, especially in Nigeria and some West African countries. Various studies have shown the effectiveness of the traditional processes in eliminating or at least reducing to tolerable levels, the contents of these substances in the fermented products of cassava to make them absolutely safe for consumption (Oyewole and Odunfa, 1989; Nweke *et al,* 2002; Shipak *et al*; 2004 ; Falade and Akingbala, 2011;). Despite all the efforts of fermentation, cassava products remain largely starchy and highly deficient in several essential nutrients, especially protein.

In our laboratory we have made some modest efforts towards enhancing the nutritional status of cassava products. In this direction, we have examined the impact of controlled fermentation, mainly by the use of non-pathogenic microfungi as has been practiced in several parts of the world, especially in Asian countries, where similar techniques have proved effective in improving their food crops nutritionally. In our studies, we have concentrated on the use of the genus *Rhizopus*.

The genus *Rhizopus* is widely distributed in nature (Frazier and Westhoff, 2005). Texturally, the mass of hyphae is wooly. They also grow rapidly, either by rapid extension of the mycelia or by wide distribution of the spores which are produced in very large numbers. They are generally considered as non-pathogenic as they are not known to cause any human diseases. Their use in food systems, which appears to originate in Asia and Japan, has been spreading fast in all other parts of the world. Some of the species involved in food systems are *R.olifosporus, R. oryzae, R. nigricans* and in our laboratory recently, *R. stolonifer.*

By following modifications of the traditional processes, some positive changes have been made to some of the traditional cassava products with regards to enhanced protein quantity and increased contents of vitamins and bio-available minerals, regardless of the cassava variety or the particular species of *Rhizopus* used. The enhancements also cut across all the fermented cassava products. Three species of *Rhizopus* (*R. oligosporus, R. oryzae* and *R. nigricans*) were used singly or in various conbinations. *R. oligosporus* was originally obtained from the Indonesian Embassy, being the predominantly and consistently used species in Asia. *R. oryzae* and *R. nigricans* were obtained locally (Adejuyitan *et al*.,, 2014). Previous attempts at increasing the protein contents of gari include those of Oboh *et al.,* (2002) using *Asperigillus niger,* which achieved 7.3% increase, and Oboh and Akindahunsi (2003), achieving 6.3% increase using *Saccheromyces cerewissuae*.
In our studies, protein contents increased from 1.35% in the traditionally fermented gari to more than 3% obtained in fermentation with single or combined species of *Rhizopus* (Table 12). Similar increases were also achieved in fufu, pupuru and lafun (Adejuyitan, 2014). Significant enhancements were also achieved with respect to the vitamin and mineral contents. Moreover, substantial reductions were achieved with respect to cyanide as well as other toxic and anti-nutritional contents.

Interestingly, the method of storage of cassava roots was found to have profound influence on the characteristics of fermented products from it. It was observed that storage in moist saw dust improved the functional and pasting properties of 'gari' produced from two varieties of cassava (TMS30572 and TMS4 (2) 425) bitter and sweet varieties respectively. The enhancement for each variety increased with increase in fermentation time. (Olaleye *et al*., 2014) Except in the case of water absorption capacity, there were little or no changes in the values of the functional properties of the samples. There were also increases in the values of the pasting properties with increases in fermentation periods, except for the pasting time and pasting temperatures, which fluctuated only slightly.

In an attempt to create varieties of foods and increase utilization of some underutilized roots and tubers, trials were made at producing analogues of conventional foods from some of these underutilized crops. A typical example is the production of 'gari' analogue from cocoyam (X*authosomas sp)*. This was done by a modification of the traditional fermentation process for 'gari' from cassava (Table 13). Cocoyam (*Xauthosuras sp),* abundantly available in several parts of Nigeria, is underutilized. Sensory evaluation of the products obtained indicated highest preference for samples fermented for 48 hours in terms of taste, crispness, aroma, and texture, which are the acceptable attributes of cassava gari, hence in terms of closeness to cassava 'gari'. The levels of the contents of the anti-nutritional factors were also drastically reduced. The colour and appearance could be enhanced by the addition of appropriate colouring, agent, if the nutritional and functional benefits of the fermented products are to be enjoyed.

Table 12: Protein content (%) of *Gari* as influenced by length of fermentation with single species of *Rhizopus.*

	Cassava Varieties		
Gari Samples	Odongbo	Oko-iyawo	Arubielu
A	3.42^{a}	3.60^{bc}	3.60^{b}
B	3.42^{a}	3.80^{a}	3.70^{b}
C	3.24^{b}	4.00^{a}	4.00^{a}
D	3.10^{c}	3.33^{d}	3.60^{b}
E	3.24^{b}	3.10^{d}	3.70^{b}
F	3.20^{b}	3.50^{c}	3.80^{a}
G	3.20^{b}	3.60^{bc}	3.62^{b}
H	3.20^{b}	3.60^{bc}	3.71^{b}
I	3.26^{b}	3.70^{b}	3.90^{a}
J	1.35^{e}	1.49^{e}	1.62^{c}

Values are means of triplicate determinations.
Means in the same column bearing different superscript are significantly different ($p < 0.05$).

Key
A-Fermentation with *R. oryzae* for 2 days B- Fermentation with R. *oryzae* for 4 days C –Fermentation with *R. oryzae* for 6 days D- Fermentation with *R. oligosporous* for 2 day E- Fermentation with *R. oligosporous* for 4 daysF- Fermentation with *R. oligosporous* for 6 days G- Fermentation with *R nigricans* for 2 days
H- Fermentation with *R. nigricans* for 4 days I- Fermentation with *R. nigricans* for 6 days J - Control, Natural Fermentation (without inoculation fermented for three days)

Table 13: Proximate composition of cocoyam 'gari'

Parameters (%)	A	B	C	D	E
Moisture	2.23 ± 0.01^{d}	2.16 ± 0.04^{c}	2.21 ± 0.01^{d}	2.05 ± 0.01^{b}	1.85 ± 0.01^{a}
Ash	2.05 ± 0.01^{ab}	2.10 ± 0.02^{c}	2.06 ± 0.01^{b}	2.03 ± 0.02^{ab}	2.02 ± 0.02^{a}
Crude protein	4.11 ± 0.01^{a}	4.17 ± 0.04^{b}	4.38 ± 0.01^{c}	4.82 ± 0.01^{d}	5.25 ± 0.01^{e}
Crude fat	3.68 ± 0.01^{a}	5.68 ± 0.01^{e}	5.03 ± 0.01^{c}	4.55 ± 0.01^{b}	5.43 ± 0.06^{d}
Crude fibre	3.63 ± 0.01^{b}	3.59 ± 0.01^{b}	3.68 ± 0.01^{c}	3.55 ± 0.01^{a}	3.76 ± 0.04^{d}
Carbohydrate	84.33 ± 0.03^{e}	82.30 ± 0.02^{b}	82.66 ± 0.03^{c}	83.01 ± 0.04^{d}	81.71 ± 0.04^{a}

Means in the same row followed by the same superscript are not significantly different.
Key: A: 0 hour unfermented cocoyam gari B: 24 hours fermented cocoyam gari C: 48 hours fermented cocyam gari D: 72 hours fermented cocyam gari E: 96 hours fermented cocyam gari

Another was the production of 'pupuru' analogue from two varieties of sweet potato: orange fleshed sweet potato (OFSP) and cream fleshed sweet potato (CFSP). In all the cases, substantial improvements were recorded especially with regards to micronutrients in the fermented products over the unfermented raw materials. The analogues also ranked very close, and in a few cases better than the conventional products (Ogunlade, 2018). The protein contents, which were generally higher than that found in conventional "gari,"pupuru" and other cassava fermented products, increased gradually (3.40–5.41%) over a 96 hour fermentation period (Table 14) Similar trends were observed with respect to the ash and fibre contents, while the carbohydrate contents showed a reverse trend (Ogunlade, 2018).

The ability of the various available species of *Rhizopus* to effectively ferment some varieties of cassava and possibly other roots and tubers, to obtain the various fermented products such as 'gari', 'lafun;, 'fufu' and 'pupuru' as earlier mentioned is an evidence that each species, or their combinations has the potential to serve as a starter culture for the fermentation of cassava and other roots and tubers.

Table 14: Proximate Composition of Fermented 'pupuru' flour analogue Orange Fleshed Sweet Potato (OFSP)

Period of Fermentation (Hrs)	Protein Content (%)	Moisture Content (%)	Fat content (%)	Crude Fibre Content (%)	Ash content (%)	Carbohydrate Content (%)
0	3.40^{b}	6.70^{f}	0.27^{a}	0.91^{c}	3.78^{a}	86.1^{d}
24	3.22^{a}	7.52^{e}	0.20^{a}	0.63^{a}	3.87^{b}	85.6^{c}
48	3.17^{a}	7.01^{d}	0.26^{a}	0.62^{a}	4.04^{c}	85.5^{c}
72	4.14^{c}	6.39^{c}	0.20^{a}	0.62^{a}	4.01^{c}	84.6^{b}
96	5.12^{d}	5.73^{b}	0.20^{a}	0.81^{b}	4.10^{d}	84.2^{b}
120	5.41^{e}	5.52^{a}	0.45^{b}	0.60^{a}	4.14^{d}	83.9^{a}

Source: (Ogunlade, 2018)

LEGUME FERMENTATION AND BIO-ENRICHMENT

Legumes are veritable sources of plant proteins, and have the highest levels of quantity and quality of all plants used for food. They are also a significant source of dietary fibers, carbohydrates, vitamins and minerals. Some of them also constitute a huge source of vegetable oils for both food and industrial uses. Typical examples include soybean, cowpea, peanut, bambara groundnut, lentils, African yam bean etc. Anti-oxidant activities in fermented legumes are also considered significant. Moreover, they are excellent sources of resistant starch (Olanipekun, *et al*., 2015; Balogun *et al*., 2015). They however contain significant amounts of toxic and anti-nutritional factors that hinder their full utilization. In an attempt to take full advantage of their potential food uses, several processing methods such as soaking for varying periods of time, boiling, germination and fermentation or any combination of these have been employed.(Balogun *et al*, 2015).

In many parts of the world, and particularly the Asian countries, fermentation of legumes has been practiced for centuries to enhance their nutritional status and to create a great variety of foods. Perhaps, the most popular of the Asian fermented foods is tempeh, a fermented soybean product that is known to originate from Indonesia. Tempeh, as mentioned earlier, has been exploited as a good meat analogue because of its quantity and quality of protein and acceptable organoleptic properties. Its use and consumption has, in recent times, spread widely across the western world, being preferred especially by vegetarians and others, who for one reason or the other, want to avoid animal proteins.

In one of our studies, imitation milk obtained from peanut (Table 15) was used to produce a yoghurt analogue, using the conventional yoghurt starter culture. The product obtained compared favourably well with the conventional yoghurt from cow milk in terms of the proximate composition/nutritional attributes, physicochemical and sensory properties (Sunny-Robberts *et al;* 2004).

Table 15: Proximate composition of Groundnut flour and Unfermented and fermented groundnut milk

Sample	Moisture content (%)	Crude protein content (%)	Crude fibre content (%)	Fat content (%)	Ash content (%)	Carbohydrate content (%)
R	6.20 ± 0.20	28.96 ±0.04	8.07 ± 0.13	43.43 ± 0.13	2.30 ± 0.04	11.04 ± 0.14
X	89.43±0..32	2.98 ± 0.03	0.78± 0.03	5.47 ± 0.40	0.44 ± 0.00	1.32 ± 0.11
Z	85.02 ± 0.14	5.95 ± 0.08	0.55 ± 0.03	4.74 ± 0.04	2.86 ± 0.01	1.02 ± 0.01

Keys: R= Groundnut flour, X = Unfermented groundnut, Z= Fermented groundnut flour

Source: Sunny-Roberts *et al*. (2004)

Legume Fermentation with species of *Rhizopus*

In our laboratory, we have produced tempeh from soybeans, either for consumption as such or for supplementing predominantly starchy or carbohydrate foods (Otunola *et al.,* 1998; 2003; 2004; Oyelade *et al.,* 2003). In all these, the nutritional status of the original products has been significantly enhanced, although in a few cases, consumer acceptability rated lower than the unsubstituted products. In such cases, addition of flavouring and / or colouring agents were always suggested.

In addition to the traditional tempeh production, we have also produced tempeh analogues from a variety of beans (Plate 2), including those with hard to cook phenomenon. In virtually all the studies, the protein contents always increased significantly, the extent depending on the particular beans concerned (Table 16), and the length of fermentation period (Otunola, and Obisesan, 2004; Otunola *et al.,* 2012; Olanipekun *et al;* 2015). The functional and pasting properties of such products were either enhanced or not significantly affected, again depending on the particular legume and length of fermentation (Olanipekun *et al;* 2014).

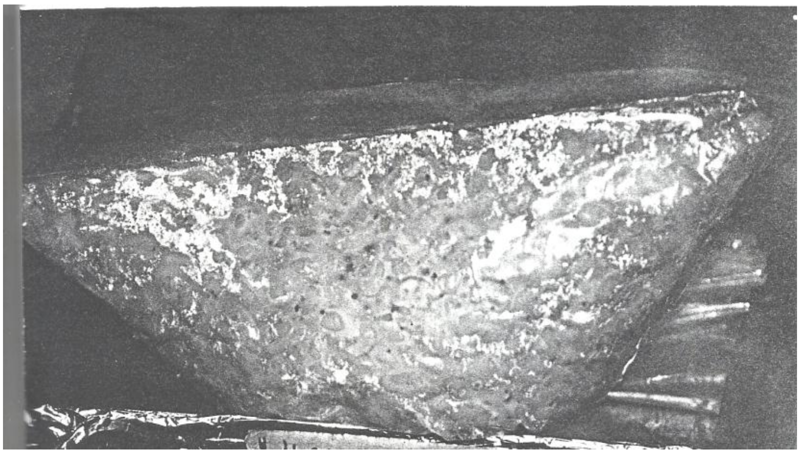

Plate 2: Tempeh analogue from cowpea

Source: Otunola and Obisesan, (2004)

For higher effectiveness, controlled fermentation by the use of starter cultures is a critical factor. In a series of our studies, we attempted to develop starter cultures for the varieties of legumes and other locally available crops. In one of the studies, (Omosebi and Otunola, 2013) we examined, on comparative basis, the efficiency of *R. oligosporus* and two local isolates of *Rhizopus (R. stolonifer* and *R. oryzae*) in the production of tempeh from soybeans. The results obtained (Table 17) indicated that the three species of *Rhizopus* investigated had equal efficiency in terms of protein elaboration and crude fibre content *R. stolonifer* and *R. oryzae* also produced significantly higher levels of vitamins B1, B2, C, D and a number of minerals than the traditionally used *R. oligosporus* . The products of the two species also had lower values for viscosity, water holding capacity but equal values of oil absorption capacity with R. *oligosporus.*

Table 16: Proximate Composition of Fermented flour (tempeh-like) and Unfermented Flours Different Varieties of Cowpea

	Moisture content (%)	**Ash content (%)**	**Crude fibre (%)**	**Ether extract (%)**	**Crude Protein (%)**	**Total Carbohydrate (%)**
T90K-54 UNFERMENTED	7.75 ± 0.10	3.65 ± 0.01	0.45 ± 0.02	2.35 ± 0.02	21.44 ± 0.20	64.36 ± 0.20
T90K-54 FERMENTED	6.30 ± 0.40	2.50 ± 0.02	0.50 ± .04	3.50 ± 0.03	24.01± 0.05	63.19 ± 0.25
WHITE DRUM UNFERMENTED	8.10 ± 0.02	4.05 ± 0.05	0.65±0.10	2.00 ± 0.00	19.29 ± .00	65.91 ± 0.01
WHITE DRUM FERMENTED	7.95 ± 0.04	4.00 ± 0.15	0.45 ± 0.15	2.50 ± 0.00	23.58 ± .00	61.52 ± 0.02
IFE BROWN UNFERMENTED	7.80 ± 0.32	3.60 ± 0.01	0.40 ± 0.00	2.05 ± 0.04	21.01 ± 0.02	65.14 ± 0.04
IFE BROWN FERMENTED	7.80 ± 0.20	2.80 ± 0.20	0.01 ± 0.00	1.75 ± 0.06	23.15 ± 0.04	66.29 ± 0.06
OBWELL UNFERMENTED	7.35 ± 0.01	4.05 ± 0.00	0.40 ± 0.00	2.05 ± 0.00	22.72 ± 0.01	63.43 ± 0.01
OBWELL FERMENTED	6.40 ± 0.02	3.10 ± 0.00	0.40 ± .00	1.30 ± 0.00	23.15 ± .02	65.65 ± 0.04

Source: (Otunola and Obisesan, 2004)

Sensory evaluation indicated equal ratings for products of the three species in term of aroma and texture, but the product obtained using *R. stolonifer* had slightly lower rating than the other two in terms of colour. The summary of this is that the local isolates (*R. stolonifer* and *R. oryzae*) performed better in terms of nutritional enhancement than the conventional *R. oligosporous*. The slight differences in a few sensory attributes could be resolved by research on appropriate coloring agents. The implication of this is that our local isolates are equally efficient, if not more in certain aspects, than the traditional species. This makes the possible commercialization of this aspect a lot easier (Omosebi and Otunola, 2013)

Table 17: Proximate composition of Tempeh Flour Samples

Sample	Crude protein (%)	Crude fibre (%)	Fat content (%)	Ash content (%)	Moisture content (%)	Carbohydrate content (%)
Tempeh by (*Rhizopus olifosporus*)	44.62 ± 0.01^{a}	0.38 ± 0.00^{a}	16.45 ± 0.0^{c}	5.60 ± 0.00^{0}	3.00 ± 0^{a}	33.52 ± 0.05^{c}
Tempeh by (*Rhizopus oryzae)*	44.85 ± 0^{a}	0.40 ± 0.00^{a}	17.12 ± 0^{a}	5.72 ± 0.06^{c}	2.50 ± 0^{a}	32.57 ± 0.01^{b}
Tempeh by (*Rhizopus stolonifer*)	44.27 ± 0^{a}	0.42 ± 0.07^{b}	16.68 ± 0.06^{b}	5.61 ± 0.06^{b}	2.50 ± 0^{a}	33.55 ± 0.00^{a}

Source: Omosebi and Otunola, (2013)

The efficiency of *Rhizopus* species in transforming locally available legumes as well as roots and tubers was also a subject of further investigation. Olanipekun *et al.* (2014) examined the effect of using three species and their combinations on the fermentation of bambara groundnut. The three species used in this study were *R. oligosprous*, *R. oryzae* and *R. nigricans*. They were found to be approximately equally efficient in improving the nutritional status of bambara groundnut in terms of protein, ash and fibre contents, as well as vitamin and mineral contents (Table 18). The three species and their combinations also effectively reduced the levels of anti-nutritional factors, and significantly improved the protein digestibility of bambara groundnut. Interestingly also, these species were able to increase the proportion of polyunsaturated fatty acids (PUFA) contents in the fermented bambara groundnut, thus enhancing the food uses of this underutilized legume (Olanipekun *et al;* 2015)

Table 18 : Effect of Fermentation Period Using the combination of *Rhizopus oligosporous* and *R. nigricans* on the Poximate Composition of Bambara Nut Flour

Fermentation period (h)	Protein content (%)	Fiber content (%)	Ash content (%)	Moisture content (%)	Fat content (%)	Carbohydrate content (%)
0	18.66^{g}	6.49^{a}	3.75^{g}	6.71^{a}	6.52^{a}	57.87^{e}
12	18.91^{f}	5.71^{b}	3.90^{f}	6.45^{b}	6.41^{b}	58.62^{d}
24	19.00^{e}	5.45^{c}	4.08^{e}	6.13^{c}	6.27^{c}	59.07^{c}
36	19.40^{d}	5.17^{d}	4.22^{d}	5.85^{d}	6.12^{d}	59.24^{b}
48	19.66^{c}	5.11^{e}	4.40^{b}	5.37^{e}	5.57^{e}	59.89^{a}
60	20.66^{b}	4.95^{f}	4.62^{b}	5.20^{f}	5.32^{f}	59.25^{b}
72	22.60^{a}	4.93^{f}	4.81^{a}	5.02^{g}	5.11^{g}	57.53^{e}

Means followed by different superscript along the same column are significantly different ($P \leq 0.05$) from one another

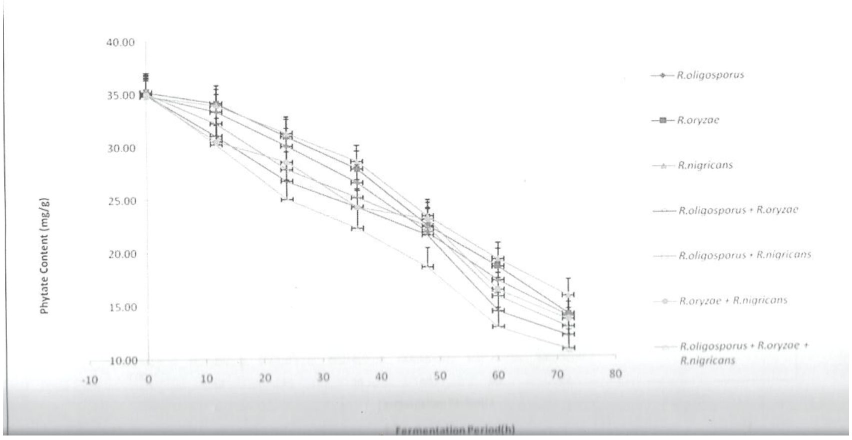

Fig. 5: Effect of fermentation on the Phytate content of bambara flour
Source: Olanipekun *et al*, (2015)

Fermentation of *Mucuna utilis* (Velvet beans) with *Rhizopus sp*

One aspect of our research focus that took a great deal of our attention was the use of selected species of *Rhizopus*, either singly, in combination or the hybrid created from them, to ferment *Mucuna utilis* locally known as velvet bean. *M. utilis* is a tropical legume that grows abundantly even under harsh nutrient conditions of the soil. It is reputed to be very high in nutrients, especially in terms of its protein quality and quantity, vitamin and mineral contents, as well as its starch and protein digestibility (Otunola and Balogun, 2008). It is however severely underutilized due mainly to its contents of toxic and anti-nutritional factors. The most prominent and most toxic of these is L-3, 4 dihydroxyphenylalamine (L-DOPA). Because of this, velvet bean, until recently, was mostly used as a cover crop, or at best exploited as a protein source in the diets of some animals such as pigs, cattle, fish and poultry (Pugalenthi *et al;* 2005).

Table 19 Crude Protein content of Fermented Dehulled and Undehulled *Mucuna utilis* flours(%)

Fermentation period	*Rhizopus oligosporus*		*Rhizopus oryzae*		Mixed culture		Hybrid	
	DEH	UND	DEH	UND	DEH	UND	DEH	UND
0	25.77a	25.66a	25.21a	25.21a	25.65a	24.95a	24.99a	25.19a
12	25.71 a	25.76a	25.42a	25.45a	26.69a,b	25.59ab	25.59ab	25.30a
24	27.89a	25.85ab	28.42b	25.58a	27.50b	26.62 c	26.30b	25.60a
36	28.04a,b	25.75a	30.94b,c	25.40a	29.01 c	25.93bc	28.35c	25.83ab
48	29.54b	26.49b	30.48b	26.05bc	30.71c	25.83bc	30.59d	26.01b
60	32.03c	26.96b	31.59 c	26.81bc	30.82cd	26.72c	31.70 e	26.80bc
72	32.90 c	28.20 c	32.69d	27.38 c	31.83 d	27.92 d	33.78 f	28.02 c

Mean values with the same subscript within the same column are significantly differrent p- value >0.05

Key:

DEH = dehulled samples; UND = undehulled samples

Source: Balogun, (2017)

L-DOPA is a precursor of the neurotransmitter dopamine, implying its severe effect on the nervous system (neurotoxic). Typical symptoms include low blood pressure, nausea, vomiting and abnormal movements.(Egounlety *et al*, 2003). It is interesting to note that L-DOPA, as toxic as it is, has a few advantages, the most important of which is its use for the treatment of Parkinson disease at low concentrations.

In our studies, we also created a hybrid from *R. oryzae* and *R. oligosporus* by the process of protoplasmic fusion, a modern biotechnological technique.(Plates 3,4 and 5) The hybrid, with morphological characteristics different from those of either parents, also performed comparably well, or even better in a few cases, to the parent organisms.

In our studies, we have also examined the effects of fermentation with two species of *Rhizopus,* their combinations and the hybrid created from them, on the contents of the toxic and anti-nutritional factors, and especially L-DOPA. This was mainly with a view to be able to exploit the food potentials and health benefits of this underutilized but valuable crop.

For the fermentation processes, pure cultures of *Rhizopus oligosporus,* and *R. oryzae* were used. They were applied either singly or in combination, and their hybrid and in each case solid state fermentation was carried out for 72 hours. Relevant parameters were monitored at a 12 hourly intervals, and dehulled and undehulled beans were used for each experiment. Results obtained indicated significant increases in the protein contents with increases in fermentation time, regardless of the species or combination used(Table 19) Moreover, the dehulled samples had higher increases than the undehulled suggesting that the hulls might have some inhibiting effects on protein proliferation (Balogun, *et al*., 2016; Balogun, 2017). The undehulled samples appeared to have greater increases with respect to fiber content than the dehulled samples, while the ash contents did not present a uniform pattern (Balogun *et al.,* 2013; 2015; 2016; Balogun, 2017). It was note worthy that the hybrid created from the two species (i.e *R. oligosporus* and *R. oryzae*) had comparable performance with the parent species with respect to the proximate components (Table 19). At the end of the 72 hour fermentation period, substantial increases were observed with respect to vitamin contents (beta-carotene, B2 and B3). Interestingly, the mixed and hybrid cultures performed better than either of *R. oligosporous* and *R. orgyzae* in this respect. (Balogun *et al*, 2017). On the contrary, all the species, their mixture and hybrid did not seem to be efficient in making the minerals available as they all showed slight decreases at the end of the fermentation period. The only exception was with respect to iron that indicated slight increases. Here again both the mixed and hybrid cultures performed better than the single species. Similar trends were earlier observed when *R. oligosporus* and *R. stolonifer* were used either singly or combined (Balogun *et al;* 2017).

Another important aspect of the work on *Mucuna* was the effective reduction of the anti-nutritional factors and toxic constituents of the bean seeds to tolerable levels. In most cases, more than 60% reduction was achieved. Moreover, both the mixed and the hybrid cultures performed better than the single cultures. (Balogun *et al*; 2015; Balogun, 2017).

The study on the effect of fermentation on the L-DOPA content may have some impact on the potential utilization of the *Mucuna* beans in food systems, especially in terms of consumption by humans and animals. This is because all the species of *Rhizopus*, their combinations and the hybrid created were very efficient in reducing the level of L-DOPA to tolerable and safe levels as recommended by appropriate organization (Fox and Lang, 2007). Although initial increases were observed within the first 24 hours of fermentation in each case (Fig. 6), drastic reductions subsequently followed achieving more than 90% reduction in each case (Balogun *et al.,* 2015; 2016; 2017).

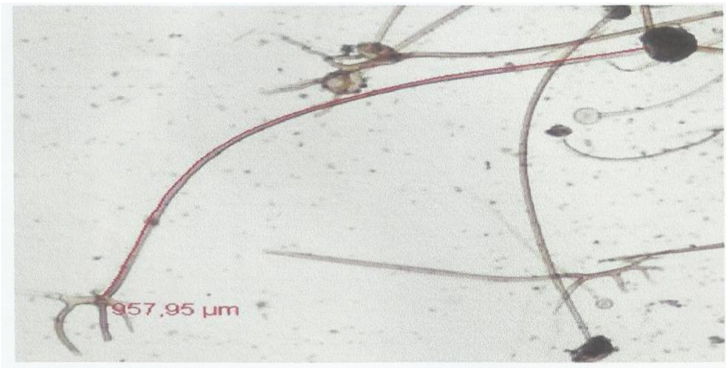

Plate 3: Hyphae of hybrid of *R.oligosporous and R. oryzae*
Source: Balogun et. al (2017)

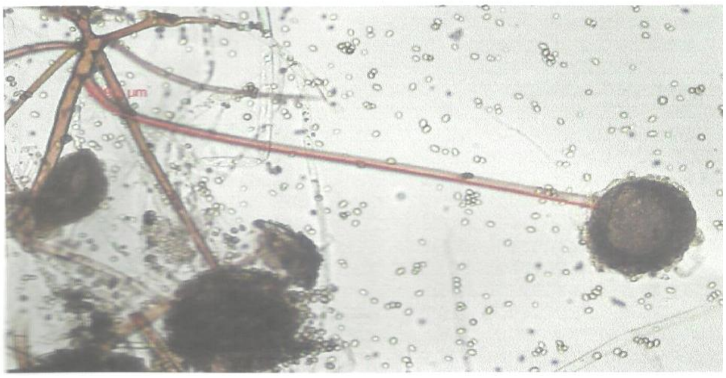

Plate 4: Hyphae of *R.oryzae*
Source: Balogun *et al*, 2017

Plate 5: Hyphae of *R. oligosporous*
Source: Balogun *et al*, 2017

The initial increases observed were probably due to the release of more L-DOPA into the surrounding medium before metabolism started in each case. The additional advantage of this reduction is the attendant health benefit of this residual amount after the 72 hour fermentation. It has been proved by earlier workers that this residual amount, when consumed in food can alleviate Parkinson disease. With less than 1,000 mg/kg residual amounts in each ease, it can be incorporated into foods safely. An amount of 1,500 mg/kg body weight daily is considered safe enough (Lee *et al;* 2010; Lurenzeti *et al;* 2010; Mugandii *et al.,* 2010).

The significant impact of these studies is that fermentation, especially with non-pathgenic microfungi, particularly species of *Rhizopus*, their combinations and the hybrid created from them, could be a viable option for the detoxification of velvet beans, effective removal of toxic anti-nutritional factors, and substantial improvement in the nutritional status, in form of increases in quantity and quality of proteins, vitamins and mineral elements. Moreover, products of velvet beans fermented with these species of *Rhizopus,* their combinations and the hybrid could qualify as functional foods due to the attendant health benefits of consuming them.

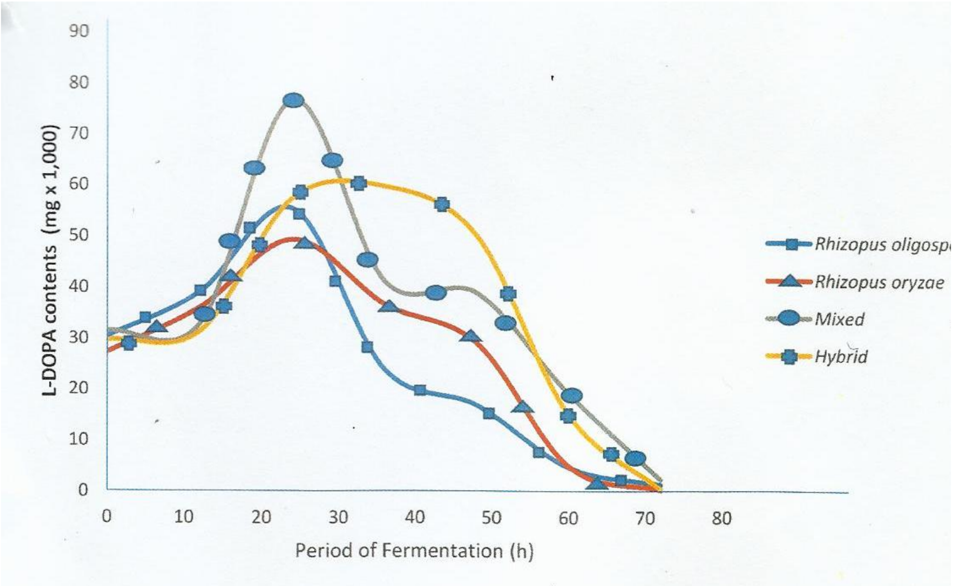

Fig. 6: L-DOPA contents of dehulled *Mucuna utilis* flour
Source: Balogun *et al* (2017)

FERMENTATION OF OTHER UNDERUTILIZED FOOD COMMODITIES

In addition to the fermentation of the major staples, i.e cereals, roots and tubers, as well as legumes, other food crops that are locally available, but due to lack of appropriate knowledge about their potential food uses especially when fermented also attracted our attention. Such crops include Cardaba banana (*Musa utilis* ABB) commonly known as cooking banana,, plantain (*Musa Sp*), and tigernuts (*Cyperus esculentus*).

With regards to Cardaba banana, fermentation consistently increased the crude protein contents of the pulp reaching more than 100% increase, depending on whether the fermentation was preceded by pre-treatment or not, and length of fermentation. Crude fibre contents of cardaba banana were however negatively affected by fermentation as the values consistently decreased. Preliminary work on the banana fermentation revealed that the protein content increased slightly (3.53 – 3.83%) and ash content (2.73 – 3.16%) while the fiber and fat contents decreased (Ayo-Omogie *et al;* 2012). . The contents of ascorbic acid and thiamine also showed increasing trends. Both iron and calcium contents also increased with fermentation time. Moreover, when plantain (*Musa* abb Paradisease) especially the ripe one, was fermented using *S. cerevissiae* as the starter culture, a beverage of an alcoholic content of about 8% was obtained after a 120 hour fermentation period. Fermentation of tiger nut (*Cyperus esculentus*) resulted in products with increased protein (6.67 – 9.23%), sugar (6.58-9.96%), but decreases in fat, dry matter, starch, crude fibre and ash contents after 72 hours of fermentation (Adejuyitan *et al.,* 2009).The observation on the proximate composition and functional properties of the fermented tiger nut flour has revealed its potential use in food systems. Other relevant works include those on elubo production from yam (Adejuyitan et al., 2010), fermented pounded yam {Otunola and Ogunbiyi, 2005) and cocoyam, tempeh and carrot mixes (Otunola and Williams 2002).

Potential Uses of Food and Agricultural Wastes

Wastes from excess or unconsumed food and agricultural residues constitute a lot of burden, especially on the environment, and particularly in developing countries. Even in the developed countries, the cost of treating and disposing such wastes is enormous. Fermentation of such wastes could prove to be a cheap, convenient and profitable way of taking care of such wastes such that they do not continue to constitute environmental menace.

In our studies we were able to make use of the yellow pulp of locust bean pod, which normally constitutes huge pollution challenges in the streams into which the local producers of 'iru' from the seeds wash them. The yellow pulp is sugary, and can lead to eutrophication and algal bloom in such streams. In the laboratory, the yellow pulp was manually removed and a weighed amount mixed with appropriate amount of sterile distilled water in a fermenter. Fermentation was by the conventional wine yeast (*Saccharomyces cerevisiae*) following the traditional wine production process. At the end of the fermentation period, an alcoholic beverage of about 6.1% alcohol content was obtained, which also compared favourably well with locally available commercial wine (Otunola, *et al.*, 2012).

Various studies have also shown that many species of edible mushrooms could be successfully cultivated on agricultural wastes. (Grillo *et al*., 2009; Banjo *et al*., 2011Anyakora, *et al*., 2014) In one of our studies, wastes from cassava, (cassava peels), rice milling (rice bran) and saw mill (sawdust) industries, singly or combined, were used to cultivate oyster mushroom (*Pleurotus ostreatus)* with appreciable yields and biological efficiency (Table 20). Proximate composition also indicated appreciable amounts of protein, ash and fibre, suggesting, high nutritional status of the oyster mushrooms obtained from all the agricultural residues (Table 20). High nutritional status of the oyster mushrooms as obtained from all of the agricultural residues.(Olaniyan, 2016) can serve as an indication of the potential value of such wastes. Analysis of the mineral and vitamin composition also indicated that the oyster mushrooms, regardless of the substrate used, contain abundant amounts of minerals and vitamins

Table 20 : Proximate Composition of Oyster Mushroom Grown on Wastes

Samples	**Moisture content (%)**	**Protein (%)**	**Ether extract (%)**	**Ash (%)**	**Crude fibre (%)**	**Carbohydrate (by difference) (%)**
100% CP	90.25±0.49[a]	1.75 ± .07[c]	0.65±0.07[bc]	2.55±0.07[g]	1.55±0.07[d]	3.50±0.00[c]
100% SD	84.80±0.42[c]	3.35±0.07[b]	0.85±0.07[a]	4.85±0.07[a]	2.05±0.07[b]	4.10 ±0.14[a]
100% RB	87.95±0.07[c]	2.45±0.07[d]	0.65±0.07[bc]	3.15±0.07[c]	2.05±0.07[b]	3.75±0.07[b]
75%CP/25%SD	88.95±0.07[b]	1.80±0.14[c]	0.60±0.00[bcd]	4.25±0.07[b]	2.00±0.00[bc]	2.40±0.14[f]
50%CP/50%RD	87.35±0.21[d]	2.90±0.00[c]	0.70±0.00[b]	3.40±0.14[d]	2.30±0.00[a]	3.35±0.07[c]
75%CP/25%RB	89.15±0.21[b]	2.40±0.00[d]	0.65±0.07[bc]	2.90±0.14[f]	2.00±0.14[bc]	2.90±0.14[d]
50%CP/50%RB	88.30±0.07[c]	2.85±0.07[a]	0.65±0.00[bc]	3.35±0.07[de]	2.20±0.14[ab]	2.65±0.07[e]
75%SD/25%RD	88.25±0.07[c]	3.75±0.07[a]	0.50±0.00[de]	3.25±0.07[c]	1.80±0.14[c]	2.45±0.07[ef]
50%SD/50%RD	88.05±0.07[c]	3.35±0.07[b]	0.45±0.07[e]	3.85±0.07[c]	1.80 ± 0.14[c]	2.50±0.00[ef]
25%SD/75%RB	89.20±0.14[b]	2.75±0.07[c]	0.55±0.07[cde]	3.35±0.07[d]	2.10±0.14[ab]	2.05±0.07[g]

Means with the same superscripts in a column are not significantly different

CP: Cassava peel substrate sample; SD: Sawdust substrate sample; and RB: Rice bran substrate sample

Source: (Olaniyan, (2016)

All these suggest that agricultural residues could support the rapid growth of oyster mushroom, and perhaps other types of edible mushrooms, with high yields, appreciable biological value, and high nutrient contents. Other workers (Abikoye *et al.*, 2016;; Asilaye *et al*., 2016) have also successfully cultivated other edible mushrooms from such agricultural wastes, with encouraging results.

Single Cell Protein (SCP)

Single cell protein is the edible protein obtained from the biomass or that extracted from the cells of microorganisms. The microorganisms involved may be pure or mixed cultures. These microorganisms include bacteria, yeasts, molds and algae. They are often used as ingredients; substitute for protein rich animal foods or in enriching predominantly carbohydrate foods. They are usually considered suitable for human consumption .They may also be used as animal feeds.

Historically, single cell protein technology, which featured prominently even during the world wars and post-war era to combat the protein gap that existed then, started in early 20th century. It also represented one of the outstanding milestones in the development of biotechnology (National Research Council (NRC) 1983; Doelle, 1994; Venmenllen *et al;* 2012; Ugalde and Castrllo, 2002)

Substrates used for SCP production include agricultural wastes, hydrocarbons, plant materials including celluloses, hemicelluloses, starch, and residues from alcohol production industries as well as simple and complex carbohydrates and their derivatives (Otunola and Fawole,1984; Willtes and Ugailde, 1987; Otunola,1992; Weibe, 2002). Techniques for increasing the concentration after sufficient biomass production has occurred include; centrifugation, floatation, precipitation, coagulation and the use of semi-permeable membranes.

Some microorganisms used for SCP Production

A. Bacteria
- *.Rhodobacter capasulatus*
- *Cyanobacteria sp*

B. Yeasts

Saccharonyces cerevssiae
- *Pichia pastous*
- *Candida utilis*
- *Torulopsis sp*
- *Gerotrichum candidum*

C. *Fungi* (mycoprotein)
- *Aspergullus oryzae*
- *Fusarium verevatum*
- *Sclerotium rolfsii*
- *Dihyporous sp*
- *Trichoderma sp*
- *Scytalidium acidophilum*
- *Edible Mushrooms*

D. Algae
- *Spirilina sp*
- *Chlorella sp*
- *Euglena sp*

Advantages of Single Cell Proteins

According to Weide (2002), single cell proteins have the following advantages:
- Very high rate of growth and multiplication; as most of them have very short generation times (bacteria 30 – 120 min; yeasts 60 – 180 min; algae 120 – 360 min). Ease of selection of strains with high yields and superior nutritional composition (Weibe, 2002).
- Microbial cells have more than 70% protein in the dry mass, unlike plants and animals where protein constitute only a small proportion of the dry weight. The amino acid profiles of SCP have excellent nutritional quantity and quality, especially in terms of the essential amino acid contents. Whole cells of the microorganisms are usually consumed, unlike the case of plants and animals in which the larger proportions are inedible or indigestible and hence have to be thrown away as waste materials.
- Many microorganisms used in SCP production also synthesize many vitamins along with the protein molecules, making them superior to plant and animal sources.

The microorganisms can utilize an array of raw materials as substrates or carbon sources. These include alkenes, methanol, methane, ethane, carbohydrates including sugars and starches. They can also utilize indigestible parts of plant materials such as cellulose, hemicellulose, pectin etc (Otunola *et al*, 1984; Willets and Ugalde, 1987).

- Some microorganisms that are autotrophic can grow on carbon dioxide, and can fix CO_2 up to 10 times more efficiently than plants.
- .Microbial biomass production is independent of seasons, and hence can be produced at any time of the year. They are also independent of day-night alternation, and hence can be cultured to grow all the time.
- Low water requirement, compared to plants and animals, hence will not compete for water with plants. Do not also require soil fertility.
- Microorganisms require far less space than plants and animals. Billions of the cells can be contained at the bottom of a small conical flask.

Disadvantages of SCP

- Due to their fast growing characteristics, they contain high concentrations of nucleic acids, especially RNA. Breakdown of nucleic acids releases large amounts of purine bases, leading to high levels of uric acid in the plasma. This can usually cause kidney stones. One remedial method for this challenge in the use of heat treatment which kills the cells after satisfactory level of production. This will allow indigenous RNases to hydrolyze the RNA releasing the nucleotides into the culture broth from the cells.
- In many cases ,the cell wall components of the microbial cells must be broken down to liberate the interior components of the cells, including the protein fraction
- Unpleasant colour and odour may result
- Ease of contamination and some contaminants may produce toxins.
- Deficiency in methionine occurs in some of them

Modern Biotechnology and Food Security

Modern Biotechnology – a term adopted by international convention to refer to biotechnological techniques for the manipulation of the genetic material and the fusion of cells beyond the normal traditional breeding barriers. Modern biotechnology can also be defined as the manipulation of the genetic properties of organisms to produce goods and services for the service and betterment of man. It is also known as Recombinant DNA Technology or Genetic Engineering, involving molecular biology. It represents an important technological option for meeting the immediate and long-term food needs of the world. Developments in modern biotechnology, have led to pesticide and herbicide resistant crops, consequently boosting food production, especially in the developed countries where such technologies have since taken roots.

In several developed countries, foods derived from genetically modified organisms (GMO) have contributed immensely towards solving their food insecurity challenges. The developing countries also have a lot to gain in terms of combating the challenges of food and nutrition insecurity. Modern biotechnology has the potential to eliminate hunger and malnutrition all over the world including the developing countries. This is because GM crops are known to be resistant to pests and diseases, have longer shelf-life, higher yields per unit of land and tolerant to hash environmental conditions. They are also reputed to have enhanced nutritional status in terms of quantity and quality of protein, abundant contents of vitamins and other essential nutrients. Their organoleptic properties, in terms of texture, taste, flavor, colour, and aroma are also improved compared to the equivalent un-engineered counter parts. The controversies surrounding their safety and detrimental effects on biodiversity and environment are being resolved in favour of enhanced use of the technology. Developing countries, including Nigeria, should not hesitate in taking advantage of the gene revolution. The availability of GM foods will certainly have some crucial roles to play in reducing hunger and malnutrition, thus increasing food and nutrition security. This has a multiplying effect as it will in time reduce poverty and diseases. Although, current developments in GM crops are not specifically designed to address the challenges of developing countries, they still can find a lot of relevance in combating the challenges posed by food insecurity.

Contributions of Microorganisms to Modern Biotechnology

Biotechnology, whether traditional or modern, has its roots in microbiology. The traditional biotechnology as represented by fermentation, may be viewed as being predominantly microbiology based, although the traditional plant and animal breading techniques are also important aspects.

In modern biotechnology, the dominant role of microorganisms as important tools is sustained, or even more pronounced. All the critical and essential tools (or living ware) are derived from microorganisms. The main ones are enumerated as follows:

A. **Enzymes**

Most if not all, of the enzymes used in recombinant DNA technology are derived from microorganisms. Examples include;

- **Restriction endonucleases (RE):** Enzymes used to cut or digest DNA molecules in very precise ways, in which each enzyme has its unique cutting site and recognition sequence on a DNA molecule. All REs used so far have been isolated from bacteria.
- **Ligases**: Used in joining pieces of DNA together.
- **Polymerases:** Used in joining nucleotides together. The most useful ones in modern biotechnology are isolated from bacteria. In particular, the thermostable ones used in Polymerase Chain Reaction (PCR) all have their origins in bacteria e.g. Taq, polymerase and Vent polymerase.
- **Transcriptases /Reverse Transcriptases:** responsible for reverse transcription

B Vectors

Virtually all vectors originated from microorganisms. These include;

- Phagemids from viruses
- Bacterial vectors such as *Azotabecter*
- Plasmids
  a. Naturally occurring
  b. Artificially constructed from fragments from various microbial sourcese.g. pUC series., pCAMBIA etc

Yeast Artificial Chromosomes (YAC)
Bacterial Artificial Chromosomes (BAC)

Health Benefits of Fermented Foods

With due respect and recognition to my colleagues in Medicine and Health Sciences, kindly permit me to lay a little more emphasis on the health benefits of fermented foods, although this has been mentioned briefly earlier, especially in relation to the enhancement of the nutritional status of fermented foods, which in turn promotes sound health This is because a healthy population has significant contributions to make towards combating food and nutrition insecurity, either directly or indirectly. This is due to the fact that individuals are involved in the food production chain in one way or the other. A healthy individual will therefore be more productive at any stage of the food production chain he finds himself.

In addition to the provision of essential nutrients, fermented foods are also carriers of probiotic microorganisms contained in them and are ingested along with the fermented foods. In the gut they multiply and promote gut health by regulating the balance of microbial ecosystem in the digestive system, which is also very vital to human health. These probiotics promote the growth and survival of beneficial microorganisms, but antagonize and suppress the survival of undesirable ones. Typical probiotics include lactic acid bacteria (LAB) bifidobacteria and some types of yeasts. They live and multiply within the fermented foods. The fermented food may also contain substances that provide nutrients for the probiotics, usually referred to as prebiotics. Both probiotics and prebiotics are therefore essential in the health promoting activities of fermented foods.

Indeed, it has recently been recognized that imbalance of microbiota in the gut has profound negative effects on the total health of humans and animals, and not just limited to intestinal diseases. Some others health challenges, including non-commutable diseases such as hypertension, diabetes, obesity and even neurological challenges are also influenced by the gut microbiota. To support this, recent experimenst in which faecal matter was transferred from lean to obese rats changed the obesity in the rats, and they became lean (Brandt *et al*., 2013; Broody *et al*, 2013; Zhang, *et al*., 2015). This and other related experiments soon led to the concept of Faecal Microbiota Transplantation (FMT) which is now being considered as a veritable means of solving a number of health challenges in the developed countries.(Brandt, 2013) This, therefore, signifies another dimension of the significant contributions of microorganisms towards achieving food and nutrition security by the consumption of fermented foods and by promoting sound health of the population.

The Emerging World of Bio-economy

Bio-economy, also known as bio-based economy, can be defined as the knowledge based production and use of biological resources to provide products, processes and services in all economic sectors within the framework of a sustainable economic system (Albert, 2007; Bugge *et al;* 2016). It is a new strategy for industry and the economy, especially in many of the developed countries. As fossil energy dries up gradually all over the world, the transition, and the need to take advantage of renewable biological resources becomes, not just an option, but a necessity. Several developed countries have placed bio economy at the heart of their investment programmes.(Wield *et al*, 2013; Olkawen, 2014).

A bio-economy relies mostly on renewable bio-resources to provide food, energy and industrial products. It also lays emphasis on the role of biogenic material flows. In this regard, the developing countries, including Nigeria, should not lag behind in this new adventure, because of the abundant bio-resources available to them. They should not allow it to slip away like the issue of the petroleum resources that have been developed for them and exploited by the developed countries.

There is no doubt that the immediate next world will be governed by bio-economy as will be propelled by Biotechnology/ Bioinformatics, Information and Communication Technology as well as Nanotechnology Interestingly there is already a lot of synergy between these frontiers of knowledge.

Conclusion and Recommendations

It is obvious that hunger and malnutrition, combined with, leading to or interwoven with poverty and diseases, have been ravaging the world for many centuries now. Unfortunately, the trend may continue, even at a more devastating level, if urgent steps are not taken globally. The multiplying effects of the unfortunate issue of food insecurity may or may not be limited to the regions of occurrence, but may spread widely globally, even with more devastating effects on the developed parts of the world, who may at the moment feel secured. This may be due to migration, (legally or illegally), leading to rapid population increases and refugee challenges in such countries.

This alarming situation of global food and nutrition insecurity has led to serious consequences, especially on the vulnerable groups, particularly children, women (especially pregnant women), and the elderly. Among the causes, food wastages rank very high. To arrest the situation, hitherto untapped facilities and resources must be harvested decisively and rapidly. Fermentation technologies, even at local and traditional levels, offer viable options in combating and eliminating hunger globally, and especially in the developing countries. These low cost technologies, that are especially suitable for rural communities stand the chance of being upgraded to industrial levels and attain sustainability. Moreover taking advantage of the more advanced modern biotechnology offers amazing promises in solving the problem of hunger and malnutrition around the world. Furthermore developing countries, including Nigeria, should follow closely the developed countries in the development of bio-based economy since they are equally, if not more blessed, as the developed countries in terms of the diversity of bio-resources.

Lastly, concerted efforts should be made globally to break the vicious cycle of hunger, poverty and disease if the world is desirous of enjoying a measure of peace in the nearest future. It is also important, and indeed imperative, that developing countries especially Nigeria, invest heavily in research, particularly those related to biotechnology/bio-informatics, information and communication technology, and nanotechnology as these are the propelling forces for the ensuing bio-based economy that may soon dominate the global landscape

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