HEALTHY FOOD FOR ALL: EXPLORING NEW HORIZONS

INAUGURAL LECTURE SERIES 32

BY

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Protocols/Courtesies

Preamble

It is with utmost gratitude to the almighty God, my Creator, and with sincere appreciation to the University administration for the privilege granted me to stand before you today to deliver the 32nd Inaugural Lecture of this great citadel of learning. God initiated the food supply chain. In the Holy Scriptures, the ancient Psalmist declared '*O give thanks unto the Lord ….who giveth food to all flesh: for his mercy endureth for ever* – Psalm 136: 1a, 25 *(KJV)'*. During the discharge of His earthly duties in the wilderness, our Lord Jesus Christ miraculously multiplied processed food for the multitudes. In addition, while the Israelites of the Biblical days were wandering in the wilderness, God gave them nutritious and healthy diet, *Manna* and *Quail*. Manna is recognized today to be the coriander seeds and together with quail meat – a balanced diet. Quail meat is one of the best known meat and its eggs have lots of health benefits. The Psalmist also declared *'Thou prepareth a table before me ……..; thou anointest my head with oil'*;….Psalm 23:6. It is therefore obvious that God Almighty is a key player in the Food Supply Chain actively involved in primary and secondary food processing to make healthy food available to all His creatures, especially humans, and a pleasing profession to God in my opinion is Food Technology.

The acclaimed father of Western Philosophy, Aristotle the great, submitted that *'Happiness is the meaning and the purpose of life, the whole aim and end of human existence'*. And in the words of Franklin Roosevelt, *'Happiness lies in the joy of achievement and the thrill of creative effort'*. Today I am glad in God, the Creator of all. I am particularly delighted being in one of God's own professions, I am happy being a Food Technologist. The global effort towards the transformation to healthy diets by 2050 for optimal human and planet health coupled with the interest of the almighty God, our creator in appropriate food processing informed the title of my lecture ***Healthy food for all: Exploring new Horizons.***

This lecture is unique in a number of ways. One, it is the very first Inaugural Lecture to be delivered in this University by a member of Staff from the Faculty of Food and Consumer Sciences since its creation, although this Lecture is the 4th of its kind coming directly from the Food Science option. The second peculiarity of this presentation is in the fact that the first Inaugural Lecturer from Food Science Option now Food Science Department of this University is the Chairman of today's lecture, the indefatigable Vice Chancellor of our great University, Professor M.O. Ologunde, *FNISFT, MWAND, JP*.

Introduction

Food is the single strongest lever to optimize human health and environmental sustainability on Earth. One of the World's greatest challenges is to secure sufficient and healthy food for all, and to do so in an environmentally sustainable manner. However, food is currently threatening both people and planet. Although global food production of calories has generally kept pace with population growth, more than 820 million people still lack sufficient food, and many more consume low-quality diets that cause micronutrient deficiencies also known as hidden hunger and contribute to a substantial rise in the incidence of diet-related obesity and diet related non-communicable diseases, including coronary heart disease, stroke and diabetes (Willet *et al.*, 2019). An estimated 2 billion people on the globe suffer from one or more micronutrient deficiencies (Graham et al., 2007), demonstrating that hidden hunger is responsible in part for the global malnutrition burden. In addition, 60% of individuals in low-income countries are food insecure.

In Nigeria and most other African countries, poverty is widespread and food and nutrition insecurity is a major challenge with protein-energy malnutrition and micronutrient deficiencies constituting important public health problems. This has negative impact on productivity, maternal and infant health, and intellectual development (Aworh, 2018). Unhealthy diets now pose a greater risk to morbidity and mortality than unsafe sex, alcohol, drug and tobacco use combined. More than 100 million Nigerian population has been estimated to live on less than $1 a day indicating poor access to healthy diet (Canagarajah and Thomas, 2001; Oshewolo, 2010, Aworh, 2015).

Micronutrient deficiencies have been defined as hidden hunger because its symptoms are not always obvious and people may not even be aware of it. Its negative, sometimes lifelong, consequences on health, productivity, and mental health, are devastating (Burchi et al., 2011). Micronutrients are nutrients (dominantly vitamins and minerals) required by humans throughout life in order to carry out a vast range of physiological functions. While it was argued that at least 51 different nutrients are needed in adequate amounts by human beings (Graham et al., 2007), there are 19 essential micronutrients —for physical and mental development, immune system functioning and various metabolic processes. Since micronutrient deficiencies lead to a vast range of diseases and other health disorders, their decrease is likely to help the achievement of the health-related United Nations Sustainable Development Goals. Sustainable food based strategies that ensure reduction of micronutrient deficiencies should therefore be highly favoured towards achieving food and nutrition security in developing countries and beyond.

Investing in nutrition security has many benefits for developing countries, because it contributes to the achievement of many other development goals related to agriculture, water, health, education, poverty alleviation and gender development. Three Sustainable Development Goals of the United Nations—Goal 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture), Goal 3 (ensure healthy lives and promote wellbeing for all at all ages) and Goal 6 (ensure access to water and sanitation for all)—are directly related to nutrition security. Secure nutrition addresses not only the required level of calorie intake, but also the proper balance of food items in a households' food basket. Therefore, food patterns with a high diversity of food groups and a variety of items with a range of micro- and macro-nutrients are important to achieving nutrition security. In last few years, researchers have got momentum to incorporate underutilized crops and industrial food by-products in the human diet for good health promotion as they especially contain phenolic compounds, i.e. phenolic acids, flavonoids and flavanols which possess antioxidant and anti-cancerogenic properties and health benefits (Amić et al., 2003; Oboh, 2005).

Of the thousands of known plant species, only 120 are cultivated for human food, and only 9 supply over 75% of the global plant-derived energy. Three crops, namely, wheat, rice and maize, account for more than half of dietary energy supply (Massawe et al., 2015). This implies that more than one hundred edible plant species are neglected or underutilized for their nutritional value. Many neglected and underutilized species are nutritionally rich and are adapted to low input agriculture. In Nigeria and other African countries, there are hundreds of lesser known indigenous crops as well as other food plants gathered from the wild that contribute to food security and play vital roles in the nutrition of the people particularly the rural populace (Aworh, 2014; NRC, 1996; 2006; Stadlmayr et al., 2010). The production and consumption system of neglected and underutilized crops have positive impact on the community households' food security. Underutilized crops have great potential to alleviate hunger directly, through increasing food production in challenging environments where major crops are severely limited, through nutritional enhancement to diets focused on staples, and through providing the poor with purchasing power, helping them buy the food that is available.

Many of these crops are well adapted to the changing climate and could thrive well under extreme drought conditions and under marginal soils. The untapped potential of these underutilized species in developing nations such as Nigeria should be unlocked to contribute to the supply of healthy foods/diets for the teeming population. Inclusion of the nutritionally rich underexploited species into the list of the major agricultural crops for the nation will be in line with one of the strategies proposed by EAT-Lancet Commission to transforming to sustainable food production for the globe which is to reorient agricultural priorities from producing high quantities of food to producing healthy foods (Willet *et al*., 2019).

A healthy food/diet should optimize health, defined broadly as being a state of complete physical, mental and social well-being and not merely the absence of diseases. Healthy diets have an optimal caloric intake and consist largely of a diversity of plant-based foods, low amounts of animal source foods, contain unsaturated rather than saturated fats, and limited amounts of refined grains, highly processed foods and added sugars. Consumers are increasingly demanding minimally processed healthy foods with more natural flavour and colour, high quality and long shelf-life. Emerging and innovative non-thermal preservation technologies such as pulsed electric fields (PEF), high hydrostatic pressure (HHP), cold atmospheric plasma, or ultrasound are increasingly considered for preserving and processing different foods (Barba *et al*., 2015; Barba *et al*., 2012; Knorr *et al*., 2011). Non-thermal processing of fruits and vegetables has been demonstrated to be a useful tool to extend their shelf life and quality as well as to preserve their nutritional and functional characteristics. PEF is increasingly used for fruit juice preservation with products already available in the market. The short pulses of the applied electric field impact the permeability of biological membranes causing reversible or irreversible permeabilization depending on the purpose of treatment. PEF could be considered as a good alternative in delivering healthy foods to all.

Food Processing

Food processing involves the transformation/conversion of raw materials (plant or animal origin) through the application of physical, biochemical or chemical processes into stable, affordable, safe and nutritious products and by-products. Usually inedible and edible raw materials are converted into more useful, shelf-stable and palatable foods or potable beverages for human consumption (International Food Information Council Foundation, 2010). Food processing dates back to the prehistoric period. It was found to be effectively used in the hunter-gather humanities as per archaeological evidences. Since prehistoric times, food processing has been a key aspect of the food production chain that links agricultural production with the provision of food for people in the form and at the time it is required (Floros et al., 2010). Some of the common industrial processes used in food manufacturing include milling, cooling/freezing, smoking, heating, canning, fermentation, drying, extrusion cooking. These processing techniques produce desired changes, which include protein coagulation, starch swelling, textural softening, and formation of aroma components.

Some benefits of food processing include destruction of food-borne microbes and toxins, and spoilage microorganisms, improved bioavailability of nutrients, extension of shelf life, improved sensory characteristics and functional properties, availability of varieties, offering of convenience and efficient use of resources and reducing environmental impact (van Boekel et al., 2010). Food processing also encompasses the use of additives which are used to increase quality (e.g. taste and appearance), extend shelf life and improve the safety of foods. A range of chemical additives (e.g. sulfur dioxide for preservation of wine, nitrites in bacon), anti-microbials (e.g. benzoic acid) and antioxidants (e.g. tertiary butylhydroquinone for retarding oxidation of oils) have been employed over the years. However, there is now a trend towards the incorporation of natural preservatives and the phasing out of some synthetic chemical additives. There is increasing interest in the use of natural anti-microbials (e.g. spices, bacteriocins, essential oils), preservatives (e.g. ascorbic acid, citric acid from fruits) and antioxidants (e.g. Maillard reaction products, polyphenols, rosemary extract) to improve food quality and shelf life (Kumar et al., 2015; Vergis et al., 2015). In addition to the move to natural food additives, newer delivery systems (e.g. nanoencapsulation), smart additives and packages are also being developed as an alternative to direct incorporation of additives to food (Carocho et al., 2014).

However, processing causes few undesirable changes to the components of food depending on the processing techniques, conditions and the type of food involved. The undesirable changes include the loss of vitamins and minerals, freshness, and flavour. There has been many reports about the negative aspects of food processing which have focussed on issues such as the detrimental effects of heat treatment on food quality (e.g. formation of acrylamide, nutritional degradation, high sugar in formulated foods, introduction of trans fats into foods) (van Boekel et al., 2010). The increasing awareness of consumers on the negative effects of conventional processing methods such as thermal processing has caused a shift in their demand for fresh like food with high nutritional content. During the last two decades, a considerable change regarding research and developments in the food processing technology has occurred. These new advances in food processing technologies come under the umbrella of non-thermal food processing. Non-thermal food processing methods are also known as minimal processing methods. These processing methods can preserve foods without substantial heating, while retaining their nutritional benefits and sensory characteristics.

Non-thermal Techniques as Alternative for Processing in Healthy or Nutritional Foods Production

Consumers’ demand for safe and highly nutritious food has increased over the years due to their knowledge of the relationship between diet, health and diseases. Hence, processing methods that will minimise nutrient losses during processing are being sought to deliver nutrient-dense foods to consumers. Nutrients retention in foods during thermal processing and maintenance of freshness of foods are hard to achieve using existing traditional thermal food processing technologies (Knorr et al., 2002). Thermal processing involves the application of heat to preserve foods through the destruction of spoilage and pathogenic organisms as well as destruction or reduction of anti-nutritional factors in foods. According to Berk (2018), destruction of microorganisms is not the only consequence of thermal processing. Other effects of thermal processing on food include among others; inactivation of enzymes, which is desirable and essential for long-term stability, changes in sensory properties and destruction of nutritionally significant components, such as heat sensitive vitamins. Due to these deleterious changes in food quality, efforts have been made to develop and optimise thermal processes that will give minimal damage to the organoleptic and nutritional quality of the product (Awuah et al., 2007; Richardson, 2004). For example, low temperature-long time (LTLT) pasteurisation of milk was replaced with high temperature-short time (HTST) pasteurisation to allow for quick processing that will limit contact time of food with heat. Subsequently, ultra-high temperature (UHT) evolved to get even better result when compared to HTST. Although the optimisation process has proved successful, non-thermal processing technologies such as pulsed electric field (PEF), pulsed light treatment (PL), ultrasounds and high pressure processing (HPP) appear more promising and are better alternatives to traditional thermal processing. Hence, novel non-thermal processing (NTP) methods that could serve as suitable alternatives to traditional thermal processing methods have been developed. NTP techniques are the emerging technologies in place of thermal techniques employed for preservation and processing of food. The adoption of these technologies is geared towards ensuring zero waste of food crops and nutrients preservation enhancement. The application of these emerging technologies is not only restricted to food processing but cut across several disciplines such as physics, chemistry, mathematics, biology, dental medicine, and acoustic engineering (Norberg *et al.*, 2015) among others. NTP is an innovative processing technology that exerts minimal impact on the nutritional and sensory properties of foods, and extends shelf life by inhibiting or killing microorganisms. Simply put, NTP technologies are processing techniques that do not involve the use of thermal energy during food processing for the destruction or inactivation of microorganisms. However, more technically, it is often used to describe technologies that are effective at ambient or sub-lethal temperatures (Pereira and Vicente, 2010). Perhaps, the use of the term non-thermal stems from the fact that the heat generated during processing is not high enough to cause significant heating of the product, but the processing is sufficient to destroy possible organisms of interest that could pose food safety threats. Currently NTP are receiving attention from consumers, producers and researchers possibly because they have the ability to inactivate microorganisms at near-ambient temperatures, avoiding thermal degradation of the food components, and consequently preserving the sensory and nutritional quality of fresh-like food products (Pereira and Vicente, 2010).

The appraisal in food technology boils down to optimal microorganisms inactivation, enhanced ability to achieve faster process, enhanced lower temperatures, relatively lower energy consumption and requirement , its potential to combat climate change due to their low carbon footprint, guaranteed high quality product and adequate sensory properties retention (Jambrak, 2018). They are reported to have achieved enviable positive impact on preservation of nutritive quality of food and as well guarantee optimal microbiological safety (Prakash, 2013). Among the various available NTP techniques, more attention will be focussed on PEF in this lecture because the bulk of my research centred on it.

Pulsed Electric Fields

Pulsed electric field (PEF) is considered as a very promising non-thermal technique of preserving foods and improving food quality. Among the emerging non-thermal processes of interest, pulsed electric field (PEF) shows promising features of inducing cell membrane permeabilisation within a very short time (µs to ms range) leaving the product matrix relatively unchanged while positively affecting mass transfer rates in subsequent processing of foods (Knorr and Angersbach, 1998; Barsotti and Cheftel, 1999; Ade-Omowaye et al., 2001a, 2002a, 2002b, 2002c; Kumar et al., 2016).

The technology involves the use of electric field pulses of short duration with electric field strength of 0.1–80 kV/cm applied to a food placed between or passed through two electrodes (Barba et al. 2018; Puertolas and Barba 2016; Koubaa et al. 2015; Buckow et al. 2014; Buckow et al. 2013). When the very short (ms or µs) and strong electric pulses are applied to food matrix, a physical phenomenon called electroporation is induced. Depending on the pulse characteristic (electric field strength, pulse shape and width, energy input), reversible or irreversible pores can be formed. Reversible pores are hydrophilic and close by themselves after a short time. With a higher intensity of the electric pulses and a longer treatment, the initially hydrophilic pores turn into hydrophobic pores that cannot be closed again. This causes permanent damage to the cell. For the microorganisms contained in the product, the loss of the boundary to the environment means the loss of viability. Plant cells, e.g. potato cells, lose their internal cell pressure (turgor) when subjected to the PEF treatment and the increase in the membrane permeability results in an easier mass transport, for example when extracting valuable ingredients.

Due to the difference in potentials, this phenomenon is manifested as local structural damages to cell walls that cause the rupture of the cell membrane in microorganisms, leading to their inactivation (Silva et al., 2017). It has been reported that PEF treatments at longer treatment time (150 μs) achieved higher microbial inactivation and prolonged shelf-life (Jin and Zhang, 1999). It was also found that microbial characteristics such as cell size, shape, or type of the cell envelopes have no certain influences on microbial resistance to PEF. On the other hand, the resistance of the bacteria to PEF treatment is influenced by pH of the treatment medium (Evrendilek, 2017).

Electric field strength, treatment temperature and energy delivery are the three most important parameters identified for PEF processing (Toepfl et al. 2014b; Amiali et al. 2007; Lebovka et al. 2005; Heinz et al. 2003). As a non-thermal technology, pulsed electric field processing causes less degradation of nutritional and sensory characteristics of foods than traditional thermal processing technologies (Buckow et al. 2013; Walkling-Ribeiro et al. 2010; Rivas et al. 2006). It exhibits many advantages such as lower treatment temperature, shorter processing time and potential continuous flow in comparison to traditional processing technologies (Walkling-Ribeiro et al. 2011; Puertolas et al. 2010), making it a very appealing technology for food manufacturers. It has been widely investigated for its industrial pasteurization and sterilization potential for liquid foods like milk, dairy products, liquid eggs, fruit juice, wine, beer and other alcoholic beverages (Milani et al. 2015; Delsart et al. 2014; Buckow et al. 2014; Timmermans et al. 2014; Monfort et al., 2010), and its use as food processing technology in solid foods (Liu et al. 2017a; Aguilo-Aguayo et al. 2017; Ignat et al. 2015; Ade-Omowaye, 2002; Knorr et al., 2002) has also been demonstrated. Interest in the food industry for PEF is rapidly growing, as it became more adaptable for continuous processing. The application of PEF as a pre-treatment stage before pressing and in combination with the mechanical operations provided increased yields, without significant impact on sensory and quality characteristics of the extracted juices (Barba et al., 2015; Ade-Omowaye et al., 2001a, 2001b).

Studies on PEF treated liquid foods and fruit beverages demonstrated encouraging potential as an emerging, novel, mild and non-thermal food processing alternative to conventional thermal processing. As with other non-thermal technologies, there is a certain thermal element in this process, which also improves its efficacy. However, during PEF treatment, much lower temperatures (40–60 °C) are employed for microbial inactivation, as compared to those used during regular pasteurization (Gabrić et al., 2018). PEF processing system is associated with minimum energy utilization and greater energy efficiency than thermal processing. In apple juice treatment, energy utilized in PEF is 90% less than the amount of energy used in high temperature and short time processing methods (HTST). Studies have confirmed that PEF-treated orange juice retains all the physical properties, along with 97.5% of vitamin C.

The following advantages have been accrued to PEF: There is instant distribution throughout an electrically conductive food; it destroys vegetative cells; colours, flavours and nutrients are preserved; there is no evidence of toxicity; it involves relatively short treatment time; energy requirements are low; it effects accelerated thawing; it is suitable for decontaminating heat sensitive foods; it is also best suitable for liquid foods; pasteurization of fruit juices, soups, liquid egg and milk; and there is no environmental hazard (Knorr and Angersbach, 1998; Barsotti and Cheftel, 1999; Kumar et al., 2015).

PEF generation and process parameters

To generate a PEF of several kV/cm within food materials, a large electrical current is necessary to flow between the electrodes in a treatment chamber for a very short period of time (µs to ms). The time between pulses is much longer than the pulse width. Therefore, the generation of pulses involves the slow charging and rapid discharge of an electrical energy storage device such as a capacitor. In general a PEF system (Plate 1) consists of an electric circuit that forms the pulse, a treatment chamber in which the pulse is delivered to the product, and in the case of a continuous PEF system a product handling system which enables the product to flow through the system. The construction of the electric circuit determines the shape of the pulse. The electric field pulses most commonly applied are in the form of exponential decaying or square waves. A pulse forming network which allows the formation of an exponential decay was used throughout the work presented in this lecture. An exponential decay voltage wave is a unidirectional voltage that rises rapidly to a maximum value and decays slowly to zero. The simplified circuit in Figure 1 describes briefly the generation of an exponential decay waveform. A high voltage generator (8 kW, Umax = 10 kV) supercharged the process capacitors combined in parallel which was then discharged to the food material in tap water placed between parallel stainless steel electrodes which are placed within Plexiglas cuvette. The discharge is controlled by a switch releasing pulses of a duration in the µs to ms range. Studies have shown that among the critical electrical parameters that must be controlled to optimise the process are field strength amplitude, impulse energy and pulse number (Barsotti et al. 1999, Knorr et al. 1994; Knorr and Angersbach, 1998). Assessment of these factors revealed marked effects on the ruptured membrane area of the treated materials. The higher the magnitude of the field strength applied the higher was the resulting ruptured membrane area. The application of pulsed electric field as pre-treatment method during processing of some plant foods including apple, coconut, carrot, paprika, potato etc showed higher ruptured areas with increasing field strength, pulse number and impulse energy (Rastogi et al., 1999; Bouzrara and Vorobiev, 2000; Ade-Omowaye et al., 2001; Taiwo et al., 2001; Angersbach et al., 1999; 2002; Ade-Omowaye et al., 2002a, 2002b, 2002c). Knorr and Angersbach (1998) reported that at low specific energy inputs (102 J/kg) maximum permeabilisation could not be achieved in potato tissues even with a pulse number of 200. However, one pulse (with an energy input of 104 J/kg) was sufficient to achieve maximum permeabilisation (Figure 2). Variation of the number of pulses at a given electric field strength indicated that an increase above 50 did not alter juice yields substantially (Knorr et al., 1994). Bouzrara and Vorobiev (2000) observed increased juice extraction from sugar beet with increasing pulse number and pulse duration. Accelerated mass transfer rates during osmotic dehydration of PEF pre-treated carrots was reported with increasing field strength up to 1.09 kV/cm by Rastogi et al. (1999).

Applications of Pulsed Electric Fields

The application of pulsed electric fields as an innovative technology can be used in various areas of the food industry and bioprocess engineering. The main applications of PEF technology are currently in the field of gentle preservation of juices and structure modification of potatoes (Siemer et al., 2018). These applications are accomplished under different processing conditions as microbial inactivation is acting on small cells while mass transfer phenomena usually involve the disruption of bigger structures such as the glands of aromatic herbs (Barba et al., 2015; Barba et al., 2017; Jäger, 2013; Puértolas et al., 2016).

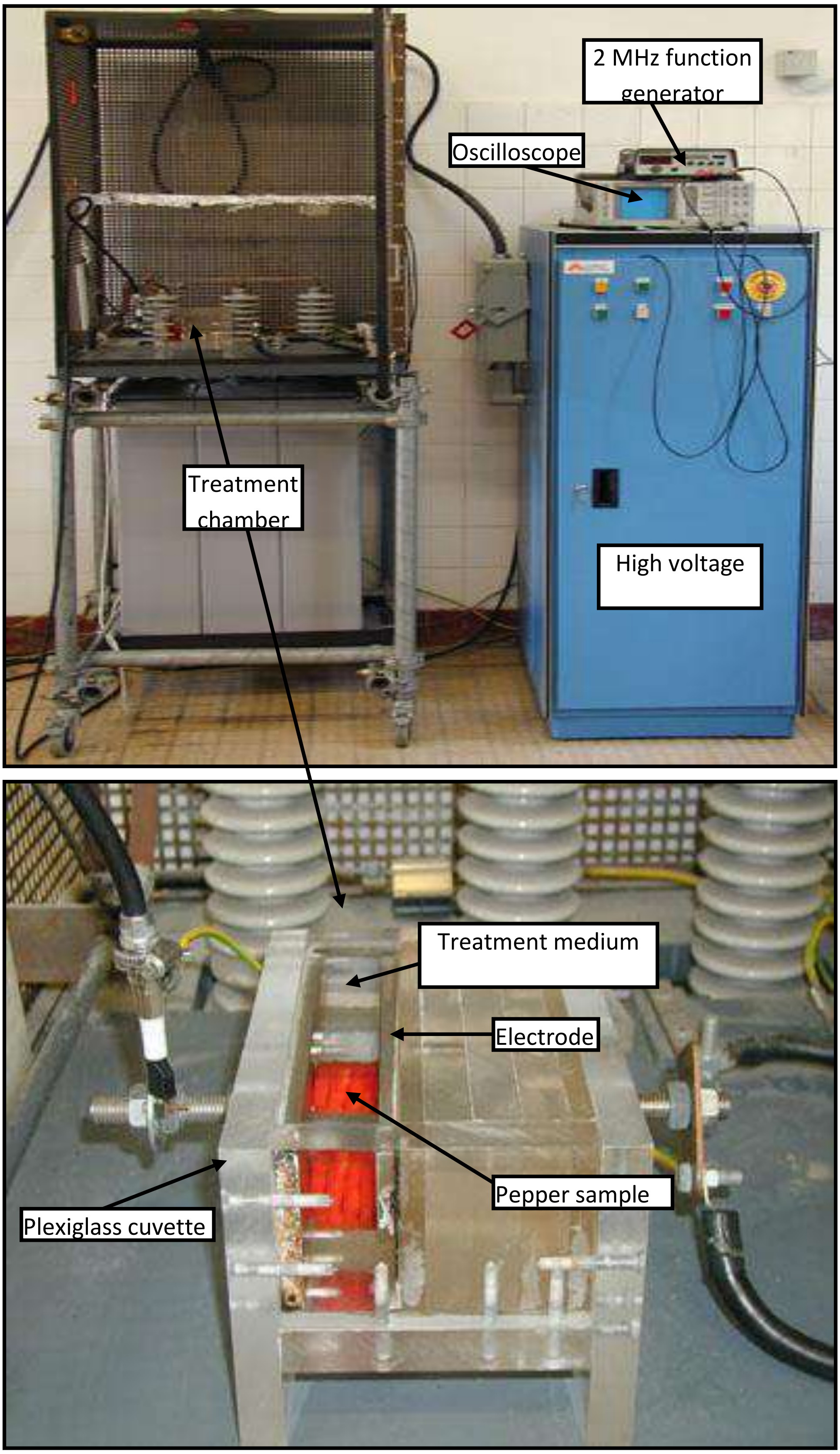


Plate 1: A pictorial view showing the different parts of a pulsed electric field equipment

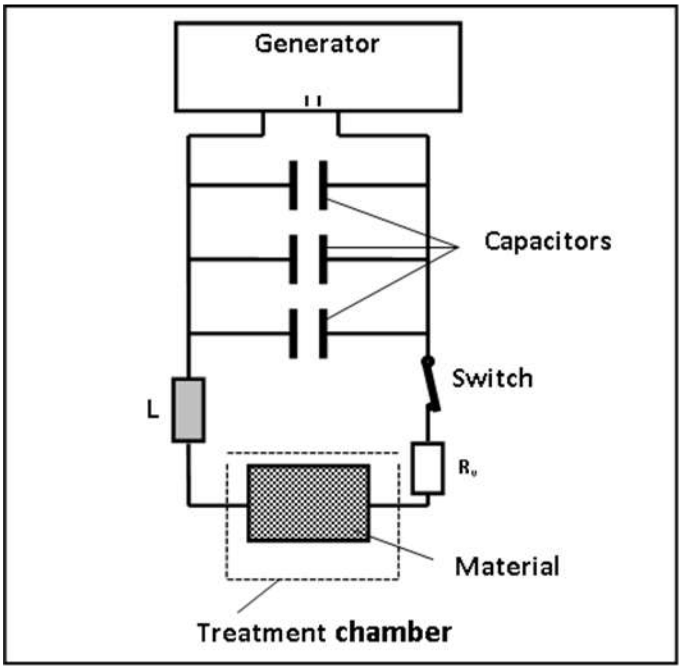


Figure 1: Circuit diagram of pulsed electric field equipment

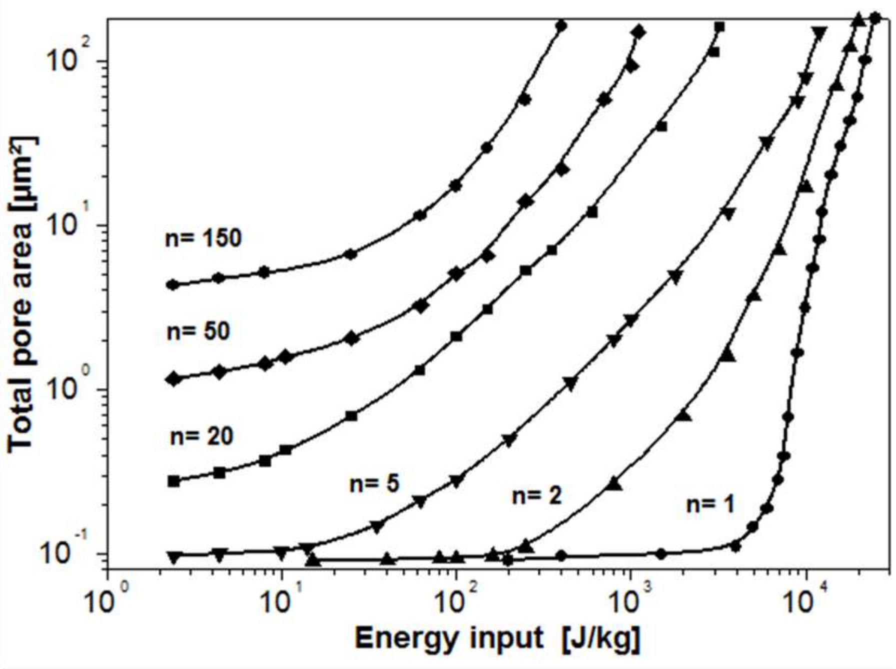


Figure 2: Effect of pulse number and impulse energy density on the extent of membrane permeabilisation (Angersbach et al., 2002)

The process parameters of PEF can be adjusted depending on the application desired. In addition, the diversity of raw materials and the availability of PEF equipment may affect the PEF process conditions. The report of Siemer et al. (2018) summarized the different areas of applications of PEF.

PEF in Fruit Juice Preservation

As a substitute for thermal pasteurisation, PEF enables microbiologically stable juice to be produced without a reduction in quality. The microorganisms which cause spoilage are inactivated with the physical principle of electroporation. As a result, the thermal load for the product is low, providing major quality advantages with regard to flavour and vitamin content. With a suitable combination of thermal energy and PEF, it is possible to inactivate resistant bacterial spores. Here as well, the thermal load is considerably lower compared to purely thermal inactivation.

Direct cooling of the product within the process following PEF (Figure 3) treatment prevents residence at increased temperatures and ensures an optimum retention of the fresh character. The temperature-time profile resulting from the process is shown in Figure 4. The Pasteur value (thermal load) of the PEF treatment is considerably lower (more than 20 fold lower) compared to the thermal treatment. The minor effect on the product by the PEF treatment is therefore only a fraction of that of thermal pasteurisation, hence it better preserves sensitive flavours and nutrients and enables a higher product quality to be achieved.

In numerous sensory tests, it was generally not possible to determine any marked difference between untreated and PEF-treated juices. However, with a comparable thermal treatment, a considerable loss of flavour as well as colour (Plate 2) can be recognised. The PEF technology is already being successfully used by several manufacturers in Europe and Asia to market premium products. Typical process costs are approximately 1-2 cent (less than 20 naira) per litre.

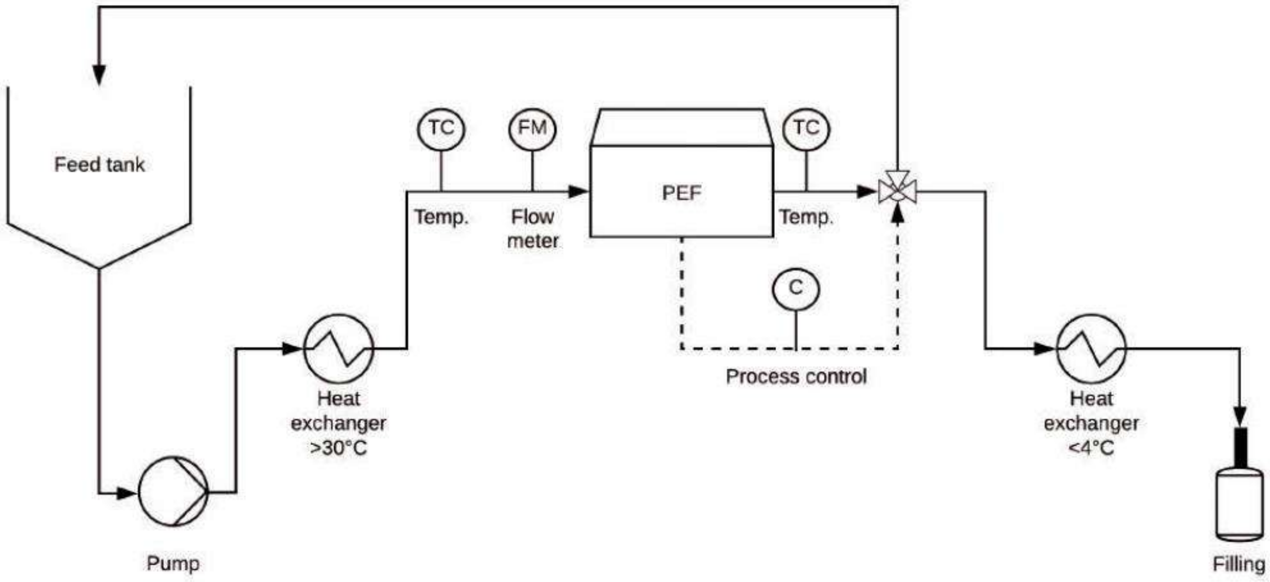


Figure 3: Flow diagram of a typical PEF process for microbial inactivation of liquids

Plate 2: Colour difference of untreated (left), thermally (centre) and PEF-treated green smoothie (right)

Source: Siemer et al. (2018)

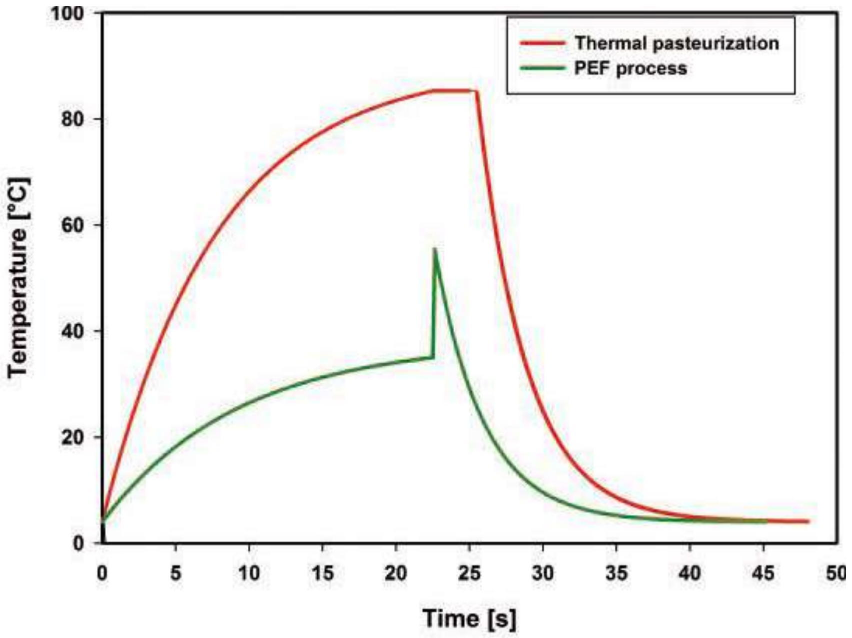


Figure 4: Temperature-time profiles of preservation with heat (red) and PEF (green)

Source: Siemer et al. (2018)

Use of PEF in the snack industry

Pulsed electric fields have been used successfully in the potato-processing snack industry (Plate 3) since 2010. It is mainly applied in French fry and chips production. When producing French fries, the PEF technology as pre-treatment before cutting has meanwhile become the standard world-wide. This is based on numerous process and product quality advantages during the entire production process. The treatment of potatoes results in tissue softening due to the discharge of cell fluid and loss of the turgor pressure. The PEF technology replaces the classic pre-heater, therefore reducing the amount of water and energy consumption by up to 90%.

Another advantage of using pulsed electric fields is that all potatoes – regardless of whether they are large or small – are treated uniformly. Due to uniform softening, a smooth cut is achieved; the raw sticks are now more flexible and break less, which leads to an increased yield. Additional quality advantages in the final product are approximately 10% lower oil absorption during deep-frying, more even browning and longer French fries.

In chips production, the advantages are similar to that of French fry processing, however the quality improvement of the final product is even more pronounced. The cutting pattern improves, resulting in reduced loss of raw material and starch during cutting, leading to a significantly increased yield. In addition, fewer chips stick together during deep-frying, eliminating the need to reject them.

As chips have a considerably larger surface relative to their weight than French fries and are deep-fried longer, the oil reduction is even higher (up to 20%), depending on the cut, the raw product and the deep-frying process.

Plate 3: A pictorial view of industrial PEF system for potato processing

Source: Siemer et al. (2018)

Mr Vice chancellor, Sir, today more than 50 PEF systems are used in the potato-processing industry world-wide contributing to the production of healthy food for all. Typical throughputs for systems in the chips industry lie between 1 and 10 t/h, and in French fry processing the line capacities are considerably higher with 10 – 60 t/h.

Use of PEF for drying

The PEF technology is a promising new application for optimising the drying process with regard to the drying time, drying temperature and quality aspects for an extremely broad range of food, and in particular for fruit and vegetables. An improvement in the drying process and/or the product quality is provided for all types of drying (hot-air, freeze, vacuum, microwave and infra-red drying, etc.). Especially for freeze, vacuum, microwave or infra-red drying, a pretreatment with PEF results in a reduction of product shrinkage and on the whole considerably more attractive product (Plate 4).

Plate 4: Freeze-dried strawberries (left: untreated, right: PEF)

In summary, the pre-treatment of food, e.g. fruit or vegetables, with pulsed electric fields leads to a higher diffusion coefficient (Ade-Omowaye et al. 2001a, 2001b, 2001c, 2002a, 2002b, 2003a, 2003b), and therefore to an optimisation of the drying process with regard to temperature and time. This results in quality advantages for many dried foodstuffs through the use of PEF.

PEF for extraction of valuable substances

The principle of electroporation for cell disruption and the resulting discharge of cell sap can be used to extract the cell contents, and in particular valuable substances. Among other things, this can be used for an increased juice yield or acceleration of extraction processes. During juice production, plant cells are generally opened mechanically, thermally or enzymatically to release the cell content (juice). The so-called mash is separated into solid material (pomace) and liquid (juice) using various methods. A physical opening of the cells by means of PEF simplifies the separation of liquids and solids without using heat, extreme mechanical crushing or enzymes. Here the advantage of the use of PEF lies particularly in the homogeneity of the method. In this case the tissue is not only treated on the surface, but all the way through so that all cells - including those inside - are pored during treatment.

The use of PEF leads, on the one hand, to an increase in the total yield of valuable ingredients and, on the other hand, process steps can be shortened and new capacities created. For example, the skin and seeds of the grapes are at times fermented with the juice for the production of red wine in order to extract the red colour caused by anthocyanins and polyphenols. Direct pressing would result in a white or rosé coloured wine from red grapes. Depending on the grape variety, the extraction process takes up to several weeks. With PEF pre-treatment of the mash, the pigments and polyphenols separate out more easily and quickly from the cells. As a result, the process step can be reduced by several days and new tank capacities can be created by the fermentation tanks being freed up earlier.

PEF in biotechnology

Another application for treatment with pulsed electric fields is stress induction for microorganisms. By choosing a lower treatment intensity, the microorganisms in the product are not killed, but are instead stimulated or a stress reaction is triggered. This effect is applied in biotechnology and can be used within fermentation to increase the speed of fermentation and/or to influence the metabolism so that other substances are formed and/or to increase the concentration of a desired substance, e.g. fat or amino acids. An example of this application is the treatment of microalgae. PEF treatment of the algae produces more valuable substances within the cell, which can then be extracted. In addition to growth stimulation of the algae, PEF can be used as a physical cell disruption method. The blue pigment from the spirulina algae is meanwhile present in many products, and as a result the demand for the dye is also increasing. The extraction rate without the use of PEF treatment is 0.2 mg/ml. By using the new technology, it was possible to increase the yield to 66.4 mg/ml. The extraction of polyphenols and the antioxidative capacity of the Scenedesmus algae shows a considerable increase.

PEF for improving peeling behaviour

The influencing of plant cells with PEF is also successfully used to simplify peeling of tomatoes. In the process, the entire tomato is subjected to PEF treatment, which then makes the skin very easy to separate from the pulp. On an industrial scale, hot steam is used to separate the skin. With approx. 2 kJ/kg, the energy requirement for this treatment is considerably higher compared to PEF treatment. In addition, the treatment is carried out at room temperature or even lower, enabling negative thermal effects on the quality of the product to be avoided.

Use of PEF in meat and fish processing

In addition to plant cells, animal cells e.g. meat and fish can be influenced by PEF treatment. Despite the different structure of meat compared to that of plant cells, PEF also has a positive effect on it. Part of the production operation of marinated meat products, which are often used in so-called ready-to-eat products, is the so-called tumble step. In the process, the meat and the brine or marinade is rolled in a tumbler in a vacuum for a certain time. The PEF treatment changes the structure so that the brine is absorbed more quickly, enabling the tumbling time to be reduced by up to 50%. This increases the effectiveness of the manufacturing process while also achieving a quality improvement with regard to the tenderness. The transfer of PEF technology to the fish and meat industry would be highly favourable due to the low energy consumption and short processing times required in PEF processing.

RESEARCH CONTRIBUTIONS

Mr Vice Chancellor, Sir, one of the major thrust of my research and contribution to knowledge has been in the area of minimal processing of foods with special attention on pulsed electric fields (PEF) as a mild gentle non-thermal technique that retains both the nutritional and sensory quality of food better than conventional thermal techniques. The findings from our studies on PEF have contributed to its commercialization in Europe and beyond. All my studies on PEF were carried out in Germany with the sponsorship of DAAD (Deutscher Akademischer Austauschdienst, German Academic Exchange Service). Lack of facilities for PEF treatment in the University after my return from Germany shifted my research focus to exploring underutilized crops as possible candidates for healthy food. The challenge of the growing number of people suffering from hidden hunger, the potential burden of climate change on commonly grown species, and the enormity of the potentially healthy underutilized crops prompted me to carry out several studies on product development from some of these species.

Pulsed Electric Field and Conventional Pre-treatments for Process and Product Quality Enhancement

Juice extraction

The primary objective of the juice processor is to obtain high yield with maximum productivity, while maintaining or improving the quality and stability of the final juice product. To achieve this goal, fruit processors rely on continuous technological support with respect to equipment, processes and processing aids such as enzymes. The use of liquefying enzymes involves strong agitation, high temperatures and lengthy treatment times (Faigh 1995). Alternative process which could preclude the accrued disadvantages involved in the use of certain enzymes would therefore be a plus in juice processing. The potentiality of PEF was therefore exploited in some studies.

Investigations were conducted on the impact of PEF treatment on yield and some quality parameters of juice from different raw materials such paprika and coconut. Results were compared to juice obtained from enzymatically treated or untreated mash. PEF treatment resulted in between 10% and 20% increase in juice yield depending on the material and PEF conditions. Juice from PEF treated paprika compared well in quality with enzyme treated or the untreated. Beta-carotene was better extracted into the juice with PEF treatment than with enzyme and other quality parameters were also adjudged better than other pretreatments (Ade-Omowaye et al., 2001a, Tables 1 and 2, Figure 5). Higher yields and better quality from PEF treated fruits have been reported by other authors (Knorr et al. 1994; Bazhal and Vorobiev 2000; Bouzrara and Vorobiev, 2000). The increased yield has been associated to the pore formation after PEF treatment which eased the separation of the juice from the cells (Barba et al., 2015; Ade-Omowaye et al., 2001b). Our findings suggested that PEF- assisted extraction would reduce production cost, enhance profitability and promote production of juice rich in natural antioxidants (vitamin C and beta carotene) which may be termed healthy drink and could be consumed for health reasons. PEF could find applications in functional food formulation as it induces better release of natural antioxidants.

Mr Vice chancellor, Sir, with the seasonality of our tropical fruits and vegetables, their high perishability and non-availability of good preservation techniques in the country and other developing nations leading to more than 25% losses, PEF could proffer amazing solutions. Many of these fruits and vegetables could be converted into juices as a means of extending their shelf life and making them available throughout the year. The increased awareness of the relationship between fruit and vegetable consumption and prevention of diseases has placed more demands for these produce. Therefore, the quest for juices having quality close to the freshly squeezed fruits and vegetables will continue to increase and as such juice processors would readily adopt methods with potentials of maximizing yield, minimizing production cost and maintain high quality. Incorporation of PEF technique into juice extraction process in Nigeria will no doubt yield profitable results. A recent study (Golberg, 2015) conducted in Israel on intermittently delivered PEF (IDPEF) for the preservation of milk in developing countries demonstrated that it does not require constant electricity supply and can be powered by a small scale 2 KW solar energy system operating 5.5 h per day in combination with small scale energy storage system. It is believed that IDPEF storage technology can empower millions of smallholder farmers in low income countries.

Table 1: Influence of pre-treatment on some characteristics of pepper mash, juice and press cake

	Treatments		
Parameters	Untreated	PEF	Enzyme
pH of juice	5.2 ± 0.1^{a}	5.2 ± 0.1^{a}	4.8 ± 0.1^{b}
Soluble solids (°Brix) of juice	6.70 ± 0.20^{a}	6.8 ± 0.2^{a}	6.7 ± 0.2^{a}
Dry matter in juice (%)	6.1 ± 0.1^{a}	6.8 ± 0.1^{b}	6.6 ± 0.1^{b}
Colour (juice) L	29.5 ± 1.5^{a}	30.0 ± 1.4^{a}	28.2 ± 1.4^{a}
a	$+15.3\pm0.8^{a}$	$+18.0\pm0.7^{b}$	$+15.5\pm0.8^{a}$
b	$+15.3\pm0.8^{a}$	$+16.4\pm0.6^{a}$	$+15.8\pm0.8^{a}$
Cell disintegration index, P_o before pressing the mash	0.80 ± 0.01^{a}	0.90 ± 0.01^{b}	0.90 ± 0.01^{b}
Juice yield (%)	81.2 ± 2.2^{a}	91.3 ± 1.4^{b}	90.4 ± 1.3^{b}
Total dry matter in press cake (%)	13.4 ± 0.3^{a}	19.3 ± 0.3^{b}	16.5 ± 0.3^{c}

Values with same letters on the superscripts along the rows are not significantly different from one another, but different letters show significant difference ($p<0.05$), $n \le 4$, n = number of readings.

Source: Ade-Omowaye et al. (2001a)

Table 2: Influence of various methods of cell permeabilisation on cell disintegration index, milk yield, protein and fat contents of coconut pressed at room temperature with manual hydraulic press (P = 15 MPa, time = 10 min)

Methods of pre-treatment	Protein content (%)	Fat Content (%)	Milk yield (%)	Cell disintegration index
Freezing-thawing	52.50±2.67^{a}	62.40±3.12^{a}	63.50±2.95^{a}	1.00±0.01^{a}
Mechanical disruption (control, finely grated)	51.60±2.58^{b}	61.20±3.06^{b}	50.00±2.50^{b}	0.90±0.05^{b}
Mechanical disruption (control,coarsly grated)	45.90±2.09^{c}	60.00±3.00^{c}	42.50±2.13^{c}	0.70±0.04^{c}
PEF process	50.00±2.19^{d}	58.00±2.90^{c}	60.00±3.00^{d}	0.75±0.04^{d}
Thermal treatment (70 °C held for 15 min)	36.30±1.82^{e}	59.50±2.98^{c}	53.00±2.65^{e}	0.73±0.04^{e}

Protein and fat contents were calculated based on the initial contents of the coconut meat. Values with the same letter along the column are not significantly different while different letters imply significant difference at $p<0.05$.

Source: Ade-Omowaye et al. (2001b)

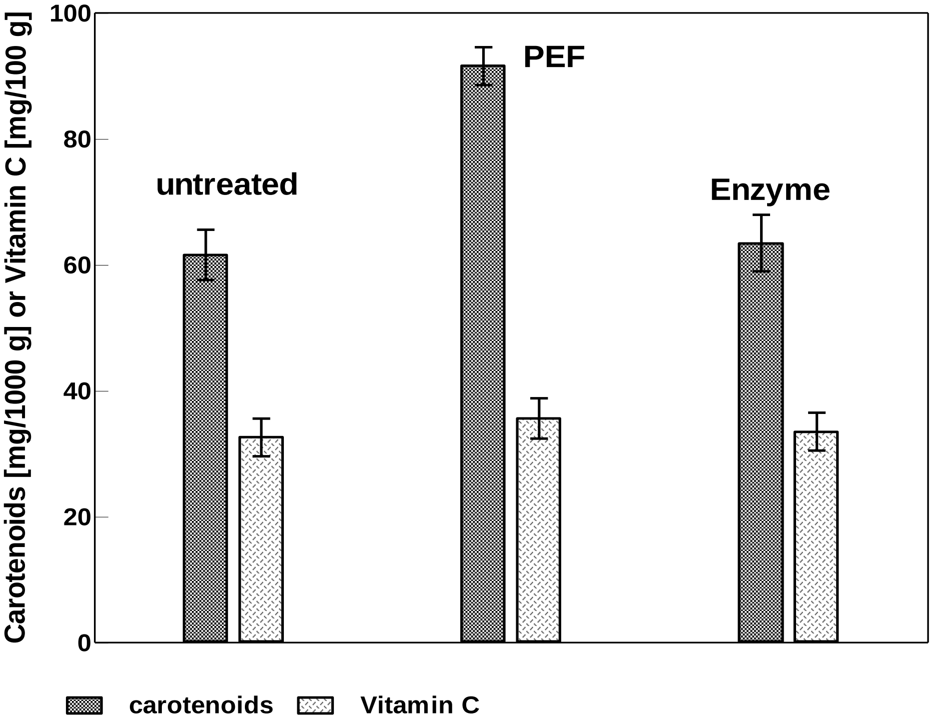


Figure 5: Influence of pre-treatment on beta-carotene and vitamin C in bell pepper juice.

Combined PEF and dehydration

Fruits and vegetables are important components of a healthy diet and are processed into a variety of products. Reduced fruit and vegetable consumption is linked to poor health and increased risk of non-communicable diseases. An estimated 6.7 million deaths worldwide were attributed to inadequate fruit and vegetable consumption in 2010 (Lim et al., 2012). Evidence indicates that fruits and vegetables consumed as part of the daily diet can help reduce the risk of coronary heart disease (Hartley et al., 2013; He et al., 2007), stroke (Hartley et al., 2013) and certain types of cancer (Boeing et al., 2012). Conventional dehydration may yield a dark colour product that has a leathery texture, poor flavour and significant nutrient reduction. Increasing consumer markets for minimally processed fruits and vegetables have prompted researchers to study various ‘combination processes’. The potential advantages of PEF with air or/and osmotic dehydration were extensively studied for their possible adoption in these processes. It is an efficient complimentary pre-processing step to thermal dehydration in the overall chain of integrated food processing. PEF has been reported to increase the permeability of plant cells (Knorr and Angesbach, 1998, Ade-Omowaye et al., 2002a). The increase in permeability of coconut and bell pepper tissues by PEF treatment resulted in improved mass transfer/reduced drying time comparable or better than other physical and chemical pre-treatments during fluidised bed drying (Table 3, Figures 6 and 7, Ade-Omowaye et al., 2001a and c).

High Pressure and PEF could be alternatives to chemical pre-treatments and could contribute to minimising environmental pollution from chemicals. Blanching of the pepper was also found to be effective as compared to these physical pre-treatments, but leaching and destruction of nutrients as well as environmental effects are considered to be major drawbacks of this conventional pre-treatment. This finding indicates that other feasible area of PEF application is in dehydration of plant foods in developing countries such as Nigeria. Drying, owing in part to sun prevalence in this region preserves majority of the agricultural produce in developing countries. This technique could be used as a complimentary step in the drying of food materials in developing nations.

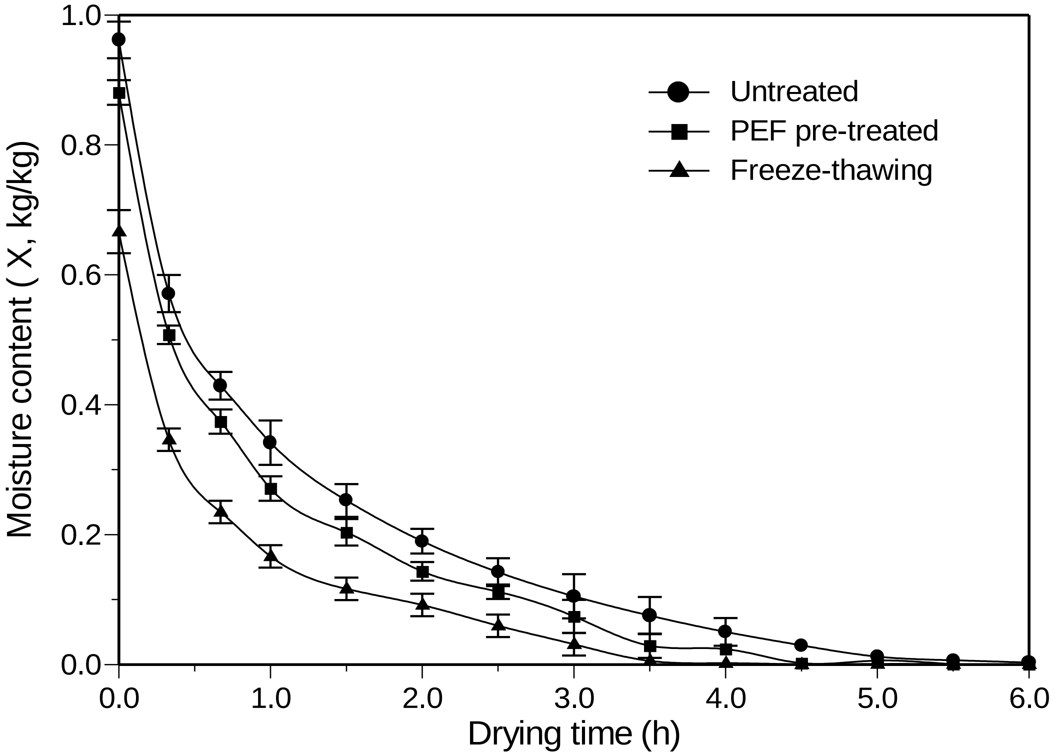


Figure 6: Air drying characteristics of pre-treated and centrifuged coconut cylinder pieces. Average initial moisture content of the samples was 52%. Source: Ade-Omowaye et al. (2001a)

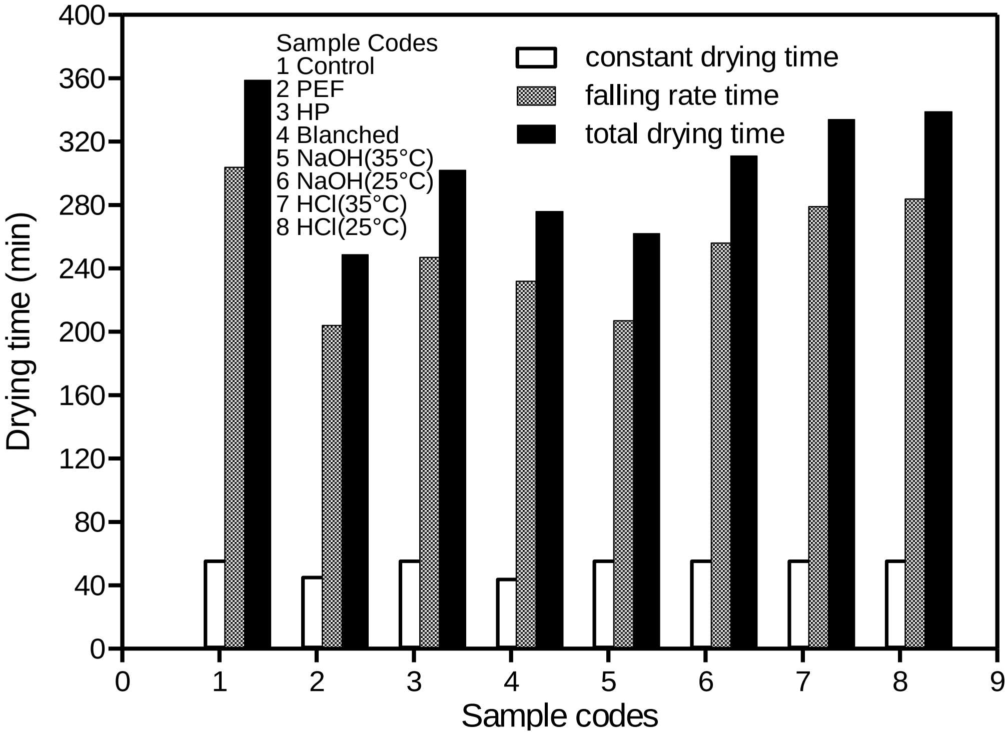


Fig. 7: Drying time during constant and falling rate period drying as well as total drying time for different pre-treatments. Drying time during falling rate period was calculated up to a moisture content 0.112 kg/kg ds for all the samples. Source: Ade-Omowaye et al. (2001b)

Table 3: Effect of various pre-treatments of pepper on drying rates, heat and mass transfer coefficients and cell disintegration indexes during its dehydration in a fluidised bed dryer at 60 °C

Pre-treatments	Critical moisture content (kg/kg ds)	Constant drying rate $R_{dc} \times 10^4$ (kg/m^2 s)	Heat transfer coefficient, h (W/m^2 K)	Mass transfer coefficient, k (kg/m^2 s)	Cell disintegration index, P_o
Control	6.10±0.20	9.68±0.15	73.13±0.10	0.043±0.005	0.00
Blanched	5.75±0.10[b]	13.20±0.21[b]	99.72±0.96[b]	0.059±0.007[b]	0.88±0.04
5% NaOH (25°C)	5.66±0.11[b]	11.03±0.31[b]	83.29±0.61[b]	0.049±0.008[b]	0.00
5% NaOH (35°C)	4.70±0.08[b]	12.25±0.13[b]	92.54±0.72[b]	0.054±0.003[b]	0.00
5% HCl (25°C)	6.09±0.10[a]	10.04±0.31[b]	75.81±0.55[b]	0.044±0.005[a]	0.00
5% HCl (35°C)	5.21±0.16[b]	10.50±0.45[b]	79.32±0.85[b]	0.047±0.002[b]	0.00
High pressure	5.18±0.13[b]	11.07±0.54[b]	83.61±0.78[b]	0.049±0.003[b]	0.58±0.02
PEF	5.16±0.05[b]	13.02±0.35[b]	98.36±0.93[b]	0.058±0.001[b]	0.61±0.03

[a] Insignificant difference to control at $p \le 0.05$.

[b] Significant difference to control at $p \le 0.05$.

Source: Ade-Omowaye et al. (2001b)

In recent years, osmotic dehydration (OD) has received considerable attention due to the low temperature and energy requirements in addition to better retention of the initial nutritional values in the final product (Taiwo et al., 2001a). Studies have reported that mass transfer kinetics during osmotic dehydration can be enhanced by pre-treating the fruit materials prior to osmotic dehydration. The influence of pre-treatments such as high pressure (HP) application on pineapples, blanching and calcium infiltration on apples, PEF application on carrots, and dehydrofreezing on apple and kiwi fruits on mass transfer kinetics have been reported (Rastogi et al., 1999).

In-depth studies were conducted on the effects of different conditions of PEF (varying field strengths and pulse numbers) and other pre-treatments prior to OD or/and air dehydration of apples, strawberry and bell peppers (Taiwo et al., 2001b; Ade-Omowaye et al., 2001d, 2002b, 2002c, 2003a, 2003b and Taiwo et al., 2003) to establish the potential advantages of PEF as a complementary step in the processing of fruits and vegetables. Minimally processed fruits and vegetables would offer good health benefit to man during off season and in non-growing countries. All the authors reported increased water loss (Figure 8, Table 4) with PEF treatment during OD, which was attributed to increases cell membrane permeability. The effect of PEF treatment on solid gain was found to be minimal. These findings suggested that solids uptake during OD may not necessarily be a function of permeabilised cells but also depends on the type of chemical and structural changes caused by pre-treatments. The authors concluded that the application of PEF is advantageous when moisture reduction and minimal alteration in product taste are desired due to minimal solid uptake. These studies and several others have shown that optimum membrane permeabilization in plant foods between 1.5 and 3.0 kV/cm can be achieved with administration of 15-30 pulses. Conclusion was also made from part of the studies that PEF treatment was a better alternative than thermal treatment which could lead to tissue softening or discolouration. Natural antioxidants (vitamin C and beta carotene) were better retained in PEF pretreated and osmotically treated samples (Figure 9). PEF could therefore be successfully used to enhance rate of unit operations such as OD and conventional dehydration yielding products with better nutrients and natural antioxidants which could be termed healthy food. PEF adoption in Nigeria may provide a sustainable intervention to the yearly losses of our tropical fruits and vegetables and contribute significantly to reducing the burden of health care.

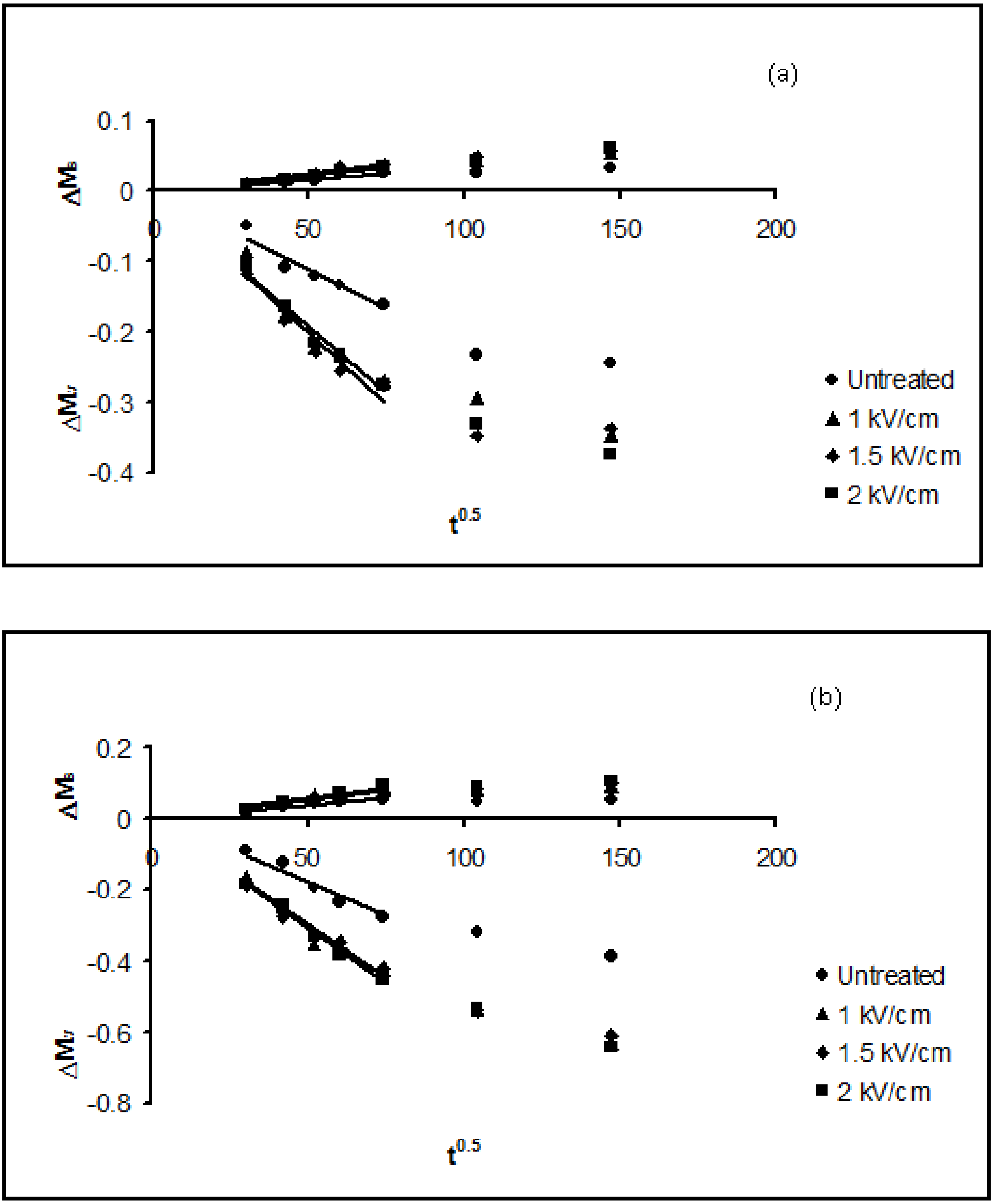


Figure 8: Water loss and solids gain as affected by field strengths during osmotic dehydration of bell peppers in (a) sucrose/sodium chloride and (b) sucrose (50°Brix) osmotic solutions.

Table 4: Influence of field strength on transfer rates of bell peppers during osmotic dehydration in two types of osmotic solutions

Samples	Osmotic solution	$K_w *10^3$ (kg/kg $s^{0.5}$)	R^2	$K_s *10^4$ (kg/kg $s^{0.5}$)	R^2	D_e*10^{10} (m^2/s)	R^2
Treatment I							
Untreated	Sucrose/NaCl	-2.2 ± 0.08^{a}	0.924	3.0 ± 0.08^{a}	0.917	2.32 ± 0.05^{a}	0.948
1.0 kV/cm	Sucrose/NaCl	-3.8 ± 0.13^{b}	0.906	4.0 ± 0.06^{b}	0.919	6.79 ± 0.08^{b}	0.920
1.5 kV/cm	Sucrose/NaCl	-4.0 ± 0.06^{b}	0.909	5.0 ± 0.19^{c}	0.900	7.01 ± 0.09^{c}	0.901
2.0 kV/cm	Sucrose/NaCl	-3.9 ± 0.08^{b}	0.974	5.0 ± 0.13^{c}	0.907	7.01 ± 0.07^{c}	0.906
Treatment II							
Untreated	50°Brix sucrose	-3.6 ± 0.13^{d}	0.939	8.0 ± 0.13^{d}	0.962	1.35 ± 0.07^{d}	0.911
1.0 kV/cm	50°Brix sucrose	-6.0 ± 0.06^{e}	0.942	12.0 ± 0.14^{e}	0.908	3.30 ± 0.06^{e}	0.911
1.5 kV/cm	50°Brix sucrose	-6.0 ± 0.10^{e}	0.940	11.0 ± 0.17^{f}	0.939	3.44 ± 0.08^{ef}	0.973
2.0 kV/cm	50°Brix sucrose	-6.2 ± 0.06^{f}	0.986	11.0 ± 0.12^{f}	0.912	$3.57\pm0.0.9^{f}$	0.900

Means with the same letter along the columns within each treatment are not $p\geq0.05$ different while those with different letters are $p\geq0.05$ different.

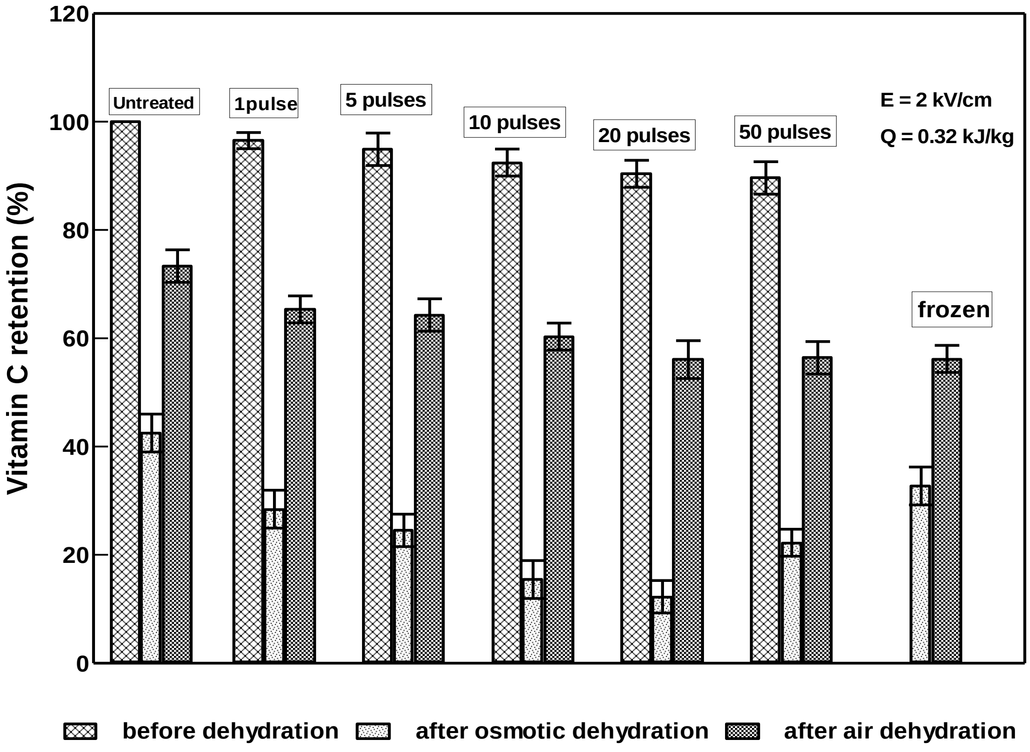


Figure 9: Vitamin C retention of PEF and pre-frozen pepper samples before and after osmotic and air dehydration

Underutilized Crops

Nomenclatures such as “Minor, Orphan, Under-researched, Forgotten or Indigenous” are used in literature for describing “Underutilized Crops” (Mayes et al., 2012; Dansi et al., 2012). These crops are perceived as crops species that had either received microscopic research considerations over time or grossly flouted by stakeholders in Agriculture such as Agricultural Researchers, Plant Breeders and Policymakers (Padulosi et al., 2013). A comprehensive portrayal of underutilized crops was given by Gruère et al., (2006) which regarded underutilized crops as plant species that; are locally abundant relative to globally abundances; the local cultivators possessed only adequate pragmatic knowledge of these species of plants but they are devoid of scientific knowledge relating to plant characteristics such as agronomic, ecological and physiology and have limited use compared to its economic sustainability.

The under-exploration of these set of crops tagged forgotten crops is majorly traceable to agronomic (subsistence level of production) and non-agronomic (social and economic) justification (Baa-Poku, 2018). A survey on undernourishment in sub-Saharan African countries alone revealed that about two hundred and thirty-seven million people are undernourished while on the global scale, about eight hundred and twenty-one million people are undernourished (Uarrota et al., 2019; FAO, 2018), by inference the level of hunger and chronic food insecurity is on the exponential increase.

Also, it is pertinent to bring to mind that by 2050, the world population is expected to be 9.9 billion. Going by this projection, 70% anticipated increase in food production was envisioned to meet the expected food demand (World Population Data Sheet, 2018; Uarrota et al., 2019). A painstaking assessment of the foregoing statistical figures showed that reliance on common staple food crops is on the verge of reaching its limits coupled with recent unpredictable harsh global climate change. These statistical figures are therefore a pointer foreshadowing the necessity to harness the hidden potentials embedded in underutilized crops, if the goal of provision of healthy food for all is to be achieved.

Potentials of Underutilized Crops as Healthy Foods

Over the last few decades, several researchers had attempted to research the hidden potentials embedded in underutilized crops not only to combat rising tide of hunger but also to provide healthy foods both for the rural dwellers as well as for all and sundry. The salient potentials of these orphan crops is far-reaching ranging from dietary diversification reinforcement, micronutrient intake improvement, soil health enhancement, fewer agricultural enhancement inputs like chemical fertilizers and irrigation to proven climate change resiliency (FAO, 2018). A comprehensive detail of these hidden potentials is thus itemized in this session.

Underutilized crops are cheaper means of ensuring better nutrition; most of these neglected local crops are endowed with superior nutrients and mineral content which are affordable, accessible and a cheaper means of diet diversification (Jaenicke, 2013). Several research discoveries had shown that the nutritional paybacks of these crops are comparatively better than those crops that are well-researched. For instance, the work of Idowu (2013) showed that walnut (*Juglans* spp.) seeds are highly protein-endowed coupled with about 15 and 60% oil content. Similarly, FAO (1996) also reported that cocoyam (*Colocasia* spp.) has its tubers to be highly rich in carbohydrate content. In addition, some varieties of wild and cultivated home-grown green leafy vegetables and fruits like African star apple (*Chrysophyllum albidum*), Bush mango (*Irvingia gabonensis*), *Amaranthus cruentus*, water leaf (*Talinum triangulare*), Lagos spinach (*Celosia argentea*), jute mallow (*Corchorus olitorius*), African eggplant (*Solanum aethiopicum*), bitter leaf (*Vernonia amygdalin*) and leaves of baobab tree (*Adansonia digitata*) have been researched and confirmed to possess substantial horticultural and nutritional values which are cheaper alternative means of supplementing the diet of hundreds of millions of rural dwellers most especially when their more common sources are either extremely scarce or absolutely inaccessible (Aworh, 2014; Guarino, 1995; Schippers and Budd, 1997). Needless to re-emphasize that enhanced utilization of these set of crop species is a cheaper, accessible and affordable means of ensuring better nutrition and combating hunger on the global scale (Idowu, 2013). Tables 5 and 6 give a summary of the nutritional profile of some underutilized commodities in Nigeria.

It is a means of enhancing villagers' income generation: they are known to provide a sort of sustainable income for the rural dwellers since time immemorial, although their production is more of household concern. A good example is bitter kola. According to Kabuye (1998), the production of bitter kola has been a huge financial relief to several farming households. Income realized from the sale of bitter kola nuts have enabled them to meet up with several expenses ranging from payment of children fees to social financial obligations among others, most especially during the non-cash crop season. Another good source of income though neglected is bambara groundnut, according to Muhammad (2014), bambara groundnut is extremely rich in protein and minerals in relation to many of these well-researched leguminous crops. Other orphan legumes like *Acacia* senegal*,* *Mallotus subulatus Sphenostylis sterocarpa,* and Gum Arabic are known to have better potentials for improving farmers income at a sustainable level (Sprent et al., 2009; Ade-Omowaye et al., 2015).

Agro-ecologies adaptability is another viable potential of underutilized crops. They are not only nutrient dense but also offer enviable prospects in marginal production areas. They are known to be drought and heat stress tolerant, pests and diseases resilient, and they are well equipped to thrive in semiarid and arid habitat and as a matter of fact they are good alternative for diversifying human diets and combating micronutrient deficiencies in poor rural societies (Padulosi and Hoeschle-Zeledon, 2004; Mabhaudhi et al., 2017). For instance, cowpea flour has been established to be good supplement for additional vitamin A and zinc in cereal-based weaning foods while its pod, grain and leaf is rich in carotenoids like lutein, β-carotene, γ-carotene, and cryptoxanthin (Hashim and Pongjata 2000; Sinha and Kawatra. 2003; Padulosi and Hoeschle-Zeledon, 2004; Ojwang et al., 2013; Mabhaudhi et al., 2017). Also, pearl and small millet alongside with sorghum have been reported to be tolerant to drought, high temperature and low soil fertility. They flourish with appreciable yield even with poor and marginal soil. Sorghum can withstand water logging condition (Taylor, 2015).

Underutilized crops form bulk of the integral part of local culture, their proliferation in local food preparations signalled a means to resuscitate culinary customs; they have enthralling merits over some of the well–researched staple crops. Aside the fact that some of these crops have distinctive coping strategies to nerve-wrecking conditions, they are means of minimizing environmental sordidness since they require less agricultural inputs such as organic fertilizers, irrigation and sophisticated biological approaches to get them cultivated. A good example of such is ginger and damar (Hellin and Higman, 2009; de Foresta et al., 2004; Massawe et al., 2015). Several of these underutilized crops are known for keeping track of cultural diversity in line with village food habits, local health practices, traditional/religious customs and social interactions (Salvi, 2016).

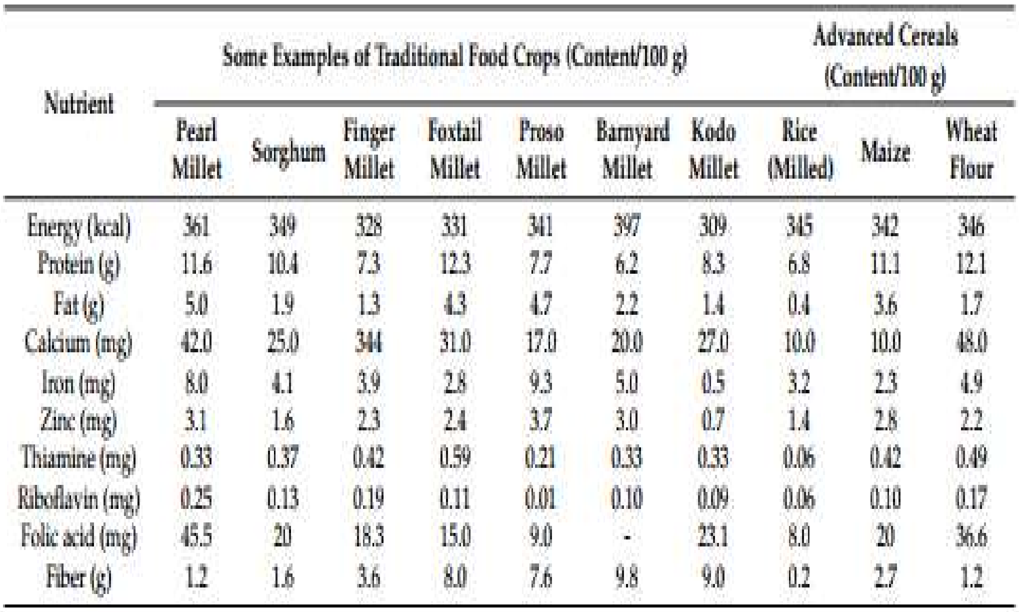
Another noteworthy potential of orphan crops is medicinal usage; some of these neglected crops are of good medicinal use most especially within local communities due to the inability of rural dwellers to be able to afford and access advance health drugs to cure their illnesses. According to Hasan et al., (2010), Aonla plant has been found to be useful in curing insomnia, scurvy, haemorrhage and leucorrhoea. It can as well slow down the ageing process being a good anti-oxidant agent. Also, in line with the research findings of Iyer et al. (2009) aonla plant is a good stimulant of insulin hormone and very effective for reducing blood sugar in patient suffering from diabetes.

Table 5: Nutrient composition of selected underutilized vegetables in Nigeria

Vegetable	Moisture (%)	CHO (%)	CF (%)	Protein (%)	Fat (%)	Ash (%)	K (mg%)	P (mg%)	Ca (mg%)	Na (mg%)	Fe (mg%)	Vit C (mg%)
Solanum aethiopicum	89.3	4.1	3.0	2.2	0.5	0.9	483	38	378	217	18	26
Adansonia digitata leaf	76.7	9.2	7.2	3.5	0.5	2.8	391	85	313	6	3.9	47
Vernonia amygdalina	82.8	5.5	5.1	4.4	0.6	1.6	437	67	162	6	2.8	27
Telfairia occidentalis	80.0	10.5	1.7	6.1	0.6	1.7	154	20	75	68	9.6	129
Gnetum africanum	83.8	6.7	4.0	3.2	1.9	0.4	-	-	128	-	2.7	56
Corchorus olitorius	80.2	6.5	3.4	7.3	0.2	2.4	480	78	291	83	5.7	78
Celosia argentea	87.6	-	-	3.2	0.3	2.7	476	35	188	240	13.2	26
Hibiscus sabdariffa calyx	86.7	8.9	1.3	2.0	0.3	0.8	276	15	195	10	4.7	30
Hibiscus sabdariffa leaf	86.7	4.1	5.0	2.8	0.2	1.2	437	65	212	6	4.1	33
Amaranthus cruentus	85.0	6.0	2.1	3.4	0.4	3.1	208	26	136	92	6.4	56
Talinum triangulare	91.2	2.9	0.9	1.9	0.1	3.0	143	26	193	89	3.2	22

(Source: Aworh, 2015)

Table 6**:** The nutrient profile of some underutilized crops



Nutrient	Some Examples of Traditional Food Crops (Content/100 g)							Advanced Cereals (Content/100 g)		
	Pearl Millet	Sorghum	Finger Millet	Foxtail Millet	Proso Millet	Barnyard Millet	Kodo Millet	Rice (Milled)	Maize	Wheat Flour
Energy (kcal)	361	349	328	331	341	397	309	345	342	346
Protein (g)	11.6	10.4	7.3	12.3	7.7	6.2	8.3	6.8	11.1	12.1
Fat (g)	5.0	1.9	1.3	4.3	4.7	2.2	1.4	0.4	3.6	1.7
Calcium (mg)	42.0	25.0	344	31.0	17.0	20.0	27.0	10.0	10.0	48.0
Iron (mg)	8.0	4.1	3.9	2.8	9.3	5.0	0.5	3.2	2.3	4.9
Zinc (mg)	3.1	1.6	2.3	2.4	3.7	3.0	0.7	1.4	2.8	2.2
Thiamine (mg)	0.33	0.37	0.42	0.59	0.21	0.33	0.33	0.06	0.42	0.49
Riboflavin (mg)	0.25	0.13	0.19	0.11	0.01	0.10	0.09	0.06	0.10	0.17
Folic acid (mg)	45.5	20	18.3	15.0	9.0	-	23.1	8.0	20	36.6
Fiber (g)	1.2	1.6	3.6	8.0	7.6	9.8	9.0	0.2	2.7	1.2

Source: Adhikari *et al.*(2017) and Gopalan *et al*. (1989).

Product Development from Underutilized Crops as Potential Healthy Food

Complementary Food

Mr Vice Chancellor, Sir, several underutilized crops such as legumes, okra seeds, tigernuts and others were studied for their suitability in food product developments ranging from complementary food for young children to flour for swallow for adults. Complementary foods are needed to supplement nutrients supplied by breast feeding of growing children. The traditional complementary foods fed to children in Nigeria are nutritionally inadequate as they are lacking in one nutrient or the other resulting in malnutrition. In Nigeria and most other developing countries, commercial complementary foods of excellent quality are either imported or produced locally and are being sold at exorbitant prices; which are beyond the reach of many low income earning and unemployed nursing mothers. In view of the nutritional requirements of infants and young children coupled with relatively high cost of available commercial complementary foods in developing nations like Nigeria, several strategies have been used to formulate complementary foods. These include combination of locally available raw materials that complement each other in such a way that they provide the recommended daily allowance for these children (Akinsola, 2017; Ijarotimi and Bakare, 2006). Concerted efforts have been geared towards generating more data on the feasibility of using the locally available and nutritious commodities in the development of traditional complementary foods of high nutrients density and good functional properties. Our studies have established optimal formulation ingredients for complementary food from Orange Fleshed Sweetpotato (OFSP), African Yam Bean (AYB) and pearl millet using a simple and adaptable technology (Idowu et al., 2019). The developed complementary food could meet the minimum standards of macro and micronutrient requirements for growing children. The total energy is within the acceptable recommended allowance. The complementary food had acceptable sensory attributes which were comparable to *Cerelac*, a commercial complementary food available in the Nigerian market. Our findings further confirm the feasibility of producing affordable and nutritious complementary food from locally available commodities which will have positive impact on the nation's economy and contribute notably to reducing nutrition insecurity prevalent in the rural areas. The product could be used as an alternative to traditional or expensive commercial complementary foods for young children.

Novel Snacks

The potentials of *Pleurotus tubberegium* (Plate 5, underutilised mushrooms) and OFSP (Plate 6) in the formulation of novel snacks were demonstrated in different studies. Mushrooms are good sources of biological active agents (Jonathan and Fasidi, 2003), which aid specific body functions in addition to being nutritious. The protein content of mushrooms has been reported to be twice that of vegetables and four times that of oranges (Bano, 1993) and significantly higher than that of wheat (Aletor, 1995). The protein in this type of mushroom is of high quality in terms of the amino acid content (Akindahunsi and Oyetayo, 2006). Amino acids play important roles in the health of man. Arginine for instance, ameliorates obesity, hyperglycemia, dyslipidemia, hypertension, cardiovascular dysfunction, and other problems of metabolic syndrome in humans and animals while enhancing milk production, mitochondrial biogenesis, growth of brown adipose tissue, wound healing, muscular strength and glycolysis, and spermatogenesis (Mateo *et al*., 2007; Doppenberg *et al*., 2010; Mateo *et al*., 2008).

Mushrooms are good sources of vitamins which include vitamins C, B_1 B_2 B_3 and D (Bano and Rajarathnam, 1988). High concentrations of minerals in *Pleurotus tubberegium* is worthy of note since certain inorganic mineral elements (K, Zn, Ca, Mn, Fe, etc) play important roles in the maintenance of normal glucose tolerance and in the release of insulin from beta cells of *islets of langerhans* (Agomuo, 2011). The iron content (5.02 mg/100g) obtained from the tuber of this mushroom could provide sufficient iron that meets the recommended daily allowance (RDA) for school age children (Ijeh *et al.*, 2009).

Pleurotus tubberegium also contains bioactive polysaccharides and could be considered as a nutritional supplement to treat diabetic complications (Huang *et al.*, 2014). It has been demonstrated that it has anti-hyperglycemic, antihyperlipidemic, hepato-protective, anti-breast cancer and antioxidant properties (Cheung and Lee, 2000; Tao *et al.*, 2006; Zhang, *et al.*, 2006). Interestingly, sclerotium has been reported to contain some compounds with antioxidant properties such as phenols, saponins (Dini *et al.*, 2009), ascorbic acid, tocopherols and storage proteins (Hou *et al.*, 2005) that have been identified with antioxidant properties. Several works of great importance have been done on *pleurotus tubberegium*. These include studies showing its potential contributions to nutrition and health (Adebayo-Tayo *et al.*, 2009; Adedayo *et al.*, 2010; Corey *et al.*, 2013; Afieroho and Ugoeze, 2014).

The steady increase in the consumption of snacks by almost all groups of people in Nigeria and beyond motivated us to develop nutrient dense/novel snacks for health improvement in different studies on the production of chin chin and cookies from *Pleurotus tubberegium* and Orange Fleshed Sweet Potato (OFSP) (Kolawole *et al.*, 2018a; Kolawole *et al.*, 2018b***)***. The nutritional composition of both the raw flours and the snacks produced from the blends were evaluated (Tables 7-10). In all the minerals and vitamins analyzed, it was found that the OFSP-sclerotium flour samples were higher than the control (wheat flour) as presented in Tables 8 and 10, respectively. Except for calcium and potassium contents, the levels of the minerals of the OFSP-sclerotium flour samples increased with increased sclerotium inclusion.

Plate 5: *Pleurotus tuberregium* sclerotium

Plate 6: Pictorial view of Orange fleshed sweet potato (OFSP)

The result of this study showed a general increase in the nutritional composition of the samples produced. Sclerotium/OFSP cookies (Plate 7) gave the best results with highest quantity of all amino acids studied except glutamic acid and proline where wheat had the highest contents (Table 10). The increasing antioxidant activity observed in OFSP samples with increasing sclerotium substitution despite the relatively lower β carotene and total phenol contents of sclerotium could be attributed to some of the antioxidant property of other components in sclerotium. Sclerotium has been noted to be rich in non-starch polysaccharides, mainly bioactive β-glucans (Tao *et al*., 2006) that have been reported to contain significant strong antioxidant potency that could be exploited as effective natural antioxidant to manage oxidative stress (Wasser, 2002).

The inclusion of sclerotium of *P. tuberregium* flour in the production of cookies and chin-chin (Plate 8) increased the chemical and phytochemical qualities of the snacks. Low protein and amino acids contents associated with OFSP had been improved in these snacks and the high phytochemical component of OFSP had also been complemented with the high antioxidant activity of sclerotium. These snacks (developed cookies and chin-chin) are not junks as popularly believed. Based on the result of this study, the consumption of these sclerotium enriched snacks (cookies and chin-chin) should be introduced into the dietary pattern of children as in-between meals and for adults as well.

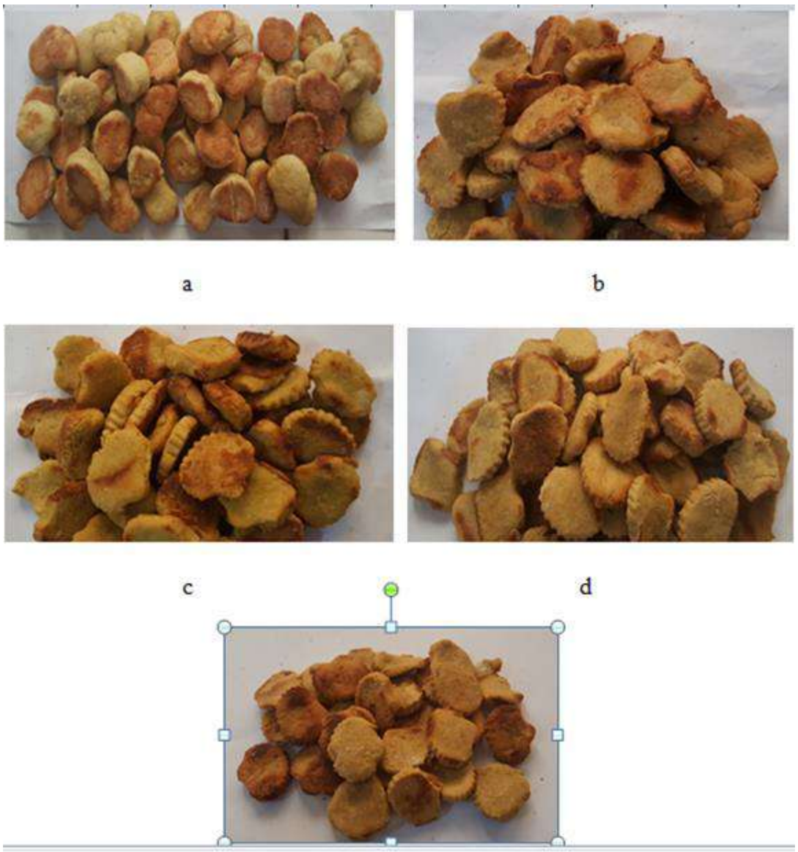


Plate 7: Pictorial view of (a) 100% wheat cookies (b) 90:10 OFSP sclerotium cookies (c) 80:20 OFSP sclerotium cookies (d) 70:30 OFSP sclerotium cookies (e) 100% OFSP cookies

Table 7: Amino acid composition (mg/100g of protein) of flour samples

Amino Acid	$W_{(control)}$	YS_1	YS_2	YS_3	Y	S
Isoleucine	3.32 ± 0.29^{c}	3.66 ± 0.39^{c}	5.71 ± 0.52^{b}	6.78 ± 0.32^{b}	1.11 ± 0.29^{d}	21.67 ± 1.36^{a}
Leucine	10.65 ± 0.37^{b}	6.85 ± 0.35^{c}	7.96 ± 0.73^{c}	10.98 ± 0.58^{b}	3.12 ± 0.69^{d}	31.34 ± 0.80^{a}
Methionine	0.95 ± 0.22^{bc}	0.25 ± 0.09^{d}	0.49 ± 0.14^{cd}	0.61 ± 0.13^{cd}	0.20 ± 0.11^{d}	1.43 ± 0.37^{ab}
Cystine	1.36 ± 0.22^{c}	1.14 ± 0.06^{d}	1.50 ± 0.16^{bc}	1.86 ± 0.06^{b}	0.95 ± 0.06^{e}	6.21 ± 0.13^{a}
Tyrosine	2.78 ± 0.09^{cd}	3.03 ± 0.16^{cd}	3.41 ± 0.24^{bc}	3.99 ± 0.14^{b}	2.45 ± 0.18^{d}	5.94 ± 0.37^{a}
Phenylalanin	2.96 ± 0.19^{e}	3.71 ± 0.27^{c}	5.17 ± 0.42^{bc}	7.15 ± 0.27^{b}	2.65 ± 0.44^{d}	29.74 ± 2.30^{a}
Threonine	4.10 ± 0.24^{de}	5.38 ± 0.34^{cd}	6.72 ± 0.51^{c}	8.92 ± 0.89^{b}	3.69 ± 0.23^{e}	21.33 ± 0.73^{a}
Tryptophan	BDL	BDL	BDL	BDL	BDL	BDL
Valine	4.11 ± 0.25^{e}	6.08 ± 0.83^{d}	8.87 ± 0.36^{c}	10.93 ± 0.03^{b}	2.69 ± 0.18^{e}	31.92 ± 1.54^{a}
Lysine	2.75 ± 0.15^{e}	4.71 ± 0.15^{c}	5.16 ± 0.26^{c}	7.50 ± 0.07^{b}	3.66 ± 0.87^{cd}	20.95 ± 0.83^{a}
Aspartic	7.47 ± 0.42^{e}	12.94 ± 0.34^{c}	13.93 ± 0.47^{c}	15.49 ± 0.81^{b}	11.82 ± 0.35^{d}	18.64 ± 0.75^{a}
Glutamic	37.73 ± 1.05^{b}	8.10 ± 1.29^{e}	13.75 ± 1.52^{d}	22.16 ± 1.40^{c}	4.27 ± 0.30^{e}	54.35 ± 3.32^{a}
Alanine	5.31 ± 0.32^{c}	4.07 ± 0.61^{d}	6.18 ± 0.36^{c}	8.49 ± 0.46^{b}	2.16 ± 0.30^{e}	22.92 ± 0.12^{a}
Arginine	4.79 ± 0.48^{c}	3.85 ± 0.78^{cd}	4.36 ± 0.46^{cd}	6.90 ± 0.25^{b}	3.34 ± 0.31^{d}	15.13 ± 0.28^{a}
Glycine	3.85 ± 0.26^{a}	1.39 ± 0.33^{c}	1.66 ± 0.36^{bc}	1.83 ± 0.17^{bc}	1.34 ± 0.20^{c}	3.93 ± 0.37^{a}
Histidine	3.20 ± 0.58^{c}	3.15 ± 0.25^{c}	4.60 ± 0.41^{b}	4.98 ± 0.19^{b}	2.68 ± 0.09^{c}	10.69 ± 0.35^{a}
Proline	10.45 ± 0.38^{a}	1.38 ± 0.32^{cd}	1.76 ± 0.44^{cd}	2.11 ± 0.40^{bc}	1.11 ± 0.30^{d}	3.56 ± 0.36^{b}
Serine	5.17 ± 0.44^{b}	2.24 ± 0.36^{d}	2.75 ± 0.45^{cd}	3.42 ± 0.36^{c}	1.82 ± 0.19^{d}	7.60 ± 0.43^{a}

Mean values with different letters in each column are significantly ($p<0.05$) different from one another. Keywords: WK-100% Wheat flour; YSK_1- 90/10 OFSP/Sclerotium flour; YSK_2-80/20 OFSP/Sclerotium flour; YSK_3-70/30 OFSP/Sclerotium flour; YK-100% OFSP flour; BDL -Below detectable limit

Table 8: Antioxidant activity of cookies samples

Sample	%
WK	6.27 ± 0.05^{c}
YSK_1	17.24 ± 0.04^{ab}
YSK_2	18.19 ± 0.08^{ab}
YSK_3	19.55 ± 0.09^{a}
YK	15.58 ± 0.19^{b}

Mean values with different letters in each column are significantly ($p<0.05$) different from one another. Keywords: WK -100% Wheat cookies; YSK_1 -90/10 OFSP/Sclerotium cookies YSK_2 -80/20 OFSP/Sclerotium cookies; YSK_3-70/30 OFSP/Sclerotium cookies; YK-100% OFSP cookies

Table 9: Vitamin contents (mg/100g) of cookies samples

Sample	Thiamine	Ascorbic acid	Niacin	Pyridoxine	Riboflavin
WK	0.01 ± 0.00^{d}	3.50 ± 0.12^{a}	2.80 ± 0.12^{a}	7.50 ± 0.15^{b}	3.80 ± 0.12^{ab}
YSK_1	0.40 ± 0.01^{b}	3.60 ± 0.06^{a}	2.90 ± 0.06^{a}	7.60 ± 0.25^{b}	3.30 ± 0.20^{b}
YSK_2	0.57 ± 0.06^{a}	3.60 ± 0.10^{a}	2.80 ± 0.10^{a}	7.90 ± 0.50^{ab}	3.50 ± 0.69^{ab}
YSK_3	0.60 ± 0.02^{a}	4.80 ± 0.12^{a}	2.90 ± 0.06^{a}	8.50 ± 0.12^{a}	4.30 ± 0.10^{a}
YK	0.22 ± 0.00^{c}	3.60 ± 0.10^{a}	2.90 ± 0.06^{a}	7.30 ± 0.10^{b}	3.20 ± 0.10^{b}

Mean values with different letters in each column are significantly ($p<0.05$) different from one another. Keywords: WK -100% Wheat cookies; YSK_1 -90/10 OFSP/Sclerotium cookies YSK_2 -80/20 OFSP/Sclerotium cookies; YSK_3-70/30 OFSP/Sclerotium cookies; YK-100% OFSP cookies

Plate 8: Pictorial view (a)100% wheat chin-chin (b) 90:10 wheat chin-chin (c) 80:20 wheat chin-chin (d) 70:30 wheat chin-chin sample (e) 100% chin-chin

Table 10: Mineral content (mg/100g) of chin chin samples

Sample	Ca	Cu	Fe	K	Mg	Na	Zn
WC	176.88±1.19^{e}	0.65±0.03^{b}	22.63±0.15^{e}	37.26±0.04^{e}	42.44±0.03^{e}	33.05±0.05^{c}	3.66±0.02^{d}
YSC$_1$	287.65±0.09^{b}	1.08±0.09^{a}	27.30±0.03^{c}	208.02±0.02^{a}	60.19±0.03^{c}	47.23±0.17^{a}	4.22±0.00^{c}
YSC$_2$	278.63±0.03^{c}	1.11±0.08^{a}	28.67±0.04^{b}	191.41±0.04^{b}	61.73±0.30^{b}	47.96±0.04^{a}	4.55±0.05^{b}
YSC$_3$	253.68±0.11^{d}	1.20 ±0.02^{a}	29.19±0.07^{a}	184.42±0.07^{d}	64.53±0.79^{a}	48.07±0.04^{a}	4.77±0.03^{a}
YC	291.50±0.08^{a}	0.51±0.09^{b}	26.60±0.13^{d}	190.17±0.04^{c}	51.66±0.03^{d}	34.00±0.43^{b}	4.14±0.03^{c}

Mean values with different letters in each column are significantly ($p<0.05$) different from one another. Keywords : WK -100% Wheat chin-chin; YSK1-90/10 OFSP/Sclerotium chin-chin; YSK2-80/20 OFSP/Sclerotium chin-chin; YSK3-70/30 OFSP/Sclerotium chin-chin; YK-100% OFSP chin-chin

Recently, there is a growing interest in the use of alternative protein sources such as edible insects for humans to meet their protein demand as the world population skyrockets. The use of insects as human food, especially by indigenous people in the third world countries is well documented. Nigeria also has its own share of edible insects and caterpillars distributed across the various zones in the country. These are usually gathered from bushes and farmland by women and children, and are processed and eaten or sold in some local markets. Cultures in Nigeria are highly variable and these affect the consumption of the insects which vary from active avoidance to occasional and substantial consumption (Alamu et al., 2013). Edible insects are rich in good protein, good fat, vitamins and minerals which could support human nutritional need.

The increased awareness of consumers on the relationship between diet and health has prompted researchers to study the potentials of antioxidants rich plant material such as fruits, vegetables and fruit peels in snack production. Lemon peel has been shown to be packed with beneficial nutrients such as vitamins, minerals and fibre, and each of them offers a range of health benefits. Lemon peel has been reported to be rich in antioxidants and compounds which could help human bodies fight against chronic diseases (Stanway and Penny, 2016).

These unconventional materials (edible caterpillar and lemon peels) have also been variously studied and still being studied for their suitability in producing healthy snacks (biscuit, cookies and chin chin) (Ade-Omowaye and others, Unpublished M.Tech. data).

Our findings have demonstrated that healthy and acceptable snacks could be developed from these unconventional raw materials thus widening their utilization, enlarging the list of available healthy food for all ages, increasing the livelihood of smallholder farmers and creating employment for the jobless.

These snacks (biscuit, cookies and chin-chin) are not junks as popularly believed. The snacks could be included in school feeding programmes and adults would also benefit immensely from its consumption.

Nutrient Enriched Bread

Consumer interest in dietary fibre has continued to increase as more information about its potential impact on health has become available. Against this background a study was conducted with the aim of widening tigernut (an underutilized crop) utilization in the country, on its possible application in baking industry because of its high level of dietary fibre and other inherent properties. Substituted wheat flour (WF) with tigernut flour (TF) at varying proportions (100:0; 90:10; 80:20; 70:30; 60:40; 50:50) was evaluated for proximate composition and physico-chemical properties. Physico-chemical properties of dough as well as sensory and physical properties of the bread produced from the different flour samples were also evaluated.

Inclusion of tigernut flour in wheat flour at levels of 10 to 50% resulted in notable increase in fibre and ash contents while protein content decreased. The significant increase in the fibre content (167 to 967%) could be nutritionally advantageous in Nigeria, where white bread is one of commonest staples among all classes of people. Evaluation of the viscoelastic properties of dough from the composite flour, physical and sensory properties of bread showed that 10% wheat flour substitution with tigernut flour yielded bread product that was similarly rated with that produced from pure wheat flour.

From the result of this study, it could be suggested that tigernut either as defatted or full fat flour might find useful application in the Nigerian baking industry (Ade-Omowaye et al., 2008). Tigernut, an under-utilized crop, demonstrated to be high in dietary fibre content, could be an ingredient in fibre-rich food products which may be effective in the treatment and prevention of many diseases including colon cancer, coronary heart diseases, obesity, diabetes and gastrointestinal diseases (Anderson et al., 1994). Report has also shown that the protein in tigernut is of high biological value considering the many essential amino acids it contains (Ojobe and Tempo, 1983).

Baking characteristics of two varieties of Orange Fleshed Sweetpotato (OFSP, mother's delight (MD) and KJ) were also studied for bread production from wheat–OFSP composite flour. A simplex lattice design under the mixture method was adopted to select the mixing ratios of composite flour from wheat and OFSP flour. The minimum and maximum levels of wheat and OFSP flour were in the range of 70-100%, and 0-30%, respectively based on literature values. The design gave eight (8) experimental runs for the formulations, all yielding an aggregate of 100% each. The formulation of the composite flour was optimized by maximizing quality indices of interest and minimizing undesirable indices. Bread samples were produced from the optimized blends. Quality evaluation and storage studies on the product were carried out. Design expert software (version 6.0.8) was used for both the experimental design and data analysis. The following conclusions were made from the study: The optimized blends of wheat and OFSP were 83.75:16.25 and 79.75:20.25 (w/w, %) for MD and KJ, respectively. Enhanced nutrient and natural antioxidant (beta carotene) were recorded for the composite flour formulated from the two varieties of OFSP. Bread from KJ cultivar had higher protein, beta carotene and energy value than from the second variety. The bread had 71% of overall acceptability. The best packaging materials for the bread was opaque High Density Polyethylene for better conservation of its beta carotene content within 2-4 days. Consumption of KJ cultivar and its products should be promoted to enhance the health of its consumer (Olatunde, 2018, Unpublished PhD thesis).

Non-alcoholic Beverage for Health Promotion

A number of non-alcoholic beverages (NABs) has been produced in beverage industries where concentrates are used to produce the soft drinks. The consumption of such food items like carbonated drinks, highly sweetened drinks, has direct correlation with degenerative diseases such as cancer, hypertension, obesity, diabetes and coronary heart disease (Dada *et al*., 2007). Moreover, the raw materials for the production of most non-alcoholic beverages are not readily available in Nigeria, leading to foreign exchange drain due to the importation of the major ingredients. Indigenous beverages have been developed from plant materials mainly from sorghum stem sheath (SSS) and few others in order to minimize health related problems emanating from consumption of carbonated drinks and to eliminate chemical addition in its formulation. Considering the enormity of sorghum production in Nigeria and the insignificant utilization of sorghum stem sheath, finding practical and economic uses for the underutilized plant part will create an opportunity to build an agro-allied economy delivering sustainable economic growth with job creation and social cohesion as key outcomes. As a consequence of increasing the use of the hitherto underutilized stem sheath in Nigerian beverage production sector, the agro-allied economy will bring benefits in a number of areas by bringing more money to the farmers. The stem of sorghum plant is largely treated as a waste in Nigeria. This wastes which arises from an annual production of about 6 million tons is quite colossal (FAO, 1995). Most of the information available in the literature shows that the sorghum stem sheath is still largely confined to traditional use only. Hence the development of a proclaimed health drink from it as variously reported (Adetuyi et al., 2007; Adedeji et al., 2013, Adekanye et al. 2015; Ade-Omowaye et al., 2015) is a very welcome development. In order to improve human health and maximize the utilization of natural resources, we have conducted several studies to produce health promoting non-alcoholic beverages from SSS (Plate 9) and other plant materials. It is known that the human health depends on the quality of the consumed beverages (WHO, 2011).

Plate 9: A pictorial view of sorghum stem sheath

The following general conclusions were made from the various studies conducted on the non-alcoholic beverages formulated from sorghum stem sheath, roselle calyce and local spices either singly or in combination (Adekanye et al. 2018; Ade-Omowaye et al., 2015; Idowu, 2015; Adedeji et al., 2013): Sorghum stem sheath powder (Table 11) is a promising rich plant material that could be used in the formulation of functional foods as evidenced in its nutritional profile. The potential of sorghum stem sheath and local spices in formulating safe, nutritious and health promoting non-alcoholic beverage (Plate 10, Table 12) for human consumption was established. The antioxidant activities of the stem sheath were comparable and in some cases higher than in some fruits and vegetables. Combinations of roselle calyx, sorghum stem sheath, ginger and spices can be used to produce a health promoting drink of good quality. Antimicrobial activities of the added spices were established as the formulated beverages without synthetic preservatives could be stored for two weeks under ambient condition without spoilage.

In a similar study, a non-alcoholic healthy beverage was developed from tigernut seeds by subjecting the seeds to various pre-treatments (germination, pregelatinization and roasting) before processing into beverage (Ade-Omowaye et al., 2008). Sensory properties of the beverage produced from the untreated tigernut were comparable to those of soymilk in almost all the quality attributes evaluated. This observation suggests that tigernut beverage could serve as a good alternative to local beverages in Nigeria. Tigernuts can be processed into varieties of milk products which can be used by special people having milk allergies such as galactosemia and lactose intolerance. The potential of sour water, maize powder, mango, soybean, OFSP, and local spices in beverage making have also been established (Ade-Omowaye et al., 2006, Unpublished M.Tech. dissertation).

Table 11: Chemical Composition of Sorghum Stem Sheath Flour

Constituent	Value
Proximate composition (%)	
Protein	3.22±0.001
Moisture	6.56±0.000
Crude fat	8.36±0.000
Crude fibre	32.02.±0.000
Total ash	5.36±0.010
Mineral composition (mg/100g)	
Sodium (Na)	127.61±0.000
Potassium (K)	138.85±0.001
Calcium (Ca)	151.71±0.010
Magnesium (Mg)	185.31±0.000
Iron (Fe)	10.96±0.000
Copper (Cu)	0.44±0.001
Zinc (Zn)	7.16±0.001
Manganese (Mn)	2.83±0.010
Lead (Pb)	0.00±0.000
Vitamin C composition (mg/100g)	
Vitamin C(mg/100g)	1,107.33±0.010
Anti-oxidant properties	
DPPH (%)	3.83±0.001
Fe^{2+} chelation (%)	8.50±0.001
Total phenols (%)	1.30±0.001
Total carotenoids(mg/100g)	5.39±0.001
Anti-nutritional factors (mg/100g)	
Tannin	3.15±0.000
Phytate	2.31±0.000
Cyanide	1.69±0.000
Oxalate	0.64±0.001

Source: Adedeji et al. (2013)

Plate 10: Samples of non-alcoholic beverage from sorghum stem sheaths and local spices

Table 12: Anti-oxidant properties of the Non-alcoholic Beverage

Sample	**Vit. C (mg/100ml)**	**Total phenol (%)**	**Fe Chelation (%)**	**DPPH (%)**	**Carotenoids (mg/100ml)**
XK	415.40a	0.600c	3.105k	0.180k	5.68a
XA	495.90b	0.645k	4.250a	1.910a	2.75k
XB	493.80c	0.670j	4.175b	1.880b	3.92j
XC	491.50d	0.720i	4.020c	1.735c	4.10i
XD	389.80g	0.750h	3.830d	1.650d	4.39h
XE	387.40k	0.785g	3.700e	1.505e	4.57j
XF	438.30e	0.830f	3.660f	1.410f	4.72f
XG	435.20f	0.870f	3.580d	1.320j	4.91e
XH	432.60j	0.920d	3.310h	1.290h	5.06d
XI	429.00h	0.660c	3.200i	1.115i	5.29c
XJ	426.10i	0.635b	3.150j	1.070j	0.180k

Values with the same letter along the column are not significantly different at $p > 0.05$.Key words: XA: 0.5% ginger XB: 1.0% ginger XC: 1.5% ginger XD: 2.0% ginger XE: 2.5% ginger (G) XF: 0.5% alligator pepper (A.P.) XG: 1.0% alligator pepper XH: 1.5% alligator pepper XI: 2.0% alligator pepper XJ: 2.5% alligator pepper XK: control (without spice). Values are means of 4 determinations. Source: Adedeji et al. (2013)

Yam flour substitute

Yam Flour (*Elubo*) is used in the preparation of stiff porridge locally called *Amala*. Though an important staple food in western Nigeria, yam flour is more expensive than other locally produced flours (eg cassava flour) which limits its consumption to the middle and high income groups. Cassava flour is a cheaper alternative but is poor in protein. Sorghum forms one of the main staples in the diet of low-income families. Ade-Omowaye et al. (2003e) investigated the effect of different pre-treatments (germination, pregelatinization or fermentation) of sorghum prior to use in the composite mixed with cassava flour. The mixes were evaluated for water holding capacity (WHC), syneresis, gel strength and proximate composition. Comparison of the results were made with those obtained from either yam or cassava flour. All composite mixtures, except the malted sorghum-cassava mix produced stronger gels than cassava flour. The mixes had physical, nutritional and sensory properties comparable to yam flour and would add to the list of foods already existing from either sorghum or cassava with better nutritional values. It could be a cheap source of food for low income earners in Nigeria.

Underutilized Crops as Foods or Ingredients in Healthy Food Formulations

Underutilized legumes

To meet the expanding protein needs of the world population, the consumption of plant foods that contain appreciable quantities of protein is of paramount importance. Human consumption of legumes has been increasing in recent years since the seeds are regarded as a source of beneficial nutrients. In fact they are recommended as health-promoting foods by health organizations and dieticians (Ojo *et al*, 2017a, Ojo *et al*, 2017b). Legumes are a useful component of balanced diets. They reduce the incidences of cardiovascular diseases (CVD), cancers and type II diabetes which are believed to be partly associated with food habits. Legumes are low in fat and are rich sources of protein, fibre, and minerals. They have a low glycemic index (small rise of glucose after a meal) and can contribute to control of blood glucose. Frequent intake of legumes may lower blood cholesterol concentration significantly. As part of a diet low in saturated fatty acids and cholesterol, they may help to reduce the risk of coronary heart disease. In addition, frequent consumption of low-fat pulses may be of assistance in weight management. Also, legumes have been said to have low allergenic capacity compared with some other sources of protein.

Nine underutilised legumes, *Mallotus subulatus* (white variety), *Cassia hirsutta*, *Canavalia ensiformis*, *Vignea subterranean* (checkered variety), *Vigna racemosa*, *Mallotus subulatus* (red variety), *Vignea subterranean* (cream variety), *Sphenostylis sterocarpa* and *Cajanus cajan* in South western Nigeria were studied to highlight their nutritional significance. Significant ($p<0.05$) variations existed among the legumes with respect to their proximate composition, fatty acid profile, total phenolic content, antioxidant activity (Table 13) and amino acid composition. The total unsaturated fatty acids were much higher than the total saturated fatty acids in all the legumes. Linoleic acid (C18:2) was the most abundant polyunsaturated fatty acid (PUFA) identified, at varying levels, in all the legumes studied (Table 14). *Cajanus cajan* had the highest total phenolic content (293.23 mg/100g) and also rated best in its antioxidant activity. The percentage total essential amino acids were between 45.53 and 48.44 (Table 15) which are considered adequate for ideal protein foods. All the legumes were good sources of total phenolics and possess moderate to high antioxidant activities suggesting that these lesser known legumes are promising commodities in combating food and nutrition insecurity in Nigeria and other countries where they are known and consumed (Ade-Omowaye et al., 2015).

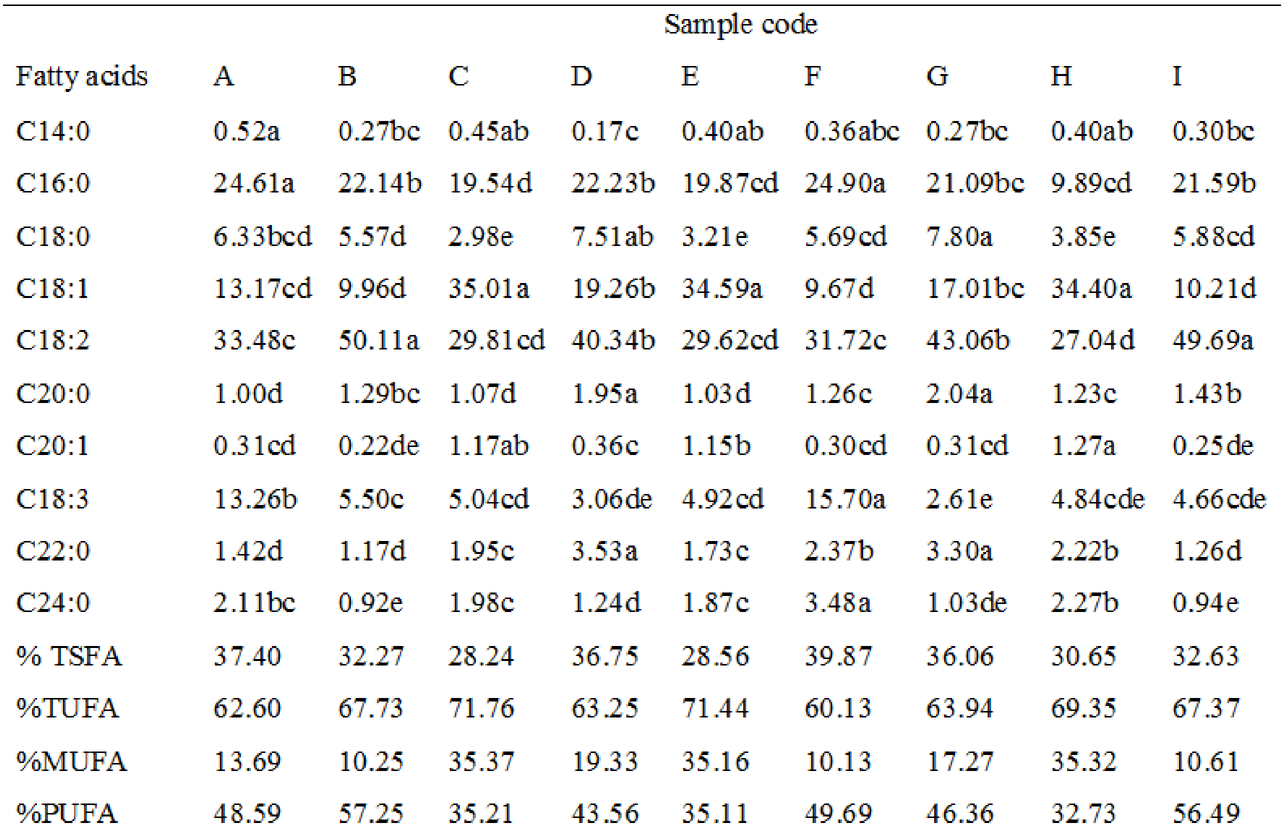
Table 13: Total polyphenolics and antioxidant activities of the nine underutilized legumes

Sample	Total Polyphenols (mg/100g)	Antioxidant activity mmolTE/100g
A	70.95g	0.55g
B	91.64f	0.39i
C	281.64c	0.70c
D	170.95e	0.88b
E	80.05g	0.45h
F	255.27d	0.66e
G	68.00h	0.56f
H	288.68b	0.67d
I	293.23a	1.00a

Means with the same letter along the same column are not significantly different ($p<0.05$).

A=*Mallotus subulatus* (white variety); B= *Cassia hirsutta*; C= *Canavalia ensiformis*; D= *Vignea subterranean* (checkered variety); E= *Vigna racemosa*; F= *Mallotus subulatus* (red variety); G= *Vignea subterranean* (cream variety); H= *Sphenostylis sterocarpa*; I= *Cajanus cajan*.

Table 14: Fatty acids compositions (g/kg) of the nine underutilized legumes in Nigeria



	Sample code								
Fatty acids	A	B	C	D	E	F	G	H	I
C14:0	0.52a	0.27bc	0.45ab	0.17c	0.40ab	0.36abc	0.27bc	0.40ab	0.30bc
C16:0	24.61a	22.14b	19.54d	22.23b	19.87cd	24.90a	21.09bc	9.89cd	21.59b
C18:0	6.33bcd	5.57d	2.98e	7.51ab	3.21e	5.69cd	7.80a	3.85e	5.88cd
C18:1	13.17cd	9.96d	35.01a	19.26b	34.59a	9.67d	17.01bc	34.40a	10.21d
C18:2	33.48c	50.11a	29.81cd	40.34b	29.62cd	31.72c	43.06b	27.04d	49.69a
C20:0	1.00d	1.29bc	1.07d	1.95a	1.03d	1.26c	2.04a	1.23c	1.43b
C20:1	0.31cd	0.22de	1.17ab	0.36c	1.15b	0.30cd	0.31cd	1.27a	0.25de
C18:3	13.26b	5.50c	5.04cd	3.06de	4.92cd	15.70a	2.61e	4.84cde	4.66cde
C22:0	1.42d	1.17d	1.95c	3.53a	1.73c	2.37b	3.30a	2.22b	1.26d
C24:0	2.11bc	0.92e	1.98c	1.24d	1.87c	3.48a	1.03de	2.27b	0.94e
% TSFA	37.40	32.27	28.24	36.75	28.56	39.87	36.06	30.65	32.63
%TUFA	62.60	67.73	71.76	63.25	71.44	60.13	63.94	69.35	67.37
%MUFA	13.69	10.25	35.37	19.33	35.16	10.13	17.27	35.32	10.61
%PUFA	48.59	57.25	35.21	43.56	35.11	49.69	46.36	32.73	56.49

Means with the same letter along the same row are not significantly different ($p<0.05$). A=*Mallotus subulatus* (white variety); B= *Cassia hirsutta*; C= *Canavalia ensiformis*; D= *Vignea subterranean* (checkered variety); E= *Vigna racemosa*; F= *Mallotus subulatus* (red variety); G= *Vignea subterranean* (cream variety); H= *Sphenostylis sterocarpa*; I= *Cajanus cajan*.

Table 15: Amino acid composition (g/kg) of the nine little known legumes

Amino Acid	A	B	C	D	E	F	G	H	I
Cyst	4.26i	5.06g	6.78a	4.73h	6.29c	5.21f	5.43e	6.43b	5.47d
Asp	26.29b	20.85i	23.49c	21.13h	22.17e	27.78a	22.13f	21.75g	22.55d
Meth[a]	2.54g	2.63c	2.74a	2.58d	2.56f	2.57e	2.57e	2.46h	2.65b
Thr[a]	9.29b	7.70f	8.59c	6.62h	8.12e	9.72a	7.26g	8.12e	8.25d
Ser	13.70b	10.31h	12.72c	10.04i	11.86e	14.78a	11.00g	12.05d	11.42f
Glu	27.32i	40.07b	29.57e	30.62d	28.30f	27.87g	31.98c	27.46h	43.31a
Gly	8.35e	7.53g	9.24a	7.05i	8.79b	8.49d	7.37h	8.55c	7.85f
Ala	9.35d	9.46c	9.51b	8.15h	8.97e	9.46c	8.52g	8.75f	9.72a
Val[a]	11.63a	9.52e	11.38c	9.04f	10.31d	11.60b	8.45i	8.96g	8.67h
Ile[a]	11.05b	8.27e	9.76c	7.97f	8.85d	11.07a	7.36i	7.72g	7.71h
Leu[a]	17.90b	16.08e	17.06c	14.96i	15.90f	18.24a	15.21g	15.07h	16.48d
Tyr	6.87e	5.20h	8.10a	5.45g	7.85c	7.67d	4.99i	7.90b	5.52f
Phe[a]	13.09d	20.88b	12.94e	10.79h	12.14f	13.41c	10.73i	11.33g	22.19a
Lys[a]	14.33g	14.46f	17.40a	13.41i	16.22b	14.56e	13.77h	15.31c	14.77d
His[a]	6.14g	8.08d	8.56b	5.95i	8.92a	6.44f	6.10h	8.49c	7.93e
Arg[a]	12.71f	13.18d	11.83g	12.96e	10.46h	14.40a	13.19c	9.74i	13.51b
Pro	8.89g	9.34f	10.05c	8.65h	9.59e	9.34f	9.85d	10.09b	11.44a

[a] Essential Amino Acids; Means with the same letter along the same row are not significantly different (p<0.05). A=*Mallotus subulatus* (white variety); B= *Cassia hirsutta*; C= *Canavalia ensiformis*; D= *Vignea subterranean* (checkered variety); E= *Vigna racemosa*; F= *Mallotus subulatus* (red variety); G= *Vignea subterranean* (cream variety); H= *Sphenostylis sterocarpa*; I= *Cajanus cajan*.

As part of our efforts in making healthy food available to all, we researched into the effects of hydrothermal processing on nutrients, anti-nutritional components and protein digestibility of eight of the underutilized legumes earlier mentioned. The seed of the eight underutilised hard-to-cook legumes were subjected to varying aqueous hydration levels (ranging from 0 to 100%) and four hydrothermal processing techniques (atmospheric boiling BAP, atmospheric steaming SAP, pressure boiling BEP, and pressure steaming SEP) (Ojo *et al*., 2017a; Ojo, 2018).

In general, the volume of water for cooking each of the legumes decreased with increase in the hydration level. This was true for each of the processing methods, BAP, SAP, BEP and SEP *(*Ojo *et al,* 2017a; Ojo, 2018 and Ojo *et al.*, 2018). Thus, processing of any of the legumes at 0% hydration level required much more water than processing at 100% hydration level. Soaking of the seed prior to hydrothermal processing decreased cooking time. For instance reductions of 37.97% and 80.18% in cooking times were observed for *Cassia hirsutta (Sese omode) and Mallotus subulatus (Pepelupe funfun),* respectively when the seeds were processed by pressure boiling (Ojo *et al***,** 2017a, Ojo, 2015).

Soaking of the seeds to varying hydration levels before hydrothermal processing induced the reduction in the concentration of the anti-nutritional components studied. The reduction ranged from 4.71% - 7.29% for phytic acid, 3.81% – 14.29% for tannin, 0.69% -1.67% for saponin and 9.51% - 12.13% for trypsin inhibitor. The lowest concentration of each of the anti-nutritional components was observed at 100% hydration level (Ojo, 2015, Ojo *et al*, 2017a).

All the hydrothermal processing methods had reduction effects on the anti-nutritional factors investigated. The percentage loss for each of the anti-nutritional factors after hydrothermal processing ranged from 57.57 – 67.56% for phytic acid, 71.26 – 90.50% for saponin and for 59.40 – 78.46% for tannin. All the hydrothermal methods caused total elimination of trypsin inhibitor in each of the legumes studied (Ojo, 2018, Ojo *et al*, 2017a).

Any processing method that will enhance the nutritive value of legumes must eliminate or reduce the anti-nutritional factors (Ojo *et al*, 2014a; Ojo, 2018; Ojo *et al*, 2017a; Ojo *et al.*, 2018). This is because the presence of anti-nutritional factors commonly found in legumes constitutes a limiting factor to their utilisation by humans and animals. Anti-nutritional factors make valuable nutrients present in legumes unavailable for absorption and utilisation . It is therefore, important that any processing method a legume sample must undergo prior to consumption should take care of these anti-nutrients. All the hydrothermal processing methods reduced and/or eliminated the anti-nutritional factors studied at varying degrees (Ojo *et al,* 2018, Ojo, 2018).

Earlier studies have shown that nutrient composition of food is not enough to determine nutrient bioavailability (Ojo *et al*, 2015, Ojo *et al,* 2018). This is because the mere presence of a nutrient in a food as determined by chemical analysis is no guarantee or indication of its bioavailability, that is, the percentage that can be absorbed from it and can be utilised by the body. Hence, the need for in vitro digestibility studies (Ojo *et al*, 2018, Ojo *et al,* 2017b). The *in vitro* multi enzyme protein digestibility (IVPD) was generally low for all the raw legumes (Ojo, 2015). The lowest % IVPD was observed for *Mallotus subulatus* – 31.06% with the highest TIA value of 34.37 mg/g and appreciable quantity of phytic acid (71.34 mg/g) but a relatively low value of tannin – 28.10 mg/g 18. This was followed by the raw sample of *Sphenostylis sterocarpa* with % IVPD of 30.16, 30.09 mg/g TIA and the highest concentration of phytic acid (71.78 mg/g). Among the raw dried samples of the legumes, the highest percentage IVPD of 46.45% was observed for *Vigna subterranean*, which had relatively low concentration of phytic acid (58.45 mg/g) (Ojo, 2015; Ojo *et al*, 2017b).

Each of the processing methods, boiling (BAP) and steaming (SAP) at normal atmospheric pressure as well as boiling (BEP) and steaming (BEP) at elevated pressure has significant effect (p<0.05) on the percentage digestibility of the legume samples. After hydrothermal processing, the highest protein digestibility of 88.81% was recorded for *Mallotus subulatus.* Lowest digestibility of 84.47% was reported for both *Vigna subterranean and Sphenostylis sterocarpa* (Ojo *et al,* 2017a; 2017b; Ojo *et al.*, 2018).

The underutilized legumes have physical and functional properties which make them potentially ideal for food uses and industrial food system. It could be inferred that flours from legumes such as *Sphemostylis sterocarpas* with high swelling capacity (58.30%) will be appropriate for the production of such local dishes as *akara* and *moinmoin*, where the volume of the final product is of economic importance (Ojo *et al*, 2015). Water absorption capacity of the flours of these underutilized legumes gave indications that the flours or protein isolates would be useful in enhancing the water binding capacity of food products like dough and sausages (Ojo *et al.*, 2015; Ojo *et al,* 2017). The proximate components of the underutilized legumes were comparable to common beans such as cowpea and some other legumes. Although, generally low in fat, unsaturated fatty acids (MUFA and PUFA) were the most highly represented among the fatty acids with values higher than 50% of the total fat. All the legumes have relatively high contents of total phenolics and antioxidant activity pointing to the potentials of these legumes as promising healthy food crops for the tropics. Soaking of the legumes notably affected the cooking time of each of the legumes. The level of hydration determines the cooking duration. Pre-soaking is a better alternative to the traditional use of a tenderizer such as trona, the safety limit of which is yet to be established. This pre-processing operation reduced loss of nutrients and save energy and time. The *in vitro* digestibility of the processed legumes was greater than 80% in all the legumes. Consumption of these legumes should therefore be encouraged so that consumers can benefit from its nutrients.

Okra seeds

Among the under-utilised protein rich foods are okra seeds. Okra (*Abelmoschus esculentus* Moench) is one of the most important vegetables widely grown in Nigeria for its tender fruits and young leaves and studies have confirmed the potential of okra seed (dried seed) as a good source of oil and protein for both the temperate regions and the tropics. Although the oil and protein of okra seed are inherently edible, the seed is not being processed for oil or protein as the production of the seed in Nigeria is limited to seedling and regeneration purposes. However, large quantities of the seed are being discarded as unfit for seedling purposes. Different studies were carried out on okra seeds to promote its utilization as an ingredient in healthy food formulation. We studied the influence of variety on protein, fat contents and some physical characteristics of okra seeds (Oyelade et al., 2003). The generated physical properties of okra seed could be used in the design of processing equipment for okra seeds and cultivars could be selected based on the desired end use. Okra seeds could be put into alternative uses in varying food formulations in Nigeria instead of regeneration purposes alone.

In an attempt to widen the utilization horizon of okra seeds in Nigeria, studies were also carried out to evaluate the effect of different pre-treatments (soaking, blanching, roasting and malting) on different quality characteristics of okra seed flour. Slight but significant DPPH radical scavenging activity increase (Figure 10) was observed in soaked samples at 18th -h while blanching resulted into progressive decrease (Adelakun et al., 2009). This finding shows that soaking could be adopted as a pre-processing step in the processing of okra seed in order to preserve and enhance the yield, protein and the antioxidant content. The antioxidant activity was also significantly increased by roasting, while *in vitro* digestibility (Figure 11) showed that most antioxidative activities were available in the intestinal phase of gastrointestinal tracts (Adelakun et al., 2009b). Functional properties (Tables 16, 17 and 18, Adelakun et al., 2010) showed that all pre-treatments resulted into increase in water and oil absorption capacities, decrease in emulsion ability and stability and decrease in foaming capacity and stability except malting, which showed an increase in foaming capacity and stability. The result of this study shows the potential of okra seeds in various food formulations. Pretreated and untreated okra seeds could therefore find useful applications in various healthy food formulations for all age groups.

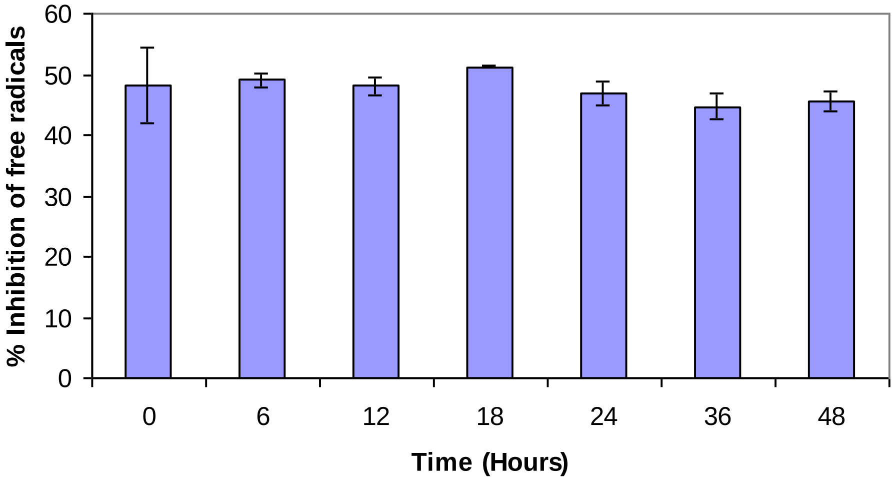


Figure 10: Effect of Soaking on the antioxidant activity of okra seed flour.

N: Raw Okra Seed; S1: Okra Seed soaked for 6 h; S2: Okra Seed soaked for 12 h; S3: Okra seed soaked for 18 h; S4: Okra Seed soaked for 24 h; S5: Okra Seed soaked for 30 h; S6: Okra Seed soaked for 48 h

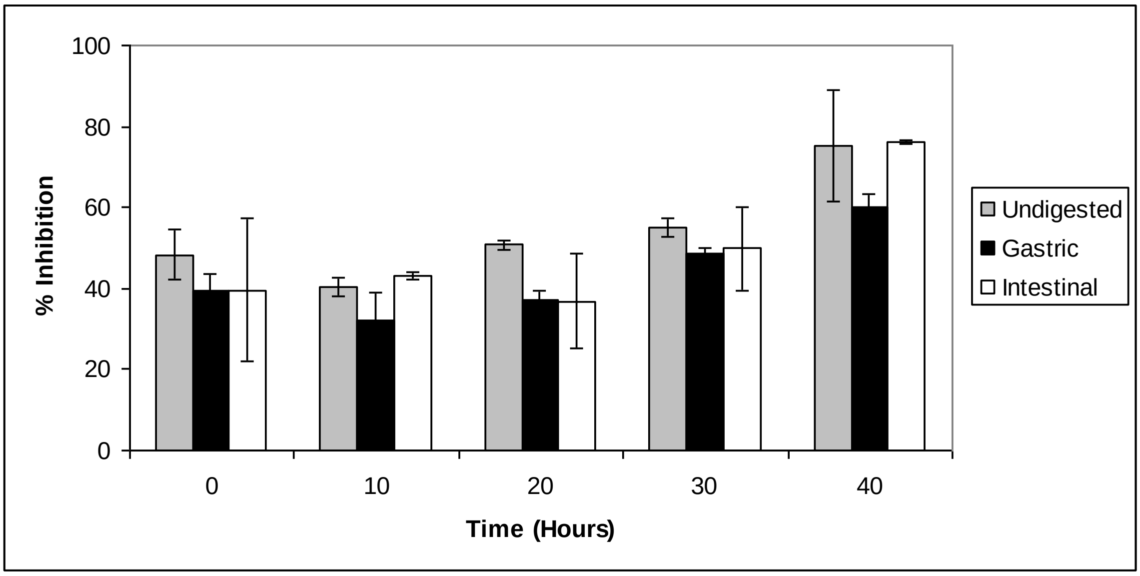


Figure 11: Effect of Roasting on the in vitro antioxidant activity of okra seed Flour

N: Raw Okra Seed; R1: Okra seed roasted for 10 min; R2: Okra seed roasted for 20 min; R3: Okra seed roasted for 30 min; R4: Okra seed roasted for 40 min

Table 16: Effect of Soaking Time (h) on the Functional Properties of Okra Seed Flour

Sample	Time (Hr)	WAC	OAC	EA	ES	FC	FS	Bulk Density (g/cm^3)	Swelling Capacity (ml)
N	0	241.6g	229.4g	44.0a	30.5a	21.0a	13.0a	0.423a	7.50d
S1	6	243.6f	231.3f	43.5a	29.0b	17.0b	12.5b	0.413b	8.17bc
S2	12	244.0e	231.7e	41.5b	27.5c	15.5c	10.5c	0.412c	8.24a
S3	18	243.8d	231.5d	38.5c	27.0c	13.5d	10.0d	0.411d	8.20ab
S4	24	251.8c	239.1c	37.5d	26.5d	12.5e	8.0e	0.411d	8.11c
S5	36	258.5b	245.5b	36.5e	25.0e	9.0f	7.0f	0.412c	8.21ab
S6	48	267.0a	253.5a	35.5f	24.0f	6.0g	4.5g	0.410e	8.18abc

Values are means of three determinations (n = 3). Values with different letter on the same column are significant ($p < 0.05$). Keywords: Water absorption capacity (WAC); Oil absorption capacity (OAC); Emulsion activity (EA); Emulsion stability (ES); Foam capacity (FC); Foam stability (FS). N: Raw Okra Seed; S1: Okra Seed soaked for 6 h; S2: Okra Seed soaked for 12 h; S3: Okra seed soaked for 18 h; S4: Okra Seed soaked for 24 h; S5: Okra Seed soaked for 30 h; S6: Okra Seed soaked for 48 h.

Source: Adelakun et al. (2010)

Table 17: Effect of Malting Time (h) on the Functional Properties of Okra Seed Flour

Sample	Time (min)	WAC	OAC	EA	ES	FC	FS	Bulk Density (g/cm^3)	Swelling Capacity (ml)
N	0	241.5f	229.4f	44.0c	30.5a	21.0d	13.0d	0.422a	7.50c
M1	1	243.6e	231.4e	44.5b	30.5a	25.0c	13.5c	0.421a	7.68b
M2	2	250.2d	237.65d	44.5b	30.0b	25.5c	14.0b	0.422a	7.44c
M3	3	252.7c	240.0c	45.0a	30.0b	27.5b	13.5c	0.421b	7.72b
M4	4	255.7b	242.85b	44.5b	30.0b	28.0b	14.5a	0.414c	8.03a
M5	5	259.9a	246.8a	44.0c	29.0c	30.5a	14.5a	0.411d	8.06a

Values are means of three determinations (n = 3). Values with different letter on the same column are significant ($p < 0.05$). Keywords: Water absorption capacity (WAC, %); Oil absorption capacity (OAC, %); Emulsion activity (EA); Emulsion stability (ES, %); Foam capacity (FC, %); Foam stability (FS, %). N: Raw Okra Seed; Okra seed malted for 1 day; M2: Okra seed malted for 2 day; M3: Okra seed malted for 3 days; M4: Okra seed malted for 4 days; M5: Okra seed malted for 5 days.
Source: Adelakun et al. (2010).

Table 18: Effect of Blanching Time (h) on the Functional Properties of Okra Seed Flour

Sample	Time (min)	WAC	OAC	EA	ES	FC	FS	Bulk Density (g/cm^3)	Swelling Capacity (ml)
N	0	241.6f	229.4f	44.0a	30.5a	21.0e	13.0a	0.422a	7.50cd
B1	10	248.2e	235.7e	43.5b	28.5a	23.0d	13.0a	0.422a	7.48d
B2	20	251.2d	238.5d	42.5c	28.0ab	25.0c	12.0b	0.421b	7.55cb
B3	30	254.5c	241.7c	41.5d	27.5b	26.0b	12.0b	0.421b	7.57b
B4	40	258.2b	245.2b	42.5c	26.5c	26.0b	11.0c	0.419c	7.64a
B5	60	269.5a	256.0a	42.5c	25.5d	29.0a	11.0c	0.414d	7.65a

Values are means of three determinations (n = 3). Values with different letter on the same column are significant ($p < 0.05$). Keywords: Water absorption capacity (WAC); Oil absorption capacity (OAC); Emulsion activity (EA); Emulsion stability (ES); Foam capacity (FC); Foam stability (FS). N: Raw Okra Seed; B1: Okra Seed blanched for 10 min; B2: Okra seed blanched for 20 min; B3: Okra seed blanched for 30 min; B4: Okra seed blanched for 40 min; B5: Okra seed blanched for 60 min.
Source: Adelakun et al. (2010)

Intermediate Moisture Fruits and Vegetables

Studies aimed at developing and applying optimal transport model constrained with higher water loss and minimal solute gain in an efficient osmotic solution management for enhancing overall economic status of the process were embarked upon. The theoretical and widely accepted concept of osmotic dehydration (OD) was employed in the design and development of a versatile OD pilot plant (Figure 12). This will curb economic losses and remove serious environmental hazards with handling of large magnitude of effluent on industrial scale when adopted.

Major factors influencing osmotic dehydration of fruits and vegetables were investigated, using mango and carrot as case samples; mathematical models that inter-relate the most significant factors in the osmotic dehydration process were established; process variables affecting the efficiency of osmotic dehydration were simulated, optimised and experimental data from bench-scale batch process were validated using the developed semi-continuous OD operation pilot plant. Typical graphs showing the effect of some factors on water loss during osmotic dehydration are shown in Figures 13 and 14. In the study, we were able to develop a system for the management of the hypertonic effluent inherent in the OD process which limits its industrial adoption and utilization. ‘Pearsons square’ algorithm was developed into an interactive computer simulation for effective re-cycling of used liquor during OD process.

Optimised processing conditions using response surface methodology showed 52.11 ^{o}Bx, 39.78 ^{o}C and 126.9 min for sucrose concentration, temperature and time of immersion, respectively to achieve 46.87% water loss and 7.33% solute gain. The pilot plant was proven to be versatile by its utilisation in comparative analysis for different agro-products such as mango and carrot. Shelf-life elongation of poultry eggs was also demonstrated (Duduyemi et al., 2013a; 2013b; 2014; 2015a; 2015b and 2017).

Attempts were made in other studies to experimentally determine the effective diffusion coefficients and equilibrium content of water and osmotic solute over a range of concentration of sucrose and sodium chloride. The solute mix was optimized based on water and solid diffusion coefficients, as well as equilibrium using response surface methodology. The graphical optimization showed that at optimum conditions (sucrose concentration and sodium chloride concentration were 21.86 g/100 g and 2.02 g/100 g, respectively, Figure 15), the following criteria were achieved: water diffusion coefficient (D_{ew}) ≥ 0.80 x 10-9 m2/s, solid diffusion coefficient (D_{es}) ≥ 0.82 x 10-9 m2/s, equilibrium moisture content ($m\infty$) ≤ 6.85 kg/kg, and equilibrium solid content ($s\infty$) ≤ 2.00 kg/kg (Ade-Omowaye et al., 2002).

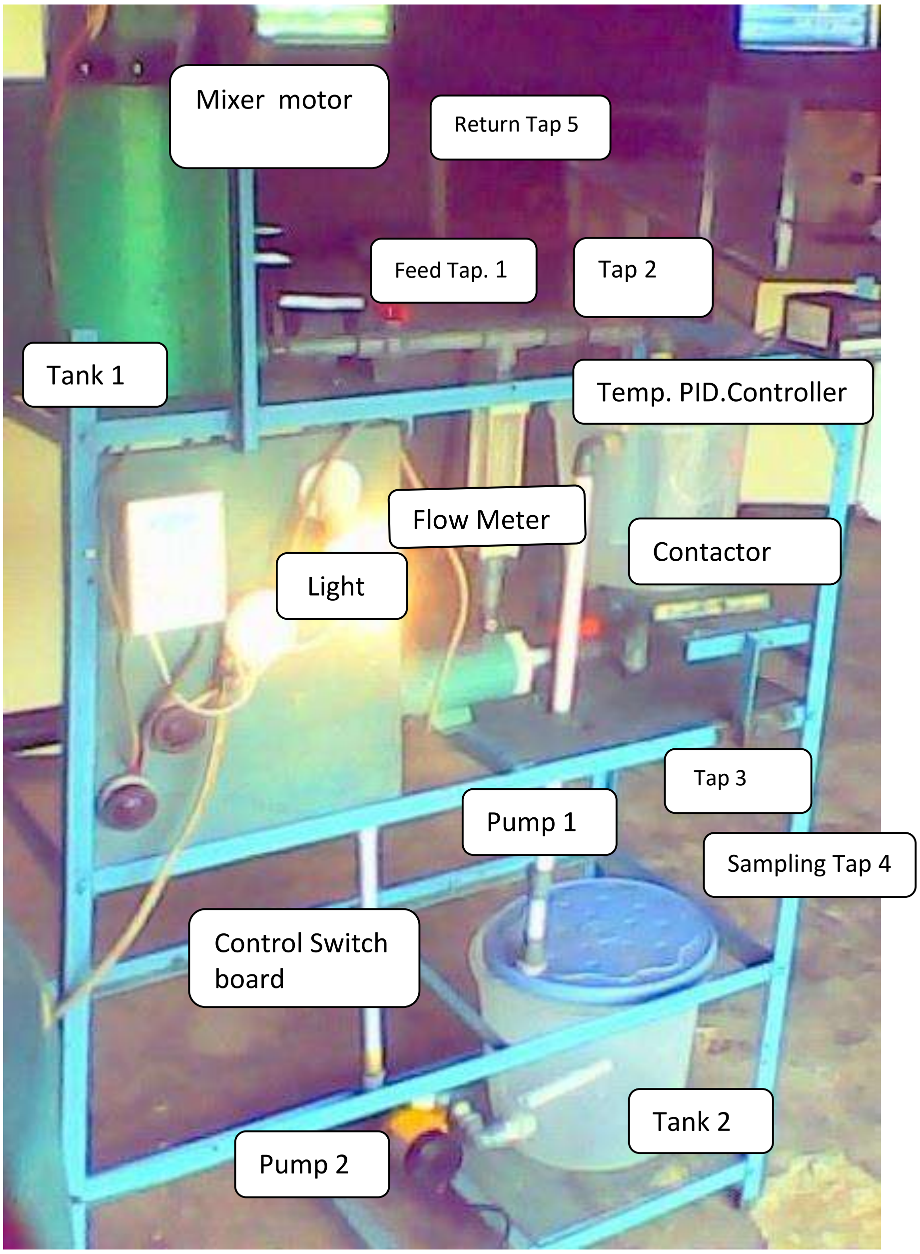


Figure 12**:** Pictorial view of fabricated pilot plant
(C.T.2, 3: Control Tap 2 and 3 respectively for flow rate regulation**)**

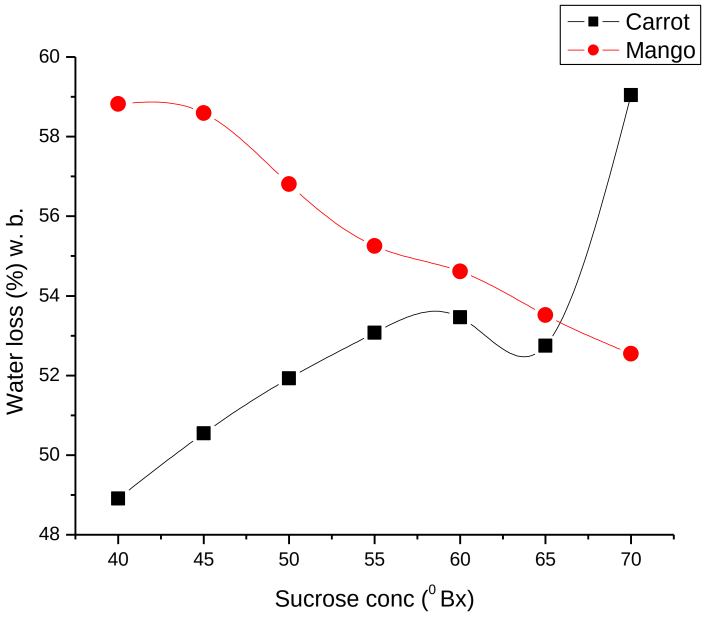


Figure 13: Effect of sucrose concentration on water loss in mango and carrot samples

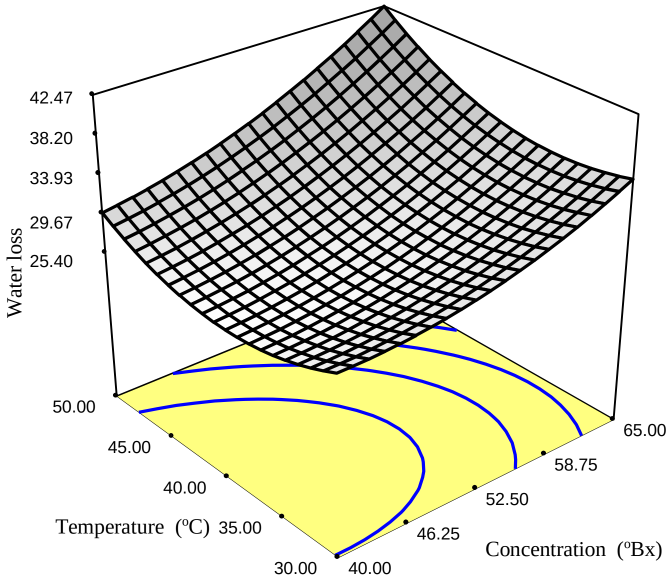


Figure 14: Effects of concentration and temperature on water loss in mango

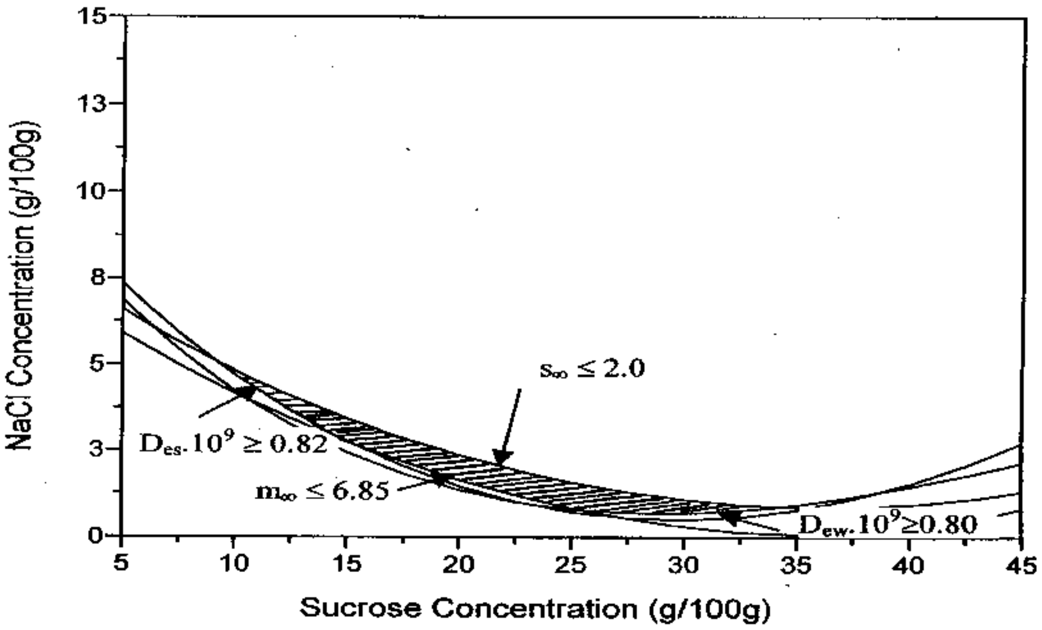


Figure 15: Super imposed contour plots showing the shaded overlapping area for the followings; water diffusion coefficient (D_{ew}) ≥ 0.80 x 10^{-9} m^2/s, solid diffusion coefficient (D_{es}) ≥ 0.82 x10^{-9} m^2/s, equilibrium moisture content (m_∞) ≤ 6.85 kg/kg and equilibrium solid content (s_∞) ≤ 2.00 kg/kg

Other Research Contributions

Unmodified starches have limited usage due to their inherent weakness of hydration, swelling and structural organization and inability to withstand other harsh processing conditions like extreme temperature, diverse pH, high shear rate and freeze-thaw variation. These adverse native starch characteristics can be improved upon for different industrial applications through a series of modification techniques.

Modified starch products are used in food, pharmaceutical, paper and textile industries. It increases the acceptability of many processed foods to consumers. They are also used to reduce costs of established food and pharmaceutical products. More expensive ingredients such as tomato solids, fruit solids or cocoa powder can be extended with combination of modified food starches, flavours and other inexpensive food substances (Olu-Owolabi *et al.*, 2010). They also have wide applications as binders, fillers, emulsions and stabilizers.

With annual production of cassava in the excess of 50 Million tonnes, glut in its marketing can be avoided by the diverse utilization of cassava through starch modification or value addition to broaden and improve utilization to prevent wastage and increase income of cassava growers hence helping to strengthen the rural economies and boost cassava farmers' income. This will invariably make Nigeria to be prominent in the world's export market. Utilization of the modified starches in the food and pharmaceutical industries will curtail drain on foreign exchange earnings. Nigeria being a major importer of corn starch could benefit immensely from locally produced suitable starch from cassava. This information prompted us to conduct series of studies on cassava starch modification for possible industrial uses in food formulations and pharmaceuticals.

Three varieties of cassava TME 419, TMS 98/0505 and TMS 98/0581 obtained from IITA were acetylated at different substitution levels and pre-gelatinized at varying concentrations. Acetylated starches were used in preparing ice-cream (Plate 11) according to the method of Choo *et al.*,2010 while pre-gelatinized starches were compacted into tablets (Plate 12) according to the method of Olu-Owolabi *et al.*, 2010 to determine their suitability as replacement for imported stabilizers and corn starches in the ice-cream and pharmaceutical industries respectively.

Plate 11: Photograph showing ice cream produced with acetylated cassava starches
A1 = Ice cream prepared with 10% acetylated starch from TME 419
A2 = Ice cream prepared with 20% acetylated starch from TME 419
B1 = Ice cream prepared with 10% acetylated starch TMS 98/0505
B2 = Ice cream prepared with 15% acetylated starch TMS 98/0505
C1 = Ice cream prepared with 10% acetylated starch 98/0581
C2 = Ice cream prepared with 20% acetylated starch TMS 98/0581

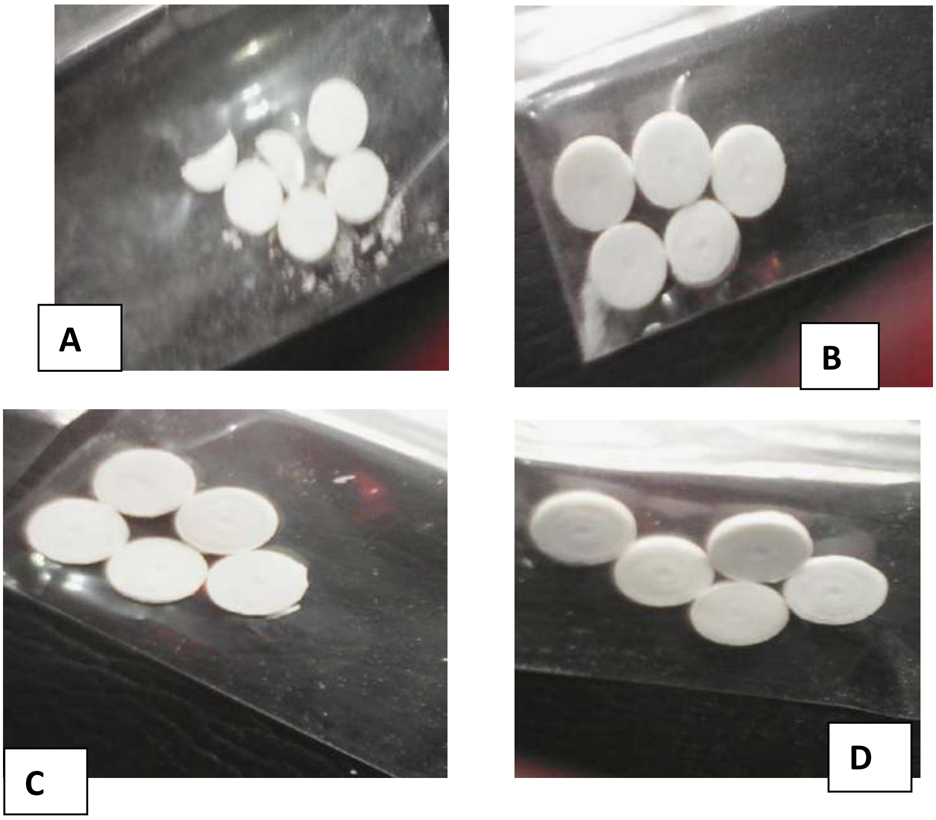


Plate1 2: Photograph showing tablet compacts from native and pre-gelatinized cassava starches

A = Sample tablets from native starch
B = Sample tablets from 25% pre-gelatinized starch
C = Sample tablets from 30% pre-gelatinized starch
D = Sample tablets from 35% pre-gelatinized starch

Acetylation did not affect particle sizes and morphology of the starches whereas particle sizes of the starches increased with levels of pre-gelatinization which positively improve the flow properties (Alanazi *et al*., 2008). This might be due to increased water absorption, hydration and swelling capacities (Table 20, Itiola and Odeku, 2005) which is an indication of good assessment of tablet disintegration ability.

Table: 19: Functional characteristics of pre-gelatinized cassava starch from TME 419 as affected by concentration

Sample	Water Absorption Capacity (%)	Hydration Capacity (%)	Swelling Capacity (%)
NaS	13.33b	203.33b	115.00b
PS25	50.00a	603.33a	321.67a
PS30	48.33a	533.33a	315.00a
PS35	53.33a	580.00a	321.67a

Mean values with the same letters within the same columns are not significantly (*p*>0.05) different. NaS = Native starch; PS25 = Pre-gelatinized starch at 25% concentration ; PS30 = Pre-gelatinized starch at 30% concentration ; PS35 = Pre-gelatinized starch at 35% concentration.

Ice cream produced from the acetylated starches had improved percentage overrun, foam stability and melt down resistance (Figure 16, Otutu *et al*., 2017a). The values obtained in this study were higher than values reported for CMC commonly used as stabilizers (Alanazi *et al*., 2008). The higher the overrun, the softer the ice cream and thereby resulting in higher profit.

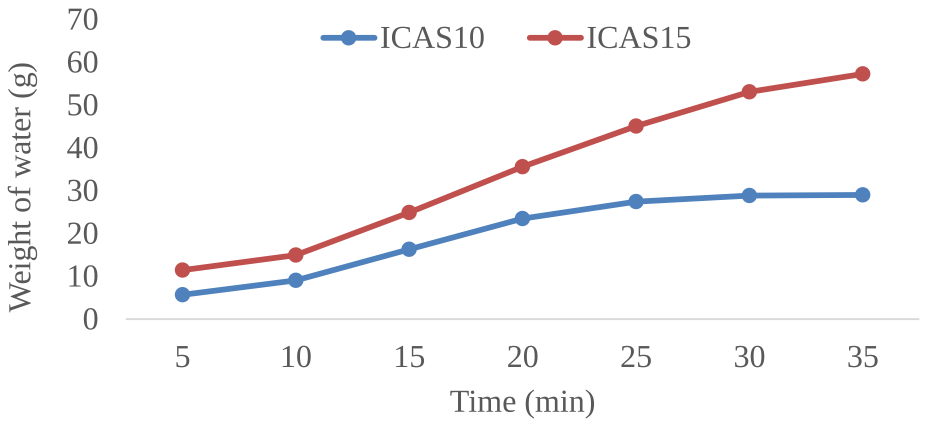


Figure 16: Melt down rate/resistance of ice cream prepared with acetylated starch from TMS 98/0505

ICAS10 = Ice cream prepared with acetylated starch at 10% concentration
ICAS15 = Ice cream prepared with acetylated starch at 15% concentration

The pre-gelatinized starches deform plastically during tablet production and it is an index of packability of pharmaceutical starches (Illi *et al.*, 2009) The pre-gelatinized starches produced harder tablets by plastic deformation, hence pre-gelatinization improved desirable properties of cassava starch that could influence the performance when employed as excipients in tablet compression (Otutu *et al.*, 2017b) and pre-gelatinized cassava starches at 25% concentration could be utilized for tablet compression. (Otutu *et al.*, 2015). These observations highlight the potentials of modified cassava starch in food formulations and pharmaceutical preparations which would definitely minimise the foreign exchanged annually expended on imported corn starch.

CONCLUSION AND RECOMMENDATION

Mr Vice Chancellor, Sir, as I round off this presentation on my exploration of new horizons of an emerging non thermal technique, PEF and value addition to underutilized crops, I like to draw the following conclusions based on our studies:

Minimal processing is not optional for healthy food and inclusion of copious quantities of plant based foods in our diet which could come from underutilized species. PEF processing is an exciting emerging technology that offers not only enhanced potential for preservation of food but which can also be used to enhance the rate of unit operations such as juice extraction, osmotic dehydration and conventional dehydration. PEF may be used to modify existing processes or to develop new, energy efficient, environmental friendly options for food and drink industry, as well as for pharmaceutical or biotechnological applications. The availability of continuous application and short processing time makes PEF treatment an attractive candidate as a novel nonthermal operation. The practicality of PEF utilization in developing countries like Nigeria is possible as it has been reported that its operation does not require constant electricity supply and can be powered by a small scale 2 KW solar energy system operating 5.5 h per day in combination with small scale energy storage system. It is believed that adoption of this technology can empower millions of smallholder farmers in low income countries.

Food products developments from various underutilized crops have been demonstrated with potentials of positive contribution to human health. The developed foods ranged from complementary food for old infant and young children, to novel snacks for all age groups, non- alcoholic beverage for young and old, nutrient enriched bread for all, enriched cereal-root flour for swallow and osmotically dehydrated intermediate moisture fruits and vegetables for the enjoyment of all and sundry. Information on the potentials of underutilized legumes and okra seeds as sources of healthy food or ingredients in healthy food formulations have also been provided.

RECOMMENDATIONS

For healthy food for all in Nigeria and beyond not to be a mirage the following are therefore recommended:

Mr Vice Chancellor, Sir, LAUTECH can pioneer research in pulsed electric fields in Nigeria to create awareness to food processors and motivate researchers to generate more relevant data that would form strong foundation for its adoption in food processing in developing countries for both food preservation and modification. A pilot scale PEF equipment can be imported at the onset after which the Engineers might attempt its fabrication. Interestingly the cost of PEF treated juice in countries of its application has been put to 1-2 cent for a litre (less than ₦20) as process cost.

Transfer of this technology and other non-thermal techniques should be promoted in this country. PEF will find application in processes like drying, fermentation, juice extraction and preservation. Its advantages outweigh the initial capital cost. More funds should be made available for research in this field and collaboration with renowned researchers in the field in the developed nations should be encouraged.

Universities should provide support for researchers to disseminate their research findings to their immediate communities to further strengthen Town and Gown relationships. Several innovative researches that could promote the underutilized species have ended up on the shelf. Industry –academic linkage should therefore be strengthened. Local industries need to take up research findings for the society to benefit from research efforts.

Universities should also champion the promotion of the consumption of healthy diets which comprise largely plant based foods such as fruits, vegetables, whole cereals, nuts, legumes and low amount of unhealthy foods such as sugars and red meat through awareness creation and focussing more on researches in these areas for optimal human and planet health. This will complement the global effort in their call for transformation to healthy diets by 2050 for attainment of human and planet health. Of the underutilized food materials in Nigeria only a fraction is being consumed as food. Not only are these foods rich nutritionally, they also have high medicinal values begging for exploitation.

Public lectures among the elites and city dwellers on the benefits regarding nutritious values of these underutilized crops should be given urgent priority. This will create awareness that will encourage proper perception and favour wide consumption of these crops. Top cooks, eateries and food vendors should be encouraged with attractive incentives from government and non-governmental agencies to help promote utilization of these underutilized crops in gastronomy and food systems.

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