FEDERAL UNIVERSITY OF AGRICULTURE
ABEOKUTA NIGERIA

79th INAUGURAL LECTURE

SCIENCE-ART INTERFACE : A PLANT BREEDER'S PERSPECTIVE

by

Professor Francis Abayomi Showemimo

(Professor of Plant Breeding and Genetics)

Department of Plant Breeding and Seed Technology (PBST)
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FUNAAB INAUGURAL LECTURE
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of

The Vice-Chancellor

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B.Sc (Agric Biology); M.Sc (Crop Improvement), Ph.D (Ibadan), FGSN, FAIMP, FIHSC

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FUNAAB INAUGURAL LECTURE SERIES

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SCIENCE-ART INTERFACE : A PLANT BREEDER'S PERSPECTIVE

Protocols

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Distinguished members and Professional Colleagues

Members of my Family,

Gentlemen of the Print and Electronic Media,

Distinguished Ladies and Gentlemen

Great FUNAABITES.

1.0. PREAMBLE

To God be the glory for His mercies, favour and love endure forever. It's a rare privilege, prestige and providence for me to stand before this august audience to present my inaugural lecture. Yes, I almost foreclosed the possibility because, I became professor in 2007 at Ahmadu Bello University, Zaria and at the verge of presenting my inaugural lecture, I transferred my service to this great University, The Federal University of Agriculture, Abeokuta.

I am here with every sense of humility to share with you my passion, patience and productivity packed as my inaugural lecture. What makes a professor is beyond the degrees obtained, work experiences, delivery system, number of students graduated, high tech researches, leadership and followership but combination of all the aforementioned along with his/her PERSPECTIVES. I must confess that to be a professor is not an easy task; it's a lifelong ambition, serious and continuous studies, high dedication, research, publications and impartation of knowledge.

Whenever, I enter any class or lecture room for the first time, I normally introduce myself to my students as a very successful, contented, happy and best Plant Breeder available. It's not out of arrogance, but to encourage them, that if I can, they too can and even be better than me. I happily announce to you, the 79th inaugural lecture series of Federal University of Agriculture, Abeokuta. It is the 15th from the College of Plant Science and Crop Production, and the 5th from the Department of Plant Breeding and Seed Technology. The first was by Late Prof. T.A.O. Ladeinde on April 26, 2006 titled "Reminiscences of an experience in teaching, research, extension and administration in academic institution in Nigeria and abroad". The second was by Prof. O.J. Ariyo on April 15, 2009, titled "Genotype and Environment interplay in Crop

Production" (Series 25). The third was by Prof. D.C.F. Akintobi on October 16, 2019, titled "Seed: Source of Life, Prosperity and Pain" (Series 61). The fourth was delivered by Prof. O.B. Kehinde on December 22, 2021, title "Generation to Generation: Plant Genetic Diversity, Continuity and Discontinuity" (Series 70).

The Bible portrays God as The Breeder- Genesis 1: 26-27 and Genesis 2:7. God created man from dust (artist impression), God breathed into the man (science of the art). My inaugural lecture titled "Science-Art Interface: A Plant Breeder's Perspectives" is a big relief to me after toying with several topics for the fact that I have operated, researched, lectured and served in several aspects of plant breeding. My inaugural lecture will showcase the meeting point of Science and Art as it relates to cultivar conceptualization up to commercialization of products as practical knowledge, and contribution to the field of Plant Breeding and Genetics, and I will make achievable recommendations.

2.0. INTRODUCTION

Agriculture is the deliberate planting and harvesting of plants and herding animals. This human invention has, and continues to, impact on society and the environment. Plant breeding is a branch of agriculture that focuses on manipulating genes, thus, plant heredity to develop new and improved plant types for use by society. Therefore, Plant breeding is a deliberate effort by humans to nudge nature, with respect to the heredity of plants, to an advantage. The changes made in plants are permanent and heritable. The professionals who conduct this task are called Plant Breeders. Plant Breeding is an ancient act that combines both science and art of crop improvement, thus, it connotes the involvement of the sexual process of plant in effecting desired change and modern plant breeding also includes the manipulation of asexually reproducing plants (plants that do not reproduce through the sexual process). Breeding is hence about manipulating plant attributes, structure, and composition, to make them more useful to human beings.

Justification for this lecture is based on the increasing human and animal populations, that have become noticeable pressure on all related factors. According to the United Nations, the world population is currently at 7.7 billion. This is expected to grow to 8.5 billion by 2030, 9.7 billion by 2050, and reach 11.2 billion people by the end of the century. Nigeria is currently the most populous nation in Africa, the seventh in the world and in the next fifty years, Nigeria is estimated to be the third most populous nation in the world, four other African countries are estimated to be among the 10 most populous nations in the world as seen in Figures 1 and 2. Such rapid growth is associated with rising demand for resources such as food and water, energy, and space, as well as education, better sanitation, and better access to healthcare. Increased population raises food demand, food costs, farm labour, or leads to over-utilization of a country's resources, affecting food security.

Agriculture is already facing several challenges to keep up with rising demand, thus, putting pressure on Plant breeders to continually come up with high-yielding, quality seeds, pure grains, disease resistant, nutritional dense and environmentally adapted varieties to meet the ever-increasing feeds, food and industrial demands. Thus, the Maputu declaration of 2003 insists that all African governments must increase agriculture budget to between 10 and 20%, provide good storage, transportation, train and empower Plant breeders to breed high-yielding, biotic and abiotic-resistant varieties, and environmentally adapted varieties (NEPAD, 2003)

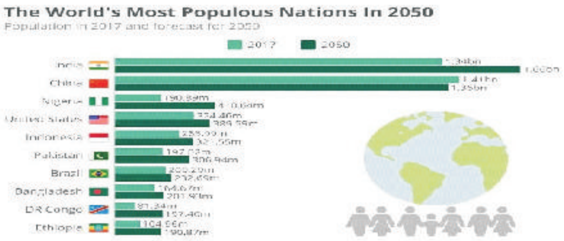

Figure 1: World's most populous nations 2017-2050 (forecast)

Figure 2: Human Population projections for some countries, continents across a century and half
Source: United Nation "World Population Prospect" via Pew Research Center

2.1 Science-Art Interface

In·ter·face (Pronounce: int-ər-fās): a surface forming a common boundary of two bodies, spaces, or phases. An interface between oil and water: the place at which independent systems meet and act on or communicate with each other: the ways by which interaction or communication is brought about at an interface. Science answers questions but art and creativity spark new ones. Gone are the days that, if you are creative you must not think analytically, and if you are precise and mathematical, you must not be creative. But science and art are currently on a continuum. The so-called divide does not exist anymore; any student gaining admission to any tertiary institution must pass with credit at ordinary level certificate. People who are on either end of the spectrum are relocating in-between. Science explaining arts and arts collaborate with science. Art interface is an Interactive function as a metaphor for communication or to be more precise, for dialogue and meaningful discussion virtually, visually, digitally and or physically.

Science-art can broadly be defined as the blending of two studies that provide useful information to the viewer from a scientific standpoint in a visually appealing way that may involve an emotional response from an artistic view. Through art, scientific developments can be communicated to the public. Art and science both render ideas about the world into a form that allows the viewer to connect to the idea. An observation, whether of a spider, a cell, or human nature, is necessary, but not sufficient to result in a meaningful work of art or a scientific finding. Scientific art can broadly be defined as the blending of two studies that provide useful information to the viewer from a scientific standpoint in a visually appealing way that may involve an emotional response from an artistic view. Thus, art becomes skill and talent to demonstrate scientific developments that are communicated to the public.

2.2. Plant Breeding as Science

Plant breeding is the science of creating and developing plant cultivars with desirable traits for use in agriculture and horticulture. The science of plant breeding involves a wide variety of complexities, creative and innovative solutions that are well grounded in advanced scientific knowledge. The choices that must be made include selection of the appropriate species, parents, genotypes, identification of the desired traits, and selection of the genetic material. Furthermore, most physical characters are genetically complex, showing recessive and some are dominant in expression. In addition, cultivars can be generated through a range of breeding techniques, including inbreeding (True to type), hybridization, mutation, molecular and biotechnological tools for breeding.

The science aspect of plant breeding is in what is responsible for the outcome, final result and publicly released cultivar (cultivated varieties; Culti-Var). Such as, the genetics of crops (genome level), manipulation of the genes (conventional and molecular tools), crop protection, physio-anatomical understanding, statistical measurements and analysis, adaptation to environment (soil, water, temperature and etc), Socio-cultural adoption (Extension, sociology and stakeholders), etc are reflections of plant make up.

2.3. Plant Breeding as an Art

Plant breeding as an art, is a diverse range of human activity, skill and resulting product that involves creative or imaginative talent expressive of technical proficiency, beauty, emotional power, or conceptual ideas. Plant breeding has always been considered to be both, a science and an art. Knowledge of genetics, reproductive behavior, physiology and agronomy of a plant species have to be coupled with creativity, intuition and the famous “breeder's eye” or “field eye balls” in order to result in successful new cultivars. Plant breeding is both an art that visualize imagination of conceived idea and ideal crop varieties. Thus, to breed a successful cultivar, there must be required creative, innovative solutions along with a deep understanding of plant designs and their genetic architecture.

Choices must be made, creativities developed, and compliments made. Ultimately, the cultivar must be commercialized for its success to be recognized and spread. The art of plant breeding involves the creativity of stakeholders and scientists together in developing cultivars with desired traits. A typical art has Concept, Content and Context, so also Plant Breeding. There are seven basic elements of art; Colour, Form, Line, Shape, Space, Texture and Value, these element are same as crop breeding values. This process requires a great deal of imagination and ingenuity, as well as a deep understanding of the genetics and physiology of plants. Innovative approaches are necessary to achieve desired results in a reasonable timeframe. Compliments must be made, as recognition of successful outcomes for breeders as reward and finally on how cultivars are commercialized as feedback

The art aspect of the interface is the ability of the public to appreciate and adopt the resultant products of Plant Breeding research; variety release for commercialization and stakeholders uptake and uses. This interface includes visual model of the crop (Shape, size, height, weight), nutritional denseness (presence of desired nutrition), organoleptic (taste and textures), adoption (cultural attachment), commercialization (economic and financial reasons).

2.4. **Dynamics of Plant Breeding**

Dynamics has its origins in the Greek word dynamis, "force, power." In physics, dynamics is the study of bodies in motion and changes in that motion, and that idea can be applied to other areas of specialization. Thus, it is the science of the motion of bodies and the action of forces in producing or changing their motion. It can be physical, moral, or intellectual forces or the laws relating to them.

Plant breeding dynamics means the force, energy, enthusiasm, excitement, and interaction that result into development and advancement of the art and science of Plant breeding. Plant breeding is the art and science of changing the traits of plants in order to produce desired characteristics. Plant breeding can be accomplished through many different techniques ranging from simply selecting plants with desirable characteristics for propagation, to more complex molecular techniques. Plant breeding started with sedentary agriculture and particularly the domestication of the first agricultural plants, a practice which is estimated to date back 9,000 to 11,000 years. Plant breeding is the purposeful manipulation of plant species in order to create desired genotypes and phenotypes for specific purposes. Classical plant breeding uses deliberate interbreeding (crossing) of closely or distantly related individuals to produce new crop varieties or lines with desirable properties. Plant breeding deals with the improvement of various characters. Plant breeding is a highly dynamic science that has experienced tremendous development during the last century. The development and advancement of plant breeding from conventional methods to use of genomics is allowing the incorporation of new tools and resources to address the important new challenges of plant breeding.

The breeder must be dynamic in his area of specialization (Plant Breeding), to make visible impact in national and international communities. The plant Breeder must have great listening ability, must not be shy to exploit options, not afraid of rejection or denials,

2.5. Historical Aspect of Breeding

In its primitive form, plant breeding started after the invention of agriculture, when people of primitive cultures switched from a lifestyle of hunter-gatherers to sedentary producers of selected plants and animals. Views of agricultural origins range from the mythological to ecological. This lifestyle change did not occur overnight but was a gradual process during which plants were transformed from being independent, wild progenitors, to fully dependent (on humans) and domesticated varieties. Agriculture is generally viewed as an invention and discovery. During this period, humans also discovered the time-honored and most basic plant breeding technique as selection, the art of discriminating among biological variation in a population to identify and pick desirable variants. Selection implies the existence of variability. In the beginnings of plant breeding, the variabilities exploited were the naturally occurring variants and wild relatives of crop species.

2.5.1. Pre-Mendelian Era

Early plant breeders did not deliberately create new variants, but they are observers turned to selecting good crops from the limited natural variability in existence. The pre-mendelian breeders are not very knowledgeable about genetic and its application, They are aware of heredity but no research was able to prove its usefulness as contribution towards crop improvement. Most of the pre-mendelian breeders are selectionists based on physical appearance without genetic bases, rules and codes.

2.5.2. *Post-Mendelian Era*: Gregor Johann Mendel (1822–1884) was Australian Monk, also a Biologist, Meteorologist and Mathematician is adjudged the "father of genetics". He has developed the 3 principles or laws of inheritance that described the transmission of genetic traits with the help of experiments with plant hybridization. Genetics stimulated research to enhance crop production through Plant Breeding (Figures 3 and 4) as milestone in plant breeding across several centuries. Below are the 3 laws that shaped the thinking of genetics and produce the modern Plant Breeders:

2.5.2.1. *Law of Dominance*

This is also called Mendel's first law of inheritance. According to the law of dominance, hybrid offspring will only inherit the dominant trait in the phenotype. The alleles that are suppressed are called the recessive traits while the alleles that determine the trait are known as the dominant traits.

2.5.2.2. *Law of Independent Assortment*

Also known as Mendel's second law of inheritance, the law of independent assortment states that a pair of traits segregates independently of another pair during gamete formation. As the individual **heredity** factors assort independently, different traits get equal opportunity to occur together

2.5.2.3. Law of Segregation

The law of segregation states that during the production of gametes, two copies of each hereditary factor segregate so that offspring acquire one factor from each parent. In other word, allele (alternative form of the gene) pairs segregate during the formation of gamete and re-unite randomly during fertilization. This is also known as Mendel's third law of inheritance.

The post-mendelian era plant breeders or modern plant breeders are able to create new variants and exploit genetic basis, genomics and application of molecular and biotechnological tools to develop and enhance crop improvement. The understanding of these laws is:

1. The law of inheritance was proposed by Gregor Mendel after conducting experiments on pea plants for seven years.
2. Mendel's laws of inheritance include law of dominance, law of segregation and law of independent assortment.
3. The law of segregation states that every individual possesses two alleles and only one allele is passed on to the offspring.
4. The law of independent assortment states that the inheritance of one pair of genes is independent of inheritance of another pair

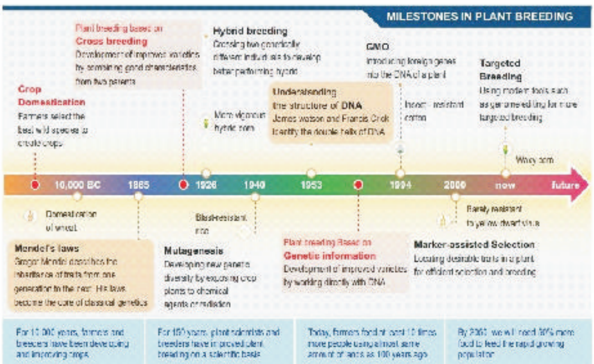

Figure 3: Milestone in Plant Breeding endeavours

Sou

Figure 4: Milestone in tools of Plant Breeding programme

Source: Adapted from Europeanseed.com

3.0. ESSENTIALS OF PLANT BREEDING

3.1. Breeding Schemes

I am involved in all the popular plant breeding types such as Inbreeding or selfing for gene fixation, Backcrossing/introgression for gene pyramiding, resistance breeding, mutation breeding for creating mutants, hybrid breeding for creating new recombinants and genetic engineering for genomic manipulations such as molecular markers, DNA finger printing, gene editing, etc. The basic steps involved in Plant Breeding types are itemized below

3.1.1. *Basic Steps for Different Plant Breeding Methods*

a. Collection of Variability/Creation of variabilities.
b. Evaluation and Selection of Parents.
c. Hybridization.
d. Selection and Testing of Superior Recombinants.
e. Testing Release and Commercialization of New Cultivars.

3.1.2. Who is a Breeder?

Plant breeders are also known as geneticists, genetic engineers or crop improvement specialists. They undertake scientific research into plant and crop-based agriculture with the aim of improving plants using breeding techniques to develop new strains/types of crops. Plant breeders improve existing plant varieties/cultivars or create new ones to improve appearance, resistance to disease, yield and other characters of interests. They may work in a commercial, academic or research setting.

3.1.3. Qualifications and training of Plant Breeders

A degree in biological sciences, biotechnology, botany, genetics, agriculture, horticulture or crop or plant science is normally required. A postgraduate qualification at Master of Science and Doctor of Philosophy in Plant Breeding are very necessary. Apart from the required degrees, a Plant breeder must have working or practical application knowledge of statistics/biometrics, experimental design, crop production technics, molecular technology, all aspect of crop protection, basic soil science, extension, sociology, marketing, etc. The Plant Breeder continues to train and retrain throughout his/her work life to overcome new crop challenges, use of new technologies and knowledge ability; Thus, the basis of BREEDERS' ARROGANCE.

3.1.4. Key responsibilities of Plant Breeders include:

a. Setting research aims and objectives
b. Producing project plans and budgets
c. Researching new methods of plant breeding
d. Undertaking laboratory, glasshouse and field trials
e. Analysing and interpreting data
f. Identifying the best varieties/species
g. Selecting parent plants for cross-breeding
h. Keeping records of your research and findings
i. Presenting scientific findings and other work
j. Making presentations
k. Writing technical publications and reports
l. Keeping up to date with current developments
m. Liaising with other plant breeders
n. Interacting with stakeholders; farmers and industrialists to

breed for specific traits
o. Managing technical staff

3.1.5. *Key skills for plant breeders*

a. Ability to work independently and motivate others
b. Excellent research skills
c. Good interpretational and flexibility skills
d. Basic computer literacy
e. Ability and stamina to manage laboratory and field
f. Patience, resilience and problem-solving skills
g. Good oral and written communication skills
h. Technical and innovative skills
i. Analytical and investigative skills
j. Strong team working skills

3.2. **Breeding Objectives**

The following are the major objectives of plant breeding:

a. To increase the crop yield.
b. To raise plants with desired characteristics.
c. To develop a disease-resistant crop.
d. Breed crops for tolerance to environmental stress (heat, salinity and drought).
e. To breed for aesthetic value
f. To breed for nutritional advantage
g. Breeding for adaptation and target locations
h. Breeding for socio-cultural demands
i. Breeding for economic empowerment
j. Increased tolerance to insect pests
k..Increased tolerance of herbicides
l. Longer storage period for the harvested crop

Figure 5: Plant Breeding Objectives

3.3. **Breeders Mentality**

a. Believe in yourself, ability and capabilities
b. focused, determined and having a cutthroat attitude
c. compromise FOR your goals never compromise ON goals
d. strong determination and willpower to get things done regardless of the hurdles
e. stand up again after the hit and heat without making excuses
f. Be calm and in control in times of adversity and look for solutions
g. Watch , learn, adopt and implement other successful breeders
h. Surround yourself with successful breeders; positive mindset propel positivity

3.4. **Comprehensive Nature of Plant Breeding**

A lot of resources (human, funds, infrastructure), energy and hard work are devoted into the science and art of plant breeding to achieve a life time ambition of variety release and commercialization. Figure 6 is a typical schematic example of intricacies that leads to successful plant breeding programme with resultant improved variety.

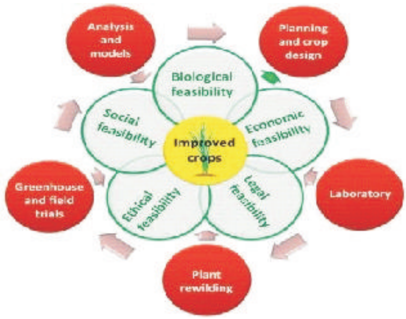

Figure 6: Intricacies of successful plant breeding programmes

3.4. Inside The Breeders' Dynamics

This is the force, zeal, strength and energy that the Plant Breeder needs to overcome complexities and challenges facing him/her. The challenges are often associated with the most important asset that the Plant Breeder has at his/her disposal is the whole plant (for tissue culture and other genetic manipulation), flower (for hybridization) and seed (to produce true to type). The flower is the most commonly used part by Plant Breeders, Figure 7 and 8 are diagrams of typical flower parts.

There are commonly four distinct whorls of flower parts: (1) an outer calyx consisting of sepals; within it lays (2) the corolla, consisting of petals; (3) the androecium, or group of stamens; and in the center is (4) the gynoecium, consisting of the pistils. Figure 7 and 8 show the different floral parts identified.

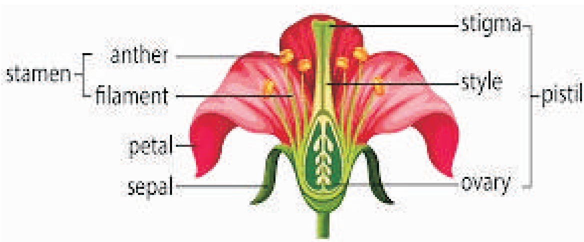

Figure 7: Typical longitudinal section of a flower

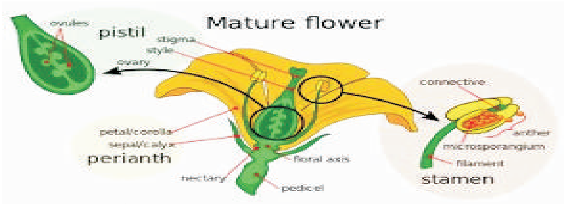

Figure 8: Expanded flower

- **Peduncle:** This is the stalk of the flower.
- **Receptacle:** It is that part of the flower to which the stalk is attached to. It is small and found at the centre of the base of the flower.
- **Sepals:** These are the small, leaf-like parts growing at the base of the petals. They form the outermost whorl of the flower. Collectively, sepals are known as the calyx. The main function of the calyx and its sepals is to protect the flower before it blossoms(in the bud stage).
- **Petals:** This layer lies just above the sepal layer. They are often bright in colour as their main function is to attract pollinators such as insects, butterflies etc to the flower. The petals are collectively known as the corolla.
- **Stamens:** These are the male parts of a flower. Many stamens are collectively known as the androecium.
- They are structurally divided into two parts:
    - **Filament:** the part that is long and slender and attached the anther to the flower.
    - **Anthers:** It is the head of the stamen and is responsible for producing the pollen which is transferred to the pistil or female parts of the same or another flower to bring about fertilization.

Pistil: This forms the female parts of a flower. A collection of pistils is called the gynoecium.

4.0. MY RESEARCH FOCUS AND CONTRIBUTION TO KNOWLEDGE

4.1. **Complexities encountered**

Mr. Vice Chancellor Sir. The breeding objectives of Plant Breeding are very numerous and very challenging for the Plant Breeder. Particularly, the current climate change and increase in human and animal populations are alarming. Similarly, the industrial needs are monumental and getting insurmountable to meet by Plant Breeders (FARA, 2014).

4.1.1. *Breeding Challenges*

The biggest constraints of plant breeding and Plant Breeders are

a. Availability of desirable gene in the crop and its wild relatives.
b. Infrastructure.
c. Trained manpower.
d. Transfer of genes from unrelated sources.
e. Lack of characterization
f. Poor evaluation of genetic diversity
g. Lack of documentation of data
h. lack of inter species relationship
i. Lack of strong breeding program
j. Funding sources.

4.1.2. *Crop Floral Design*

The floral biology and structure of crop plants (Figures 7 and 8) are very important to Plant Breeders, which forms part of plant biology that the Plant Breeder needs to study and understand to help make pre-plant breeding decisions of types of plant breeding method to adopt. Flower incompatibility make hybridization difficult, thus, it could be a major hindrance to successful crop breeding. The self and cross pollinated flowers are quite different and require different approaches to carry out a successful breeding activity on them (Britania, 2023)

4.1.3. *Yield increase*

Throughout the existence of agriculture, one of the main issues of interest to farmers and other stakeholders was the issue of increasing crop yield. Yield is a complex character with several factors contributing to high or low crop yield. Thus, questions such as what are the best ways to increase crop yield per acreə What are the factors that affect crop yield mostə Recently, in view of the constant growth of the world's population, this issue is becoming more and more relevant. What can growers do to have bountiful crop harvestə The most viable, valuable, cheap and readily available way of yield increase is to breed for per se yield increase (high yielding quality seeds). I have worked on crop yield increase in Sorghum, Maize, Rice, Cowpea, etc using selection indices, genetic gains, hybridization to breed for yield gains (**Showemimo,** 2002, Showemimo, **2007**)

4.1.4. *Nutritional gain*

Malnutrition represents a serious issue in Nigeria. The statistics for children under five shows that 19.9% children are underweight, 32.0% are stunted and only 58.2% of children are appropriately breastfed. Malnutrition statistics indicate severe nutritional gaps occurring during the crucial first 1000-day window of a child's life and continuing through to early childhood. Under-nutrition, overweight and obesity are on the rise, especially among adults in urban areas. Consumption of nutritious animal source foods such as fish has remained static, consumption of vegetables and pulses has declined by 7%, and consumption of sugar-sweetened beverages has increased by 39%. In Nigeria, 5 of the top 10 risk factors that drive disability and death are related to diets. All these gaps in diet quality stemming from insufficient dietary intake, to micronutrient deficiencies and to overconsumption point to critical flaws within the national food system. The major nutritional problems and their consequences are identified below. Breeding biofortified crop is a ready solution such as for cereals as seen in our research publication (Showemimo, *et al.*., 2020, Odame, *et al.*, 2013, Walker, *et al.*, 2014). The following are necessary vitamins, micro and macro nutrients needed for human wellbeing.

i. *Vitamin D deficiency*

Vitamin D is vital for maintaining bone health. It is also known to prevent certain types of cancers. Some symptoms of vitamin D deficiency include fractures, bone and muscle weakness, and osteoporosis. Lack of vitamin D can also lead to diabetes, blood pressure, and multiple sclerosis. In children, it causes rickets.

ii. *Vitamin A deficiency*

Vitamin A is essential for healthy eyesight, strong immunity, and cell development. It can lead to blindness and damage the immune system.

iii. *Vitamin C deficiency*

This is important for strong immunity and healthy skin. It can cause weight loss, fatigue, damaged and dry skin, etc. A person with a lack of this vitamin can get injured easily.

iv. *Vitamin B12 deficiency*

Vitamin B12 is responsible for maintaining a healthy nervous system and the production of red blood cells. Lack of this vitamin causes Crohn's disease, parasitic infestation, celiac disease, and atrophic gastritis.

v. *Protein deficiency*

Proteins, considered the body's building blocks, are essential for strong and healthy bones and muscles. A protein deficiency can lead to fatigue, weakness, slow healing of wounds, and oedema of the legs, hands, and abdomen. Lack of protein causes malnutrition disorders such as Marasmus and Kwashiorkor in children.

vi. *Iron deficiency*

Anaemia is one of the most common problems caused due to iron deficiency. Lack of iron also causes fatigue, paleness, and shortness of breath. Iron is a crucial mineral for making haemoglobin in the blood.

vii. *Iodine deficiency*

Iodine is an essential mineral for the production of thyroid hormones, which help in growth, and brain development and regulates our metabolic changes. Goitre is a common problem of iodine deficiency. In children, this deficiency causes mental retardation and growth abnormalities.

viii. *Folate deficiency*

Folate plays a vital role in the formation of RNA and DNA. If a pregnant woman has folate deficiency, the child can develop congenital disabilities such as spina bifida. Fatigue, mouth sores, swelling of the tongue, and greying of hair are some symptoms of folate deficiency.

4.1.5. *Brewing advantages*

The brewing industries are faced with challenges of crops having great malting qualities. The Plant Breeders are relied on to provide or improve crop with excellent brewing advantages. Such crops must have indicators of malting quality: malt extract (ME), diastatic power (DP), kolbach index (KI), wort viscosity (VIS), free amino nitrogen (FAN) content, soluble protein (SP) content, wort β-glucan (WBG) content, and protein content (PC). These are very difficult and complex characters to breed or inculcate into specific crops. Thus, the Plant Breeder is expected to overcome such complexities. My particular involvement in this area of research is in brewing and malting quality of Sorghum by my graduate supervisor, Late Professor C. C. Nwasike on SAMSORG-17 (SK5192) with high and acceptable brewing quality (Nzelibe and Nwasike, 1995). I also used SAMSORG-17 in other quantitative and qualitative genetic studies (**Showemimo, 2006**).

High quality malting quality crop should have the following characteristics and they are complex characters to breed:

- Pure lot of an acceptable variety
- Plump and uniform kernels
- Less than 5% of peeled, broken, or damaged kernels
- Germination of 95% or higher
- Protein content between 9.5% to 12.5% (dry basis)
- Moisture content below 13.5%
- Free of disease and low DON content
- Clean and free of insects, admixtures, ergot or foreign material

4.1.6. *Ornamental uses*

Floricultural or ornamental crops are for wellness and meditational recreation very popular in Europe, Asia and America where it command premium price. Breeding such crops, though not popular in most African countries is very lucrative but difficult to achieve the breeding goals. All I have done in this area is review research to present invited paper at a training workshop in Beijing China (S**howemimo, 2008**). Some of the acceptable characters for ornamental crop breeding are time consuming, there are different breeding methods, and it requires a lot of funding. The special characters include

4.1.6.1. *Quality attributes*

It is the most important attribute and they vary for several crops. Such as novel colour, longer spike length, more number of florets /spike, orientation of florets on the spike etc. For other crops, it includes flower colour, stem length and strength, bud length, bud shape, freeness from blemishes etc.

4.1.6. 2. *Flower variations*

Variations in flower colour, shape, size and form and foliage characters etc. are other important considerations in flower crop improvement programme.

4.1.6.3. *Flower yield advantage*

Increase yield of economic produce. In floricultural crops, increasing yield signifies increased number of flowers per plant per unit area. A newly evolved variety with suitable quality characteristics could only be commercialized if it is giving optimum flower yield and could give economic returns to the growers.

4.1.7. *Resistance to biotic stress*

Biotic stress is stress that occurs as a result of damage done to an organism by other living organisms, such as bacteria, viruses, fungi, parasites, beneficial and harmful insects, weeds, and cultivated or native plants. Plants struggle with many kinds of biotic stresses caused by different living organisms like fungi, virus, bacteria, nematodes, insects etc. These biotic stress agents cause various types of diseases, infections and damage to crop plants and ultimately affect the crop productivity.

Selection is an important method for breeding of varieties resistant to biotic stresses. It is an important means of isolating or identifying sources of disease resistance. Normally the sources of resistance are available in natural populations, wild species, introductions and spontaneous mutants. Resistance breeding is **an** important strategy for reducing crop losses caused by disease. The innate immune system allows plants to recognize their pathogens, often providing strong levels of resistance. Such qualitative resistance is, however, often rapidly overcome as pathogens evolve to evade recognition. I have contributed to scientific knowledge in the area of resistance breeding researches. I had published research findings in area of entomology and weed stresses tolerance and resistance (**Showemimo, 2006, Showemimo,** and Kimbeng, 2005).

Things to note in breeding for resistance to biotic stresses:

i. Resistance breeding is an important strategy for reducing crop losses caused by disease.
ii. The innate immune system allows plants to recognize their pathogens, often providing strong levels of resistance. Such qualitative resistance is, however, often rapidly overcome as pathogens evolve to evade recognition.
iii. In addition to innate immunity, plants also have diverse defences that are more subtle in their effects and are only beginning to be understood. Quantitative resistance is considered to be more durable than qualitative resistance.
iv. Breeding for long-lasting resistance is critical in many plant–pathogen systems and typically involves combining multiple and diverse resistance genes.
v. Sustainable approaches to disease management involve breeding for genotypes with diverse resistance loci but can also entail the use of diversity among plants at different spatial and temporal scales.
vi. New breeding methods can increase crop improvement. However, which resistance genes are used, their performance over time (durability) and their influences on

other traits (trade-offs) must be considered and assessed as part of the breeding process.

4.1.8. *Resistance to abiotic stress*

Abiotic resistance may be defined as the resistance of plants against abiotic factors such as flood, drought, salinity, heat, low nitrogen, water logging, frost, lodging to increase the yield of the crop. Four breeding methods, viz. 1) Introduction 2) Selection 3) Hybridization 4) Mutations are commonly used for development of drought resistant crop cultivars. In self-pollinated crops, introduction, pure line selection, mass selection, hybridization (Pedigree method and backcrossing) and mutation breeding are used. I have worked and I am still working on low nitrogen efficiency, drought tolerance, salt resistance/tolerant crops (Showemimo, and Olarewaju, 2007, Kargbo, *et al.*, 2019)

Effects of abiotic stress on crops:

a. Reduced seed germination and seedling development
b. Poor vegetative growth
c. Reproductive growth is severely affected
d. Plant height and leaf area reduced
e. Significantly reduction in leaf weight
f. Reduced photosynthesis
g. Reduced stomatal conductance
h. Significantly reduction in the total dry matter.

4.1.9. *Crop adaptation issues*

Adaptability is defined as the ability of a crop (or variety) to respond positively to changes in agricultural conditions. The trait is genetically controlled and provides an ability to exploit environmental attributes, both natural and agronomic. At the societal level, the major factors constraining them from adapting to climate change were poverty, farmland scarcity and inadequate access to more efficient inputs, lack of information and poor skills, land tenure and labour constraints. Adaptations make it easier for plants to survive in their specific habitat, and reproduce, passing those traits on to their offspring. All plants, no matter where they grow, are adapted to certain conditions, which can include temperature, available water, soil type, and interactions with animals and other organisms. Crop adaptation issue is largely referred to as Genotype x Environmental interaction. Multi-locational testing and farmers participatory selection and testing is prerequisite to variety releases. I had been part of all the cereals varietal evaluation in several environments by the Plant Breeding team of Institute of Agriculture Research, Ahmadu Bello University.

Factors that affect crop adaptation are:

a. Water
b. Wind
c. Sunlight
d. Temperature
e. Rainfall
f. Photosynthesis
g. Microbes increase the fertility of the soil
h. Pollinating agents

Plant breeders are expected to breed crops stable, durable and having good yield under good and extreme environmental conditions. Such breeding activities involve time and money to accomplish. More so, the issue of climate change is continuum and a major concern to plant breeders and other stakeholders

4.1.10. *Crop adoption and social context***:**

Improved agricultural technology is the use of technology in agriculture with aim of improving yield, efficacy and profitability. Consequently, to curtail food and nutritional insecurity, which is a problem in our society today, smallholder farmers as a matter of fact must adopt improved agricultural technologies to increase productivity of food crops (Sennuga, *et al.*., 2020; Jegede, *et al.*., 2021). Technology is primarily of two components which are physical components and informational components. Despite the fact that sustainable agricultural technologies and practices have been developed and introduced to farmers in both developed and developing countries, there are concerns about low levels of adoption. Empirical evidence of the past 40 years shows that adoption of new practices can be hindered by a wide range of factors, from financial to attitudinal, from personal to social, from agronomic to regulatory. Conclusions that can be generalized across different contexts could help in moving the institutional and policy environment in a direction that strengthens the move towards a more sustainable food production. Figure 9 summarizes the issues of new technology adoption in our social context

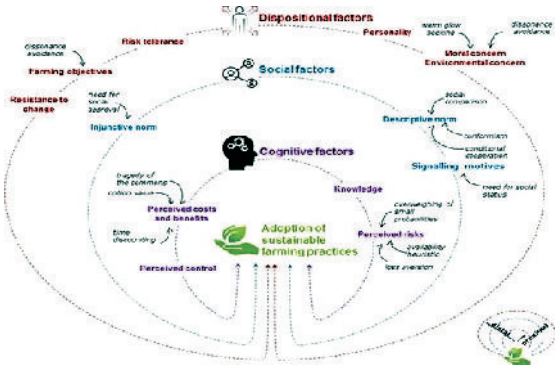

Figure 9: Crop adoption Social matrix

4.2. **Choices Available**

Plant Breeders are constantly faced with making choices, I strongly believe that looking inward is necessary before outward. So what are the choices available to Plant Breedersə Choices to improve or create a new crop cultivar are based on the use of different methods, and mode of crop reproduction available, which include:

a. Self-fertilization, where pollen from a plant will fertilize reproductive cells or ovules of the same plant

ii. Cross-pollination, where pollen from one plant can only fertilize a different plant

Iii. Asexual propagation (e.g. runners from strawberry plants) where the new plant is genetically identical to its parent

iv. Apomixis (self-cloning) where seeds are produced asexually and the new plant is genetically identical to its parent

The mode of reproduction of a crop determines its genetic composition which, in turn, is the deciding factor to develop suitable breeding and selection methods. Knowledge of mode of reproduction is also essential for its artificial manipulation to breed improved types (Figures 10, 12 and Table 1). Only those breeding and selection methods are suitable for a crop which does not interfere with its natural state or ensure the maintenance of such a state. It is due to such reasons that imposition of self-fertilization on cross-pollinating crops leads to drastic reduction in their performance.

Practical breeding purpose, identified four categories of plant breeding: Line breeding (autogamous crops), population breeding (allogamous crops), hybrid breeding (mostly allogamous crops, some autogamous crops), clone breeding (vegetatively propagated crops).

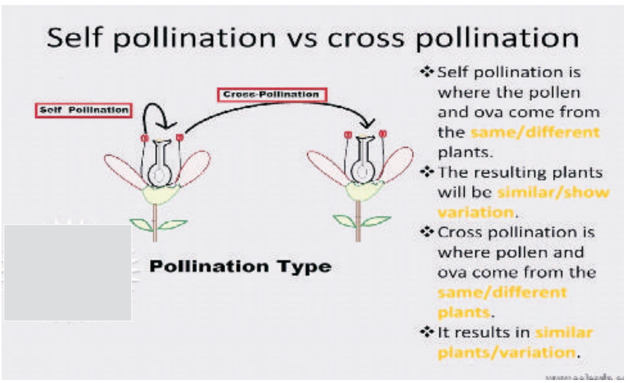

Figure 10: Advantages of self and cross pollinated crop plant

Table 1: Comparative analysis between sexual and asexual method of plant reproduction

	Sexual reproduction	Asexual reproduction
1	It involves the fusion of the male and female gamete.	It does not involves the fusion of the male and the female gamete
2.	It requires two (usually) different individuals.	It requires only one individual.
3.	The individuals produced are not identical to their parents and show variations from each other and also, from their parents.	The individuals produced are identical to the parent and are hence, called clones.
4.	Most animals reproduce sexually. Both sexual and asexual modes of reproduction are found in plants.	Asexual modes of reproduction are common in organisms having simple organizations such as algae and fungi.
5.	It is a slow process.	It is a fast process.

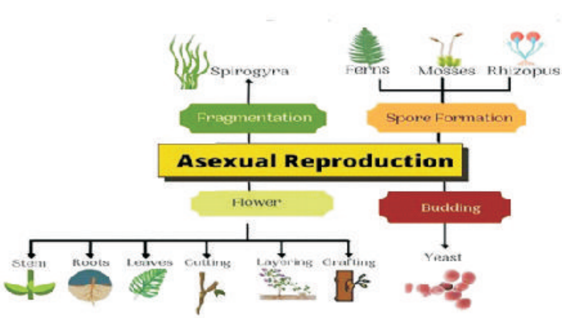

Figure 11: Asexual mode of plant reproduction
Source: www.plantsrepeoduction.com

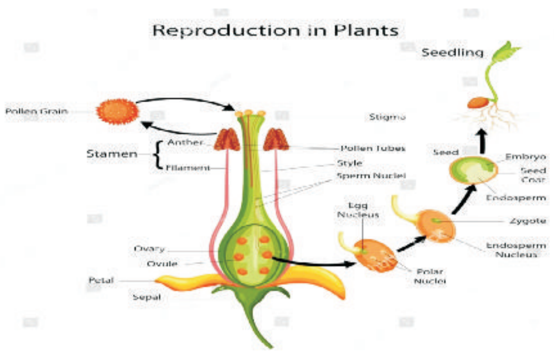

Figure 12: Process of reproduction in Plant
Source: www.plantsrepeoduction.com

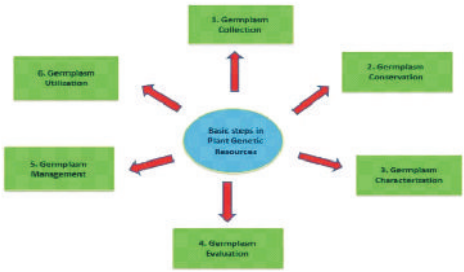

Figure 13: Basic steps in deployment of Plant Genetic Resource

4.2.1. *Germplasm build-up*

Germplasm is the term used to describe the seeds, plants, or plant parts useful in crop breeding, research, and conservation efforts. Plants, seed, or cultures are germplasm when maintained for the purposes of studying, managing, or using the genetic information they possess. They are genetic resources such as seeds, tissues, and DNA sequences that are maintained for the purpose of animal and plant breeding, conservation efforts, agriculture, and other research. Germplasm consists of land races, modern cultivars, obsolete cultivars, breeding stocks, wild forms and wild species of cultivated crops (Figures 13 and 14). Germplasm includes both cultivated and wild species and relatives of crop plants. Several kinds of germplasm collections have evolved over the years in response to particular needs: base collections, back-up collections, active collections, and breeders' or working collections. I have been involved in germplasm collections, using various methods of collections, particularly wild relatives and farmers planting materials. That was what gave us 2 improve open pollinated sorghum and Ofada rice that were released as commercial varieties in Nigeria and other Countries (**Showemimo, *et al.*, 2011**).

4.2.2. *Exotic genotypes*

These are Plant Genetic Resources. They include wild species, released varieties from other countries and landraces which often carry many agriculturally desirable and undesirable alleles that need to be worked on in their new environment (Figure 12).

However, genetic studies can identify the agriculturally valuable traits of wild species, and introgression breeding can transfer these traits to commercial varieties

4.2.3. *Local collections*:
Local Variety means a plant variety, which originates within the country, adapted but not improved within the country, registered in the Community/State Biodiversity Registry and other crop types declared by the National Center for Genetic Resources and Biotechnology (NACGRAB), Ibadan Nigeria as localized crop.

4.2.4. *Selection for breeding purpose*:
Selection is the basis of planting breeding. This refers to the art of selection (skills, talents and experience). It is also the ability to walk into a field and advance a subset of plant individuals (by saving their seeds/tubers/cuttings and replanting them) that meet our objectives. Looking back through time, this is how crops were domesticated and improved upon. Farmers picked out the plants that yielded the best, had large edible parts, weren't bitter, hairy or poisonous, etc. This is in contrast to natural selection or "survival of the fittest," which of course happens in natural ecosystems, but also happens in agricultural fields too. The ability to practice selection in our field depends on genetic diversity that is expressed in the plant's phenotype (Figure 13 and 14). The following are useful terminologies associated with crop selection:

i. Allele
One of several versions of a gene; different versions have different functions or are non- functional. It is usually caused by genetic mutation at some point in the crop's history.

ii. Heritability
The proportion of observed (phenotypic) variation that is genetically determined, and therefore heritable by offspring.

iii. Heterozygous
Two different alleles for a gene present in plant; one copy of each.

iv. Homozygous
Two copies of the same allele are present.

v. Segregation
In a population, segregation refers to phenotypic variation resulting from the random assortment of alleles into pollen/egg cells, creating offspring with different phenotypes. For example, some offspring of a heterozygous purple-podded pea plant produce purple pods and some produce green pods.

Figure 14: Sources of variability

4.2.5. *Use of General Combing Ability*

It is the mean performance of a genotype when crossed with a series of other genotypes. Crop breeders typically utilize combining ability analyses to choose parents with high General Combining Ability (GCA). The average contribution or performance of inbred lines in a series of hybrid combinations is known as General Combing Ability (GCA). An inbred line's general combing ability is assessed by crossing it with other inbred lines and comparing the single cross progenies' overall performance. The additive gene activity impacting a genetic trait in such a way that each boosts the trait's expression is referred to as general combining ability. The general combining ability variance estimates additive genetic variance, which is necessary for narrow sense heritability estimation (**Showemimo,** and Olarewaju, 2002). General Combining Ability (GCA) is linked to the breeding value of the parents as additive genetic effects. Therefore, combining ability analysis helps to identify superior parents to be used in breeding programs or to identify promising cross combinations for cultivar development (Acquaah, 2007, Showemimo and Nwasike, 1996).

4.2.6. *Use of Specific Combining Ability*

Specific Combining Ability (SCA) is the departure of the performance of crossings from the average general combining ability of two parental lines. Specific Combining Ability (SCA) is the relative performance of a cross that is associated with non-additive gene action, predominantly contributed by dominance, epistasis, or genotype x environment interaction effects, and is directly related to the breeding value of parents. GCA, SCA and heterosis were obtained for all the first set of Sorghun hybrids released and commercialized in Nigeria (Aba, *et al.*., 2001). I had also used all the above choices in my doctoral studies on head bug resistance in Sorghum (Showemimo *et al.*, 2006).

4.2.7. *Basis for Gene action*

Gene action refers to the behaviour or mode of expression of genes in a genetic population. Knowledge of gene action helps in the selection of parents for use in the hybridization programmes and also in the choice of appropriate breeding procedure for the genetic improvement of various quantitative characters. Thus, Gene action refers to the mechanism through which a gene exerts its influence on a particular phenotypic trait. Hence insight into the nature of gene action involved in the expression of various quantitative characters is essential to a plant breeder for starting a judicious breeding programme. There are four types of gene action: additive, dominance, epistatic, and overdominance.

Main features of gene action are briefly presented below:

i. Gene action is measured in terms of components of genetic variance or combining ability variance and effects.

ii. Depending upon the genetic variance, gene action is of three types, viz. additive gene action, dominance gene action and epistatic gene action. Dominance and epistatic gene actions jointly are referred to as non-additive gene action.

iii. Gene action can be studied with the help of various biometrical techniques such as diallel analysis, partial diallel cross, triallel analysis, quadriallel analysis, line x tester analysis, generation mean analysis, biparental cross and triple test cross analysis.

iv. Gene action is affected by various factors.

Table 2: Gene action in different types of genetic materials

Genetic material	Type of gene action
(*a*) *Self-pollinated species*	
1. Pure line variety	Additive but no genetic variation
2. Mass selected variety	Additive and additive epistasis
3. Multilines	Additive and additive epistasis
4. Varietal blends	Additive and additive epistasis
(*b*) *Cross-pollinated species*	
5. Composite variety	Additive, dominance and epistasis
6. Synthetic variety	Additive, dominance and epistasis
7. Random mating population	Additive, dominance and epistasis
(*c*) *Both self and cross-pollinated species*	
8. F_1 Hybrid	Non-additive and no genetic variation
9. F_2 population	Additive, dominance and epistasis

Role of gene action in Plant Breeding:

Knowledge of gene action is useful to a plant breeder in three principal ways:

i. Selection of parents for hybridization

ii. Choice of breeding procedures for the genetic improvement of various quantitative characters, and

iii. Estimation of some other genetic parameters.

4.2.7.**1.** ***Selection of Parents***

Selection of parents for hybridization is an important step in plant breeding. Good general combining parents can be identified by combining ability analysis. In self-pollinated species, good general combining parents can be used in the hybridization programme for obtaining superior segregates in the segregating generations and in cross pollinated species such parents can be used for the development of synthetic and composite varieties.

4.2.7.**2.** ***Choice of Breeding Procedure***

The inheritance of yield and most of the yield contributing characters is polygenic in nature and displays continuous variation. The choice of appropriate breeding procedure depends on the type of gene action involved in the expression of these characters in a genetic population

Table 3: Breeding procedures in relation to gene action

Type of gene action	*Breeding procedure to be adopted*	*Possible outcome*
(a) Self-pollinated species		
1. Additive	Pure line selction Mass selection Progeny selection Hybridization and selection	Pure line variety Mass selected variety New variety Superior segregant or new variety
2. Non-additive	Heterosis breeding	Hybrid variety
(b) Cross-pollinated species		
1. Additive	Recurrent selection for *gca* Synthetic breeding Composite breeding	Population improvement Synthetic variety Composite variety
2. Non-additive	Heterosis breeding Recurrent selection for *sca*	Hybrid variety Population improvement
3. Both additive and Non-additive	Reciprocal recurrent selection	Population improvement

4.2.8. *Application of Heterosis*

The mid-parent heterosis (MPH) and better-parent heterosis (BPH) were calculated by the formulas as follows: **MPH = [F_1-(P_1 + P2$_)$/2]/[(P_1 + P_2)/2] × 100%** and BPH = (F_1-HP)/HP × 100%, where F_1 is the value of F_1 hybrids, P_1 and P_2 are the phenotypic value of parents, HP is the phenotypic value of higher value parents. The following are classification of heterosis:

4.2.8.1. ***Average heterosis***

In quantitative genetics, mid-parent heterosis refers to a hybrid's superiority over the mean of its parents. Average heterosis or relative heterosis occurs when the hybrid outperforms the mid-parent. On the basis of the mid-parents, the average heterosis in the crosses was calculated. Several researchers have determined it for a variety of agronomic and physiological parameters in diverse crops.

4.2.8.2. ***Heterobeltiosis***

Blum, *et al.*. (1990) defined heterosis as the hybrid's advantage over the best parent, as measured in comparison to the superior or a better parent. The dominance or overdominance of the hybrid over the better parent resulted in its superiority. The degree of heterosis provides the simplest and easiest measure of genetic diversity and gives a preliminary idea about the likely gene action involved in determining a particular character. Parent versus crosses performance is probably the most basic comparison in quantitative inheritance, and the degree of heterosis provides the simplest and easiest measure of genetic diversity and gives a preliminary idea about the likely gene action involved in determining a particular character (Kargbo, *et al.*, 2019). For various crop traits, several authors reported heterosis over better parents.

4.2.8.3. ***Standard heterosis***

Standard heterosis refers to a hybrid's higher performance in terms of desired features above a standard commercial hybrid variety (Akinwale, *et al.*, 2014). It is also known as economic heterosis and has practical significance in plant breeding. The commercial value of a hybrid would be determined mostly by how well it performed in relation to the best commercial variety of the crop species in question. Standard heterosis is the most essential from a practical standpoint since it aims to generate desired hybrids that outperform existing high-yielding commercial varieties (Kargbo, *et al.*, 2019)

.4.2.8.4. *Heterotic grouping and heterotic pattern*

When related or unrelated genotypes from the same or separate populations are crossed with genotypes from other genetically distinct germplasm groups, they show similar combining capacity and heterotic response (Begna, 2021). Heterotic grouping is the process of identifying genetically diverse groups that produce superior hybrids when crossed based on morphological per se performance and genetic relationship. Heterotic grouping identifies suitable hybrid parents by combining ability information (Akinwale, *et al.*, 2014). Based on specific combining ability (SCA) effects of grain yield (Kargbo, *et al.*, 2019) and heterotic grouping based on General Combining Ability (GCA) of multiple traits (HGCAMT). This is the approach of classifying existing germplasm into various heterotic groups and identifying eligible parents for making crosses (Akinwale, *et al.*, 2014).

Any breeding program targeted at hybrid production must start with the identification of inbred lines with a strong combining ability. As a result, information on combining ability-based heterotic grouping can assist breeders in choosing parents for crosses. To get the most out of heterosis for hybrid cultivar development, germplasm must be assigned to different heterotic groups. Similarly, knowledge on genetic diversity is critical for hybrid breeding and population improvement project, which use it to analyze genetic variety and categorize individuals into heterotic groups. It is preferable to organize the germplasm into heterotic groups for an efficient hybrid breeding effort.

The key to ensuring sustained genetic gain in hybrid breeding is to broaden the genetic foundation of heterotic pools. The heterotic grouping of parental lines and identification of their combining ability aided in the selection of parents and breeding tactics for effective hybrid creation. Studies of germplasm combining capacity and heterotic grouping improve its use inbreeding and the selection of suitable parents for superior hybrid combinations (Akinwale, *et al.*, 2014). Crosses between inbred lines from genetically dissimilar groups are likely to have higher degrees of heterosis than crosses between lines from genetically related groups. A heterotic pattern is a set of heterotic groups, which might be populations or lines, that exhibit high heterosis and, as a result, high hybrid performance in their crossings.

The notion of heterotic patterns is essential because it aids breeders in selecting parents for line development and testers in evaluating the combining capacity of newly generated inbred lines, simplifying germplasm administration and organization (Akinwale, *et al.*, 2014). Heterotic groups and patterns assist breeders in making more efficient and consistent use of their germplasm by utilizing complementing lines to maximize the results of a hybrid breeding effort. In order to make use of heterosis for hybrid formation, germplasm must be assigned to different heterotic groups and patterns. Once heterotic groups and patterns have been identified, a high number of hybrid combinations can be created in a short period of time due to the grouping of lines into distinct clusters which prevents the generation of unneeded hybrids from heterotic patterns.

Heterosis is shown in F_1 hybrids produced by crossing two inbred parents that perform better. The nature and magnitude of heterosis over mid-parent, heterobeltiosis, and economic heterosis present in genetic stocks influence the choice of parents for effective hybridization. The positive or negative reaction of heterosis is largely determined by the breeding aims and the type of crops employed. Heterosis has contributed greatly to enhanced crop productivity and is the foundation of global agribusiness worth billions of dollars.

4.2.9. *Implication of Heritabilities*
Two specific types of heritability can be estimated. The broad-sense heritability is the ratio of total genetic variance to total phenotypic variance. The narrow-sense heritability is the ratio of additive genetic variance to the total phenotypic variance. Heritability estimates range in value from 0 to 1.

i. Broad-sense Heritability (h^2_{bs}) is expressed as $\mathbf{h^2} = \delta^2_g/\delta^2_{\mathbf{p}}$, where h is the heritability estimate, δ^2_g the variation in genotype, and $\delta^2_{\mathbf{p}}$ the variation in phenotype.

ii. Narrow-sense heritability is expressed as $\mathbf{h^2} = \delta^2_A/\delta^2_P$, δ^2_A is the variation in additive genetic variance/value δ^2_P is the variation in the total phenotypic variance

Narrow-sense heritability is calculated by dividing additive genetic variance by total phenotypic variance. This narrow-sense heritability captures only that proportion of genetic variation that is due to additive genetic variance/values (V_A), the estimate ranged between 0 and 1 that describes the proportion of total phenotypic variance attributable to additive genetic variance.

4.2.10. *Deployment of Genetic Advance*
Genetic advance explains the degree of gain obtained in a character under a particular selection pressure. High genetic advance coupled with high heritability estimates offers the most suitable condition for selection. The utility of heritability therefore increases when it is used to calculate genetic advance,

which indicates the degree of gain in a character obtained under a particular selection pressure. Thus, genetic advance is another important selection parameter that aids breeders in selection program. According to Johnson *et al.*. (1955) heritability is classified as low (below 30%), medium (30% - 60%) and high (above 60%); and genetic advance (as percentage of mean) is classified as low (<10%), moderate (10% - 20%) and high (>20%).

Formula of genetic advance is
$GA = K \times h^2 \times \delta_P$
Where K is Standard Selection Index
h^2 is heritability of character under selection
δ_P is phenotypic standard deviation

4.3. Creativities and Approaches
Mr. Vice Chancellor, Sir, this aspect of my research has to do with thinking outside the box to solve problems and providing lasting solutions. Most often, the genetic materials readily available are not helpful in solving persistent challenges, thus, the following steps were taken to resolve some of the challenges encountered during my research activities.

4.3.1. *Creating genetic variability*
Genetic variability refers to the tendency of individual genetic characteristics in a population to vary from one another. It may also refer to the potential of a genotype to change or deviate when exposed to environmental or genetic factors. Genetic variants are differences in DNA sequence between individuals in a population. Structural variations, single-nucleotide polymorphisms/variations (SNPs/SNVs), insertion and deletion variations, copy number variations, and translocations and inversions are the main types of variants. It utilizes the genetic variation between individuals within a plant species and combines the desired properties into new and improved varieties. Plant breeding is dependent on genetic variation, and new variation is

fundamentally important for introduction of new traits in breeding programs. The presence of genetic variation in plant populations is useful for conservation and breeding programs. Plant genetic diversity offers opportunity for researchers to develop new improved varieties with, desirable traits, which accommodate both farmers and breeders preferred traits.

4.3.2. *Use of R-Lines, A-Lines and B-Lines*
A-line is the cytoplasm-genetic male sterile line where the male sterility is jointly controlled by recessive nuclear gene and sterile cytoplasm. B-line is isogenic line of A-line, the only difference is in male sterility and fertility. R-line possesses fertility restoration gene. The source of male sterile cytoplasm used is wild abortive. In this method there are three different lines i.e. A-line or male sterile lines, B-line or maintainer line and restorer line or R- line. For maintaining A-line it has to be crossed with B-line and for producing hybrid seed A-line has to be crossed with R-line. The practice of hybridization has greatly contributed to the increase in crop productivity. A major component that exploits heterosis in crops is the cytoplasmic male sterility (CMS)/nucleus-controlled fertility restoration (Rf) system. The development and use of hybrid rice varieties on commercial scale utilizing male sterility and fertility restoration system has proved to be one of the mile stones in the history of sorghum, maize and rice improvement. I worked with R-lines, A-lines and B-line (restorer lines) in the production of the first set of sorghum hybrids released in Nigeria (Showemimo, 1991).

4.3.3. *Hybridization process*
Hybridization is a technique which helps in developing crop varieties having favourable traits like resistance to diseases and pests, high yield, etc. This involves **cross-breeding of parent** plants having desirable features. Hybridization in simple terms is defined as the breeding of two different organisms from genetically diverse groups or species. Hybridization is a very old

technique that has been used to increase the genetic variability among the population. Hybridization is performed on animals as well as plants, this is done to ensure the maximum benefit from the commercial point of view. Classical hybridization techniques are focused to produce a genotype with favourable traits like pest resistance, and high flowering potential among plants to increase their commercial values. Hybridization is also performed in animals to induce genetic variability or heterozygosity of the genome.

Hybridization is largely dependent on the sexual cross between two genetically distant strains of the same species, but due to the presence of various reproductive barriers, breeding was limited to sexually compatible groups, thus limiting the gene flow, which resulted in limited opportunities to improve the crop genotype. Hybridization is performed to produce and promote heterozygous strains over a homozygous generation. The main reason behind this is to improve the crop genotype and establish commercially important traits in crops, for example, drought resistance. When hybridization is performed, favourable traits are selected and plants are bred. These heterozygotes contain the trait from both parents, thus they are assumed to have favourable traits.

Another reason for supporting heterozygosity is the induction of variability. It is the genetic variability among the population that ensures a better chance of survival of the population. Another positive impact of heterozygosity of genome achieved by hybridization includes heterosis, which can be attributed to either dominance, over-dominance, or epistasis. Heterosis is the enhanced performance of the hybrid offspring for the selected traits. This is also known as hybrid vigour or outbreeding enhancement.

Hybridization can be classified into two groups namely, sexual hybridization and somatic hybridization. Sexual hybridization is the comparatively classical approach, it is subjected to the sexual compatibility barrier. Somatic hybridization is a rather modern approach, it is performed in vitro. It can be defined as the fusion of two protoplasts.

There are generally eight steps to hybridization, they are as follows:

1. **Selection of Plant**
   It is referred to as choosing both the parental plants for the process, the plant must be healthy and can grow in the given condition are the two main prerequisites of the process.
2. **Homozygosity**
   Inducing homozygosity in the parental plants is important to establish the purity of lines, that is, eliminating the unwanted traits. It is achieved by self-pollination or selfing of the parental plants over generation to achieve the result.
3. **Emasculation**
   It is the process of removal of male reproductive organs from the flower. It is mainly performed in bisexual flowers and is avoided in unisexual flowers. The removal of anthers or stamens (male reproductive organ) must be carried out without harming the ovum. It is done prior to pollen shading. The following methods that are used for emasculation, scissors method, hot water treatment, alcohol treatment, and suction.
4. **Bagging**
   It can be defined as a method to cover the ovum of the flower. It is done to prevent cross-pollination of the flower by other pollen. The bags are made up of paper, butter paper, and vegetable parchment paper.
5. **Tagging**
   It is the process of attaching a tag to the emasculated plant, which contains information about the number of field

records, date of emasculation, date of crossing, and name of the plant to which it is crossed.

6. **Crossing**
   It is the process of artificial cross-pollination. In this process pollen from selected parents is placed on the stigma of the flower, to allow fertilization.
7. Harvest
   The seeds from this progeny are collected, and are stored with the original tag.

8. **F_1 Generation**
   The seeds give rise to the filial one generation or first filial generation which is then subjected to a selection of hybrids among it.

Results of hybridization include both the positive and negative impacts on the plant, they are as follows:

- **Heterosis** is the hybrid phenomenon through which hybrid progeny shows enhanced performance in certain traits which may include, phenotypic superiority as compared to parents in terms of biotic and abiotic resistance and, increased yield and growth rate.
- **Sterility and unviability** are the main barriers to hybridization. This can be because of incompatible mating, chromosomal rearrangements, or down expression of certain genes due to epistasis.
- Hybrid breakdown is arrested or stunted pollen tube growth, and embryo abortion is also among some of the harmful impacts that can generate in case of unsuccessful hybridization.

4.3.4. *Correlations or character association*

The word correlation is used in everyday life to denote some form of association. We might say that we have noticed a correlation between foggy days and attacks of wheeziness. However, in statistical terms we use correlation to denote association between two quantitative variables. We also assume that the association is linear, that one variable increases or decreases a fixed amount for a unit increase or decrease in the other. The other technique that is often used in these circumstances is regression, which involves estimating the best straight line to summarize the association.

The degree of association is measured by a correlation coefficient, denoted by r. It is sometimes called Pearson's correlation coefficient after its originator and is a measure of linear association. If a curved line is needed to express the relationship, other and more complicated measures of the correlation must be used.

The correlation coefficient is measured on a scale that varies from + 1 through 0 to – 1. Complete correlation between two variables is expressed by either + 1 or -1. When one variable increases as the other increases the correlation is positive; when one decreases as the other increases it is negative. Complete absence of correlation is represented by 0.

4.3.5. *Regression or relationship*

This is a situation where two variables or characters are related and responsive to each other. It means that when one changes by a certain amount, there is a corresponding change on an average by a certain amount on the other variable or character. The relationship can be represented by a simple equation called the regression equation. In this context, "regression" (the term is a historical anomaly) simply means that the average value of y is a "function" of x, that is, it changes with x.

The formula is **Y = a + b X**

Where Y is dependent variable,

X is independent variable,

b is slope and

a is the intercept.

The regression equation representing how much y changes with any given change of x can be used to construct a regression line on a scatter diagram, and in the simplest case this is assumed to be a straight line. The direction in which the line slopes depends on whether the correlation is positive or negative. When the two sets of observations increase or decrease together (positive) the line slopes upwards from left to right; when one set decreases as the other increases the line slopes downwards from left to right (**Showemimo,** and Olarewaju, 2002). As the line must be straight, it will probably pass through few, if any, of the dots.

4.3.6. *Path-coefficient analysis*:

Path analysis is a form of multiple regression statistical analysis that is used to evaluate causal models by examining the relationships between a dependent variable and two or more independent variables. By using this method, one can estimate both the magnitude and significance of causal connections between variables, as seen in Figure 15 (Echekwu and Showemimo, 2004, **Showemimo, *et al.*, 2004**). Typically path analysis involves the construction of a path diagram in which the relationships between all variables and the causal direction between them are specifically laid out.

Key Takeaways of Path Analysis

1. By conducting a path analysis, researchers can better understand the causal relationships between different variables.

2 To begin, researchers draw a diagram that serves as a visual representation of the relationship between variables.
3 Next, researchers use a statistical software program (such as SPSS or STATA) to compare their predictions to the actual relationship between the variables.
4 All causal relationships between variables must go in one direction only (you cannot have a pair of variables that cause each other)
5 The variables must have a clear time-ordering since one variable cannot be said to cause another unless it precedes it in time.

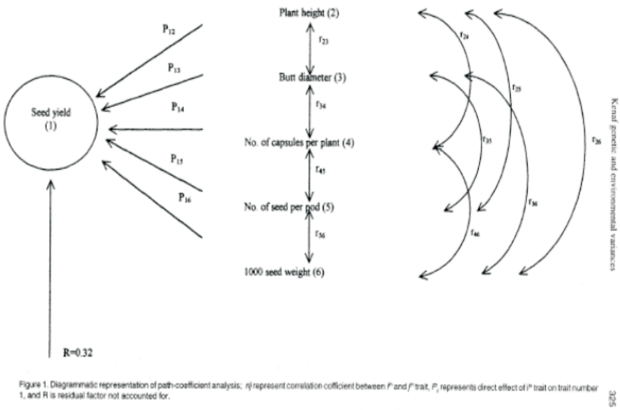

Figure 15: Diagrammatic representative of path analysis in Kenaf

4.3.7. *Principal Component Analysis*

Principal components analysis is a technique that requires a large sample size. It is a popular technique for analyzing large datasets containing a high number of dimensions/features per observation, increasing the interpretability of data while preserving the maximum amount of information, and enabling the visualization of multidimensional data. Thus, it is a tool for identifying the main axes of variance within a data set and allows for easy data exploration to understand the key variables in the data and spot outliers as seen in Figures 16-19 (Showemimo *et al.*, 2021,

Showemimo *et al.*, 2022). Similarly, Principal Component Analysis (PCA) is a technique for reducing the dimensionality of such datasets, increasing interpretability but at the same time minimizing information loss. It does so by creating new uncorrelated variables that successively maximize variance. Finding such new variables, the principal components reduces variation into solving an eigenvalue/eigenvector problem, and the new variables are defined by the dataset at hand, not *a priori*, hence making PCA an adaptive data analysis technique.

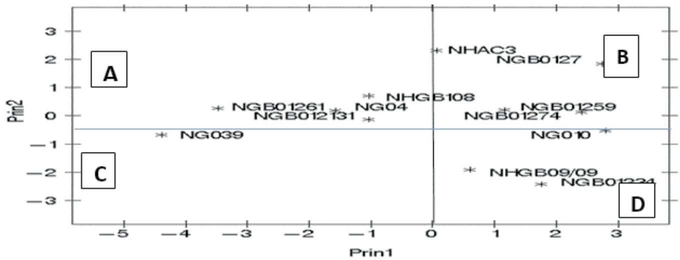

Figure 16: Bi-Plot analysis classifying 12 amaranths based on PC2 vs. Pc1

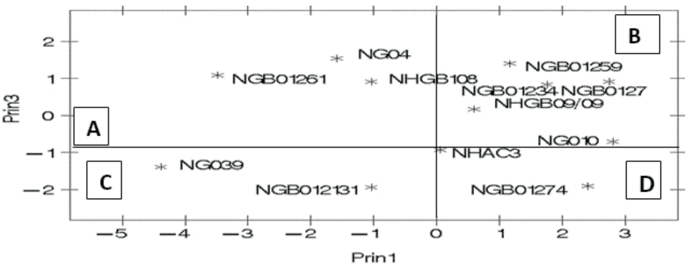

Figure 17: Bi-Plot analysis classifying 12 amaranths based on PC3 vs. Pc1

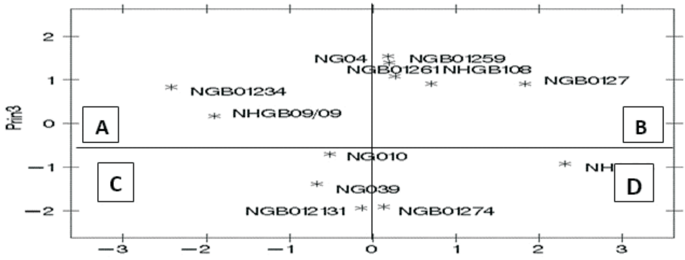

Figure 18: Bi-Plot analysis classifying 12 amaranths based on PC2 vs. Pc2

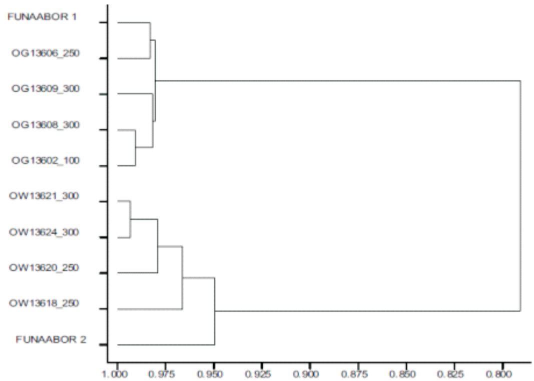

Figure 19: Dendogram from proximate of Ofada mutants (@M and parents

4.3.8. *Mutation Breeding*

Plant mutation breeding, also called variation breeding, is a method that uses physical radiation or chemical means to induce spontaneous genetic variation in plants to develop new crop varieties. "Mutation" is the source of most genetic variation and the motor of evolution. Induced mutagenesis is one of the most efficient tools that has been utilized extensively to create genetic variation as well as for identification of key regulatory genes for economically important traits toward the crop improvement. Mutations can be induced by several techniques such as physical, chemical, and insertion mutagen treatments; however, these methods are not preferred because of cost and tedious process. Nonetheless, with the advancements in next-generation sequencing (NGS) techniques, millions of mutations can be detected in a very short period of time and, therefore, considered as convenient and cost efficient. Furthermore, induced mutagenesis coupled with whole-genome sequencing has provided a robust platform for forward and reverse genetic applications (Adewusi, *et al.*, 2022).

Moreover, the availability of whole-genome sequence information for large number of crops has enabled target-specific genome editing techniques as a preferable method to engineer desired mutations. Numerous induced mutagenesis methods are available for plants. Over the last century, physical mutagens, like fast neutron, UV, X-ray, and gamma radiations, and chemical mutagens, including N-methyl-N-nitrosourea (MNU), sodium azide, hydrogen fluoride (HF), methyl methanesulfonate (MMS), or ethyl methanesulfonate (EMS), have been widely explored. Gamma radiation was used to create variability in FUNAABOR 1 AND FUNAABOR 2, the resultant mutants were selected for increase yield, earlines, strong stalk and higher antioxidants (Adewusi, *et al.*, 2022). Furthermore, biological mutagens include Agrobacterium and transposon-based chromosomal integration. The EMS-induced mutation is a highly effective method and, therefore, commonly used in crop breeding to develop improved crop varieties. Ramkumar *et al.*., 2019, tested three EMS-induced stay-green mutants and wild-type for their effectiveness for drought tolerance in rice.

4.3.9. *Molecular Marker Approach*

This is the use of molecular tools to enhance plant breeding activities.

There are three major types of genetic markers:

i. Morphological (also known as 'classical' or 'visible') markers which themselves are phenotypic traits or characters; such as flower colour, seed shape, growth habits or pigmentation

ii. Biochemical markers which include allelic variants of enzymes called isozymes; these markers have differences in enzymes that are detected by electrophoresis and specific staining

iii. DNA (or molecular) markers which reveal sites of variation.

The major disadvantages of morphological and biochemical markers are that they may be limited in number and are influenced by environmental factors or the developmental stage of the plant

The advantages of DNA Markers include

a. They are widely used markers due to availability and abundance for application
b. They arise from different classes of DNA mutations such as substitution mutations (point mutations), re-arrangements (insertions or deletions) or errors in replication of tandemly repeated DNA
c. Unlike morphological and biochemical markers, DNA markers are practically unlimited in number, and are not affected by environmental factors and/or the developmental stage of the plant.

DNA markers may be broadly divided into three classes based on the method of their detection:

1. Hybridization-based;
2. Polymerase chain reaction (PCR)-based and
3. Sequence-based

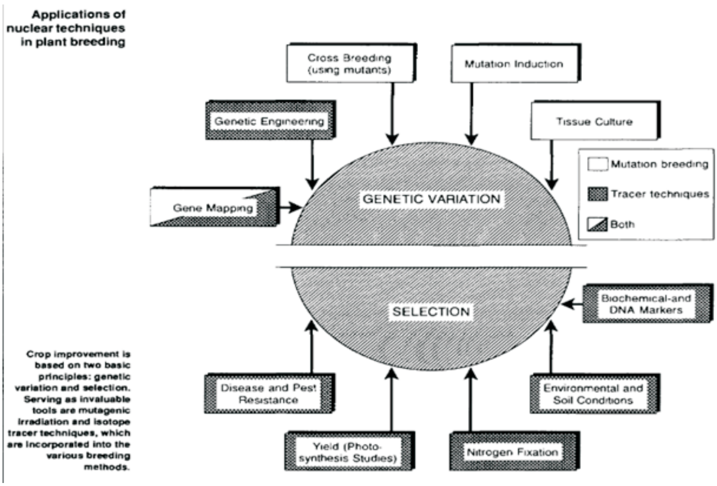

Figure 20: Diagrammatic expression of nuclear technics in plant breeding programme

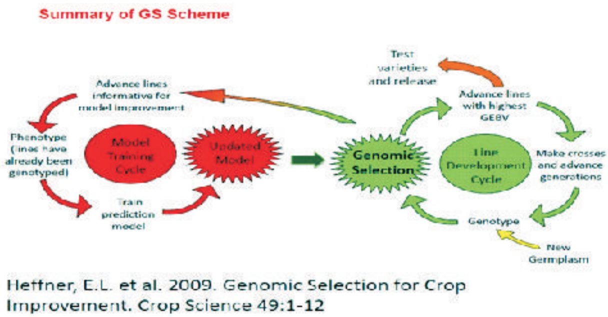

Figure 21: Crop Genomic Selection Scheme

Benefits of Marker Assisted Breeding/Selection (MAB/S)

a. Reduced Linkage Drag
b. Marker assisted back Crossing
c. Gene pyramiding
d. Resistance genes
e. Marker Assisted breeding of polygenic traits
f. Keeping track of all genes involved in complex traits
g. Introduction of novel characters
h. Back Cross
i. Effective exploitation of exotic germplasm
j. Higher genetic gain per unit time
k. Increased Reliability
l. Not affected by environmental factors
m. Increased efficiency
n. Traits that come later in the development stage can be scored before
o. Reduced costs as compared to multi-environment trials

Genomic Selection (GS) –Concept:

GS is based on utilization of high-density marker application
GS differs from QTL-based breeding approaches in that it uses all markers in a prediction of performance genomic estimated breeding value (GEBV) **Utilization of GS and its benefits:**

1. GS has advantage of increasing genetic gain by reducing

cycle time
2. Reduce phenotyping cost by predicting GEBVs of untested lines
3. Filtering bulk of lines in stage 1 trials before advancing them to next level
4. More accuracy to capture variation by including alleles with minor effects apart from those alleles with major effect

4.4. Commitments of Purpose

4.4.1. *Overcoming Disappointments and Discouragements*
National and international legislations and treaties affect Plant breeders and limit their success in feeding the populace. Thus, there is a strongly pronounced tendency in environmental sociology and politics to discuss questions concerning how to deal with ecological problems more or less in isolation from broader societal and politico-economic changes. Even global environmental problems such as climate change, desertification, salinity, erosion, etc. are major discourages of Plant Breeders. There is protective right of wild plants and domestication species, and their uses. Germplasm conservation and protection of genetic resources is a major problem to Plant Breeders.

The problem area is the regulation of biodiversity which is characterized by a high degree of overlap between global environmental and distributional conflicts of interests. Trade-Related Aspects of Intellectual Property Rights (TRIPS) was frequently mentioned. Without exaggeration, this sub-agreement of the WTO can be described as the most controversial international agreement that affects IPR, plant variety protection, Plant Breeders' right, etc. Overcoming the above problems is to use Rationale for participatory plant breeding approach. The term Participatory Plant Breeding (PPB) is used here in the context of bottom-top approach in breeding, plant breeders agreeing to various degrees of farmer involvement in the breeding process. This was done to avoid the erroneous belief that stakeholders have no say. The fundamental importance of PPB is in the joint control of breeder-stakeholders' objectives and resultant variety release in plant breeding programme.

4.4.2. *Funding and infrastructural issues*

Government budgeting, institutional budgeting, fund releases are limiting, and at times are not forth coming, The major focus of infrastructure investment has been on irrigation, transportation, electric power, agricultural markets etc. These not only contribute to agricultural growth at macro level but also to the wide disparity between different regions with respect to the growth of agriculture. The growth of agriculture in Nigeria has not been encouraging because of falling labour input, particularly because of high rural–urban labour force migration. Another reason is deficient transport infrastructure like road which is a vital determinant of low technological adoption, cropping choices and of low agricultural productivity in developing countries.

4.4.3. *Working and Walking round government policies*

Public breeder restriction, staffing, funding, well equipped laboratory, food security and food importation policies are bottleneck hindering successful plant breeding programmes. Policy makers should take note and apply the following suggestions to gain participants' commitments:

i. Government and Institutional leaders should recognize the contribution of plant breeding to improved food security and income generation in Nigeria.
ii. Policy makers should appreciate and understand the long-term nature of plant breeding endeavours and the needs for sustained support to ensure its success.
iii. Encourage multi-stakeholder participation in decision-making processes and set good environment that support conservation and use of genetic materials.

iv. Make available and affordable locally sourced farm equipment and inputs
v. Provision of finance facilities, discourage importation and encourage exportation
vi. Reconstruct the irrigation system in Nigeria
vii. Provide strong and caring leadership and followership

4.4.4. *Commitment by National Agriculture Research System and Universities*

I. Improve priority setting, incorporating awareness of markets and consumption chains and the paths of scientific and technological innovation.
ii. Play an increasingly active role in decision making, especially in connection with capacity building and the need to strengthen it.
iii. Adopt a multi-disciplinary approach to plant breeding, including biotechnology, where appropriate.
iv. Attempt to develop a solid and stable infrastructural and financial national base to ensure sustainability of crop improvement.
v. Seek to develop improved linkages, including those with farmers and the private sector, particularly with the informal seed sector where possible.
vi. Increase awareness of the strategic importance of sustainable crop improvement.
vii. Monitor and evaluate the impacts of IPR/IP on the development and effectiveness of breeding so that adjustments of strategies can be made on an informed basis.

4.4.5. *Understanding Crop incompatibility*

Self-incompatibility (SI) is defined as the inability to produce zygotes after self-pollination in a fertile hermaphrodite plant, which has stamens and pistils in the same flower. This structural organization of the hermaphrodite flower increases the risk of self-pollination leading to low genetic diversity. Self-incompatibility

(SI) mechanisms prevent self-fertilization in flowering plants based on specific discrimination between self and non-self-pollination. Since this trait promotes outcrossing and avoids inbreeding, it is a widespread mechanism of controlling sexual plant reproduction. Incompatibility in plants is of two main types, namely: (I) heteromorphic which is associated with differences in floral structure such as the length of the style, and the level of the anthers; (2) homomorphic which type is not associated with differences in floral structure.

The following are methods of overcoming incompatibility:

i. Mixed Pollination
ii. Bud Pollination
iii. Styler Pollination
iv. Intraovarian Pollination
v. Test tube Pollination
vi. Treatment of Style with Heat
vii. Irradiation
viii. Treatment with Chemicals
ix. Use of CO_2
x. Parasexual Hybridization.

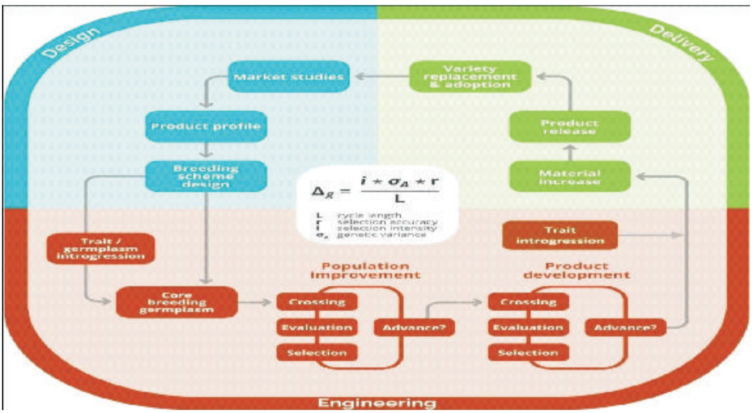

Figure 22: Crop engineering, design and delivery system

4.5.1. *Variety Releases*

Through traditional plant breeding, humans have developed thousands of different varieties of food crops across the world. By protecting seed diversity, it will allow farmers to control their food system, protect biodiversity and build resilience against climate change. It provides choice to the farmers to cultivate a specific variety, based on their need for crop diversification. A variety refers to a genotype or group of genotypes which have been released for commercial cultivation by National Variety Release Committee under National Center for Genetic Resources and Biotechnology (NACGRAB), Federal Ministry of Agriculture of the Federal Republic of Nigeria. Variety release is the evidence and product of several years of breeding. It is the artistic part of plant breeding, where a crop is scientifically bred for specific reasons including adoption and appreciation.

Reasons for breeding new crop variety are:

i. Higher yields

ii. Improved quality: like baking in wheat, cooking in rice, malting in sorghum, vitamin A fortification in cassava, quality protein in maize. etc.

iii. Resistance/tolerance to pests

iv. Resistance/tolerance to diseases

v. Tolerance to abiotic stress like drought, flood, salt and iron toxicity.

vi. Early maturity

vii. Good agronomic characteristics like dwarfness in cereals

viii. Photo- insensitivity

ix. Elimination of anti-nutritional factors

x. Good storability

For the purpose of variety registration and release if a crop variety is bred for other characteristic other than yield, such character must be of economic, nutritional and medicinal importance, and the yield factor must not be compromised.

There are the requirements for registration and release of crop varieties:
For a crop to be registered and released as a new variety in Nigeria it must have passed the test for Distinctiveness, Uniformity and Stability (DUS) and as well as Value for Cultivation and Use (VCU).

DUS is an acronym for:

a) Distinctiveness: new variety should be clearly distinguishable from any other existing varieties in Nigeria
b) Uniformity: individual plant of new variety should be sufficiently uniform at the same growth stages in the expression of their characteristic.
c) Stability: the genetic traits of the new variety should be stable through generations

The DUS test is an internationally recognized procedure standardized mainly for the protection of plant variety released. The test is used to assess novelty of new varieties and also used to gather information regarding the botanical description of new varieties. In DUS test plots, candidate varieties are compared with similar existing varieties (check varieties) where agronomic characteristics (like yield, maturity date, height), morphological characteristics (like colour, shape, and size), physio-genetical characteristics (like tolerance to pest and disease) and general tolerance to biotic and abiotic stresses are evaluated following the International Union for the Protection of New Varieties of Plants (UPOV) guidelines. The DUS test is to be carried out at the On-station or at any designated DUS testing sites for at least 2 years/ two different giving seasons.

Value for Cultivation and Use (VCU) implies that for a crop to be registered as new variety, it must be beneficial to farming and industrial communities.

The objectives of VCU test for a candidate variety to be registered are to know:

a) The adaptation and stability across varied environments,
b) Agronomic performance,
c) Reaction to pests and diseases,
d) Resistant/tolerant to abiotic stresses, when compared with existing varieties.

The VCU test is to be carried out during the multi-locational trial for two years in different environments.

The variety to be registered must have superior/trait performance over the existing ones with the farmers or currently registered variety in Nigeria. And, the variety or its progeny must not be detrimental to human or animal health and safety of the environment when grown and used as intended.

1.5.2. Stakeholders Requests

All agricultural-based stakeholders preferred to be included in pre-breeding activities to post-breeding evaluation of products as seen in Figure 23

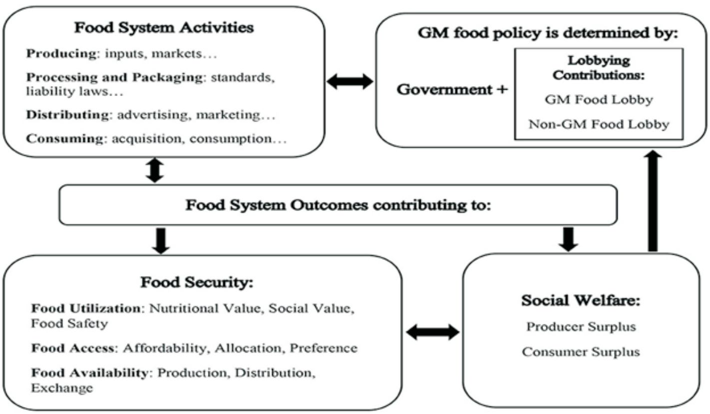

Figure 23: Stakeholders' involvement in food system activities

4.5.3. *Target Breeding*

A modern era of targeted crop breeding is upon us. Traditional plant breeding aims to change traits/genes in a specific crop to obtain the desired characteristics in the offspring. This targeted trait is often linked to a specific change (mutation) in the parental plant's genetic code (DNA), which the breeder then attempts to develop progeny from, containing target market characteristics.

Though this process seems relatively straight forward it is not, since some traits are 'hidden' (in the form of recessive genes), while other traits are transferred to the progeny in large groups (linked) that may include undesirable traits as well (linkage drag).

Unwanted traits are also randomly transferred to the progeny which means, as the number of desired traits increases, the number of progeny required to obtain an individual with all the desired traits and development cost, increases dramatically. The number of genes becomes even more complicated when breeding with grain crops. This is especially the case for wheat, with its three large complex genomes, having multiple copies of a single gene that originated from the ancestry donor backgrounds.

The breeding process always aims to produce cultivars faster and therefore currently uses tools such as molecular selection (marker-assisted breeding), embryo rescue and double haploid generation and speed breeding to accomplish this as highlighted in Figure 24. This ultimately results, after many years (eight to twelve years) of breeding and selection cycles (including traditional trait screening and molecular selection), in the release of higher yielding and adapted cultivars.

Some of the new breeding technologies in the breeder's toolbox will now allow precision breeding. The ability to transfer a specific trait by targeting the specific genetic code or gene region responsible for the desired outcome. These new plant breeding tools include a wide variety of technologies, ranging from directed nucleases for targeted mutagenesis to technologies that transfer the trait of interest but does not result in permanent DNA changes (Figure 24).

The tools in the new breeding toolbox that are really making a huge impact are those belonging to the directed nucleases group. Nucleases are enzymes that can cut DNA. Some of these nucleases recognize and cut only specific DNA sequences (e.g. meganucleases), while others use engineered proteins to target specific DNA for cleaving. The usefulness of meganucleases are limited since they can only target and cut at their specific DNA recognition sequences, which will very rarely be within the target trait region desired by the breeder. These technologies require expensive, time-consuming protein engineering skills by experienced individuals.

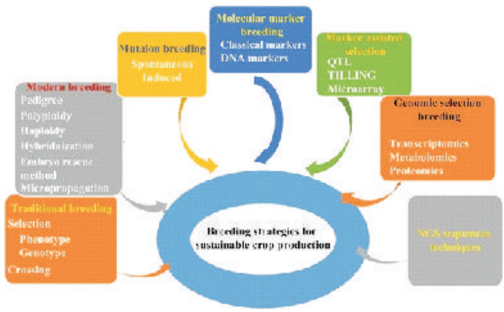

Figure 24: Tool kits available for Plant Breeding strategies

4.5.4. *Categories of Seed Production*

Seed has become a major mainstay in agricultural business, to the plant breeders' seed is an essential product of several sleepless night, hard work and lots of breeding efforts. Seeds have become the most important commodity of plant breeding business and Plant Variety Protection Right (PVR or PVPR) and Plant Breeders Right (PBR) as patent materials. There are 5 basic categories of seed in Tables 4 and 4 types of seed in Figure 25

Table 4Different classes of seed, producers and certification needed

Class of seed	Institutes/Organization/Agencies	Supervision	Certification
Nucleus seed	Developer, breeder, parent institutes	Breeder, developers	No need, responsibility of parent institution or developers
Breeder Seed	Developer, breeder, parent institutes, registered organization	Breeder, developers	Members assigned by seed certification agencies
Foundation Seed	Central Government agencies, State Departments, Agriculture Universities, State Farms, Private seed companies, Farmers producer organization	Concern producer	Members assigned by seed certification agencies
Certified Seed	Central Government agencies, State Departments, Private seed companies, Farmers producer organization, Agriculture Universities, State Farms	Concern producer	Members assigned by seed certification agencies
TL Seed	Any organization and farmers	Concern producer	No need, responsibility of producer

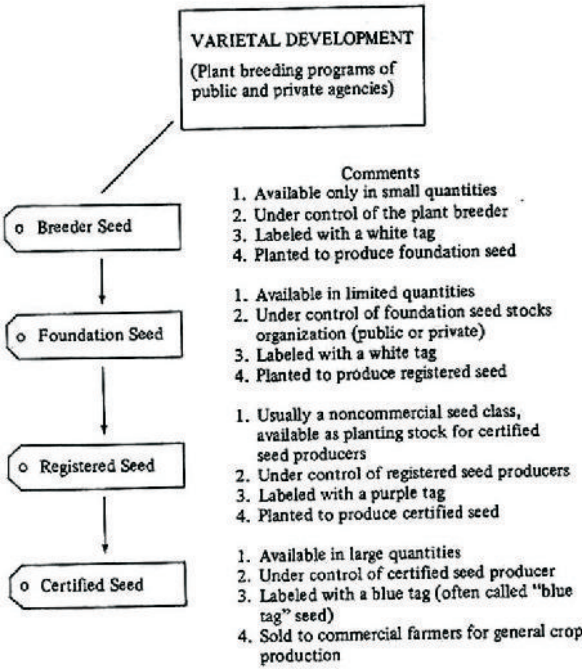

Figure 25: Variety Seed systems development for both public and private sectors

4.5.5. *Market Driven Production*

Plant breeding activities in our current dispensation tend more towards resolving topical issues and market driven approaches. There are ten key points to note for a successful market-driven plant breeding approach:

1. Understanding clients' means clients is central to demand-led variety design and improving the adoption of new varieties. Before starting a breeding programme for a particular crop, it is necessary to be clear on: who the clients are; what factors influence their buying decisions; and what the needs, preferences and problems of each client are.
2. Farmer adoption is demand-led approaches increase the likelihood of new varieties being adopted by farmers.
3. Value chains are demand-led approaches build on and go beyond farmer-participatory breeding. They include consultation not only with farmers, but also with all clients and stakeholders along the whole crop value chain.
4. Urban and rural consumers occupy important position for the Plant Breeders to consider their needs and preferences of consumers living in both rural and urban environments. Rapid (rural and urban) appraisals can be extended to gathering information not only from farmers but also from consumers and clients who live in towns and cities.
5. Markets and client segmentation is necessary for Plant Breeders to understand markets and client segmentation to be able to prioritize their breeding targets.
6. Market research and intelligence gathering is the gathering of market research at the start of a breeding programme needs to be complemented by regular consultations with stakeholders at key decision points along the development stage plan from new variety design to post-market release. The primary objective is to gain

new insights, test assumptions, demonstrate and obtain feedback on new variety/lead germplasm performance and stimulate demand.

7. Breeding entrepreneurship is the involvement of Plant Breeders in promotion and sales of breeding end products, formulations, rights and protocols that can contribute to economic growth, better livelihoods for farmers and increased food security. Improved varieties can change lives.
8. Market creation means to maximize market existence and nurture innovation, therefore, a balance is required between using demand-led approaches and enabling new technologies to drive innovations. Both approaches have value and they complement one another.
9. Role of the plant breeder is not to conduct researches alone. Plant breeders do more than make crosses and lead selection programmes. A breeder must also be an integrator of inputs and be able to assimilate information and incorporate a broad range of views, including those of non-technical experts. This requires assimilating data, looking at its implications and making decisions based on information from diverse areas, including agricultural economics, markets, market research and the core scientific functions of breeding.
10. Breeding experience is based on demand-led approaches to retain emphasis and place value on the breeder's eye ball and experience.

5.0 THE MAKING OF NEW CROP CULTIVARS (VARIETIES)

Mr. Vice Chancellor, Sir, variety release is the art of Plant Breeding. It is the representation and manifestation of imagination, thought and concept that are appreciated physically.

It is every animal or plant breeder's desire to release crop cultivars or varieties as mark of crown, productivity and fruitfulness in one's life cycle. Similarly, the plant breeder is always happy to reproduce himself in other plant breeders by way of training, teaching, leading and motivation. Lastly creating a breeding team is leaving behind, a legacy worthy of emulation.

I am privileged to have partaken, produced and prospered in all the above. I have worked as plant breeder under the following senior plant breeders Late Professors C. C. Nwasike, D.A. Aba and S.G. Ado before heading the team of researchers on Sunflower and Rice breeding. I have to my credit 8 varieties of sorghum (4 Open pollinated variety and 4 hybrid varieties), 6 varieties of maize, 4 varieties of sunflower and 2 varieties of Ofada rice. That is really outstanding, and glory be to God!

5.1. **Sorghum Cultivars**

Sorghum (*Sorghum bicolor* (L.) Moench) is an important food crop in Africa and is the fifth most important cereal crop grown in the world, as well as the most important cereal food in the Northern states of Nigeria. Nigeria is the second largest producer of sorghum, grown on about 5.9 million ha with current annual production estimated to be about 6.7 million tonnes.

5.1.1 *Open Pollinated Sorghum Varieties (OPV)*

Four OPVs were officially released for commercial production. They were obtained from recurrent selection, using 5% selection intensity at each generation of selection till homogeneity. Selection was primarily for grain yield, quality, hardiness, local food, malting qualities, production, no lodging, earliness, nitrogen use efficiency and adaptation to low moisture environments. Five Plant Breeders partnered for the release of these varieties under the backstopping of their respective institutes Table 5.

Table 5: Profile of 4 Open Pollinated Varieties of sorghum

S/No	Variety Name	Original Name	Year of Release/ Registration	Developing Institute	Breeder/ Collaborating Scientists	Outstanding Characteristics/ Potential Yields
1.	SAMSORG-41	NGSB-96-30	1982/1996	ICRISAT, Kano and IAR, ABU	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	Hard grains with good local food quality, high Yield and drought tolerant
2.	SAMSORG-40	400 NGSB-96-31	1982/1996	ICRISAT, Kano and IAR, ABU	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	Non lod ging, drought tolerant, and non scent variety with good response to fertilizers, grains have good food and malting quality.
3.	SAMSORG-39	NR-71182	1982/1996	IAR, ABU Samaru, Zaria	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	High yielding (2.5-3.5t/ha), early maturing bred for Sudan Savanna
4.	SAMSORG-38	NR-71176	1982/1996	IAR, ABU Samaru, Zaria	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	High yielding (2-3t/ha), early Maturing bred for SudanoSahel areas.

5.1.2 *Hybrid Sorghum Varieties (Hybrid)*

The four sorghum hybrids are the first set of sorghum hybrids officially released in Nigeria as commercial varieties for all stakeholders. They were bred considering GCA, SCA, heterosis, per se performance, genetic gains and selection intensity of top performers. These four varieties were bred mainly for high grain yield advantage, earliness, drought hardy, good malting qualities and specific adaptation (Table 6).

Table 6: Profile of 4 hybrid sorghum varieties

S/No	Variety Name	Origina l Name	Year of Release/ Registration	Developing Institute	Breeder/ Collaborating Scientists	Outstanding Characteristics/ Potential Yields
1.	SAMSORG-H1	NSSH-91001	1982/1996	IAR, ABU, Samaru, Zaria	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	High yielding (3-4t/ha), early maturity
2.	SAMSORG-H2	NSSH-91002	1982/1996	IAR, ABU, Samaru, Zaria	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	High yielding, early maturing bred for Northern Guinea Savannah
3.	SAMSORG-H3	ICSV89002-NG	1982/1996	ICRISAT, Kano and IAR, ABU	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	Stable, high yielding (44.5t/ha), drought tolerant and good grains hybrid with good malting properties
4.	SAMSORG-H4	ICSV89009-NG	1982/1996	IAR, ABU Samaru, Zaria	D.S.Murty, S.C. Gupta, C.C. Nwasike, D.A. Aba & F.A. Showemimo	Stable, high yielding (45t/ha), drought tolerant and good grains hybrid

5.2 **Maize Cultivars**

Maize (*Zea mays* L.) is the world's leading crop and is widely cultivated as cereal grain that was domesticated in Central America. It is one of the most versatile crops having wider adaptability. Globally, maize is known as queen of cereals because of its highest genetic yield potential. It is 3rd ranked crop in term of calorie provision. The six major types of maize are dent corn, flint corn, pod corn, popcorn, flour corn, and sweet corn. I was a member of the breeders that released 6 varieties of maize for several purposes (Table 7).

Table 7: Profile of 4 Open Pollinated sunflower varieties

S/No	**Variety Name**	**Original Name**		**Year of Release/ Registration**	**Developing Institute**	**Breeder/ Collaborating Scientists**	**Outstanding Characteristics/ Potential Yields**
1.	SAMSUN-1	SSL 803		2010/2010	IAR, ABU, Zaria	***Breeders*** F. A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J.	Early maturing, drought tolerant, good see quality and very high antioxidants. (2.42mg of Vit. A, 0.26mg of Vit. C and 14.48mg of Vit. E). yield is 2.21t/ha. Bred for all Savanna Ecological Zones
						Omage & V.I.O. Ndirika	
						Omage & V.I.O. Ndirika	
2.	SAMSUN-2	SSL 806		2010/2010	IAR, ABU, Samaru, Zaria	***Breeders*** F. A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J. Omage & V.I.O. Ndirika	Medium maturing, good seed quality, yield 2.53t/ha , drought tolerant and good antioxidants especially Vitamin E. breed for all Savanna Ecological Zones

3.	SAMSUN-3	SSL 807	2010/2010	IAR, ABU, Samaru, Zaria	***Breeders*** F. A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J. Omage & V.I.O. Ndirika	Late maturing, large seed with good seed quality, yield is 2.27t/ha, and drought tolerant and ver y good antioxidant bred for all Savanna Ecological Zones
4.	SAMSUN-4	SSL 809	2010/2010	IAR, ABU Samaru, Zaria	***Breeders*** F. A. Showemimo, F.C. Orakwue,.	Early maturing, good seed quality, yield (2.83t/ha), drought tolerant

5.2.1 *Open Pollinated Maize Varieties*

Three of the varieties released in 2009 were for good grain yield and qualities. They were also released for lowland ecologies, extra early maturing, drought escaping and Striga tolerant (Table 7).

5.2.2. *Quality Protein Maize (QPM)*

SAMMAZ-14 popularly known as Obatampa was released for commercial acceptance in Nigeria for its high quality protein content, after screening and evaluation in several locations and years for adaptation and stability within Nigeria agro-ecological zones. SAMMAZ-14 was released specifically for high lysine and tryptophane contents (Table 7). It is medium maturing with good stout stalk, non lodging, good seed quality, high yield and tolerance to Striga. This variety was obtained through cycles of selection to eight generation. The seed was dent and opaque under fluorescence light illumination, this variety was selected for both seeds and good plant architecture

5.2.3. *Drought Tolerant Maize (DTMA)*

SAMMAZ 28 was bred for drought tolerance combining striga and streak tolerance, yellow coloured seeds, grain yield is 4.0t/ha and bred for low land tropical ecologies. The morphological, molecular and physiological mechanism includes adjustment in photosynthetic efficiency, decrease in cell size by protoplasmic resistance, low plant temperature, high translocation of metabolites, high carbohydrate metabolism, use of ZmPYL genes to tolerate limiting moisture of drought hardiness. After 8 cycles of bias selection for minimum anther-silking interval, water use efficiency and high selection index under moderate and severe drought stress conditions under control and open conditions, SAMMAZ 28 was outstanding and released for commercial purpose (Table 7).

5.3. Sunflower Cultivars

Sunflower (*Helianthus annuus*) the name "Helianthus" is derived from "Helios" meaning "sun" and "anthus" meaning "flower". It is called sunflower as it follows the sun, always turning toward its direct rays. It originates from central and north America. Lately its importance as an oil crop has grown and at present, it is the second most important oil crop next to soybean. Total annual world production is some 20.9 million tons of seed from some 18 million ha, (FAOSTAT, 2001). Sunflower thrives in climates ranging from arid under irrigation to temperate under rainfed conditions, but is susceptible to frost. Mean daily temperatures for good growth are between 18 and 25°C. The total growing period varies from 60 days to 200 days. Sunflower oil is most popular because of its light color, bland flavour, high smoke point and high level of linoleic acid which is good for heart patient. Sunflower seed contains about 48– 53 percent edible oil (FAOSTAT, 2021).

All the 4 sunflower varieties released for commercial cultivation are the first set in Nigeria (Table 8). They are all OPVs and are product of several cycles of selection to 7 generations. Each of the

Sunflowers released was selected for different maturities, height, agro-climatic adaptation, yield, high antioxidants and high commercial oil content value.

a) SAMSUN-1 and SAMSUN-4 were bred for early maturing, drought tolerance, good seed quality and very high antioxidants Vitamin A, C and E, the oil is light colour, high smoke point and high level of linoleic acid. The yield for SAMSUN-1 is 2.21t/ha and the yield for SAMSUN-4 is 2.83t/ha Table 8. They were both bred for all Savanna Ecological Zones.

b) SAMSUN-2 is medium maturing, good seed quality, yield of 2.53t/ha. It is drought tolerant and has good antioxidants especially Vitamin E. It is bred for all Savanna Ecological Zones but performed better in southern and northern guinea savannah agro-ecologies Table 8. It is medium in height, the oil colour is light yellow with high linoleic acid.

SAMSUN-3 is late maturing, large seed with good seed quality, yield is 2.27t/ha, drought tolerant and very good antioxidant bred for all Savanna Ecological Zones (Table 8). It has large bold darkish seeds. It is tall, high compensation for senescing leaves, head size is moderate, it is not lodging, the oil colour is light brown.

Table 8: Profile of 4 Open Pollinated sunflower varieties

S/No	Variety Name	Original Name	Year of Release/ Registration	Developing Institute	Breeder/ Collaborating Scientists	Outstanding Characteristics/ Potential Yields
1.	SAMSUN-1	SSL 803	2010/2010	IAR, ABU, Zaria	***Breeders*** F.A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J. Omage & V.I.O. Ndirika	Early maturing, drought tolerant, good see quality and very high antioxidants. (2.42mg of Vit. A, 0.26mg of Vit. C and 14.48mg of Vit. E). yield is 2.21t/ha. Bred for all Savanna Ecological Zones
2.	SAMSUN-2	SSL 806	2010/2010	IAR, ABU, Samaru, Zaria	***Breeders*** F.A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J. Omage & V.I.O. Ndirika	Medium maturing, good seed quality, yield 2.53t/ha , drought tolerant and good antioxidants especially Vitamin E. breed for all Savanna Ecological Zones
3.	SAMSUN-3	SSL 807	2010/2010	IAR, ABU, Samaru, Zaria	***Breeders*** F.A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists*** B. Tanimu,. S. Misari, M. Mahmud, A.D. Akpa, E.A. Egwurube, J.J. Omage & V.I.O. Ndirika	Late maturing, large seed with good seed quality, yield is 2.27t/ha, and drought tolerant and very good antioxidant bred for all Savanna Ecological Zones
4.	SAMSUN-4	SSL 809	2010/2010	IAR, ABU Samaru, Zaria	***Breeders*** F.A. Showemimo, F.C. Orakwue,. S.G. Ado,. M.Y. Yeye, ***Collaborating Scientists***	Early maturing, good seed quality, yield (2.83t/ha), drought tolerant and excellent antioxidants especially Vitamin A, C and E good for

5.4. Ofada Rice Cultivars

Ofada rice is one of the major types of rice grown in Nigeria it has a very high socio-cultural attachment. This variety got its name from the fact that it was popularly grown and processed in a village called Ofada, in Ogun State, the South-West Nigerian. However, other surrounding villages such as Mokoloki, Owode-Egba, Oba, Kobape, Moloko-Ashipa, other villages and farming communities adopted the rice and they are major producers of Ofada rice. Documented history has it that the crop was first grown in Ofada, Abeokuta, Ogun State. It was introduced through missionary activities between the 1850s and 1860s. However, the elderly farmers and stakeholders believed that a returnee soldier from Burma war brought some seeds along with him to plant in Ofada, from there it spread to other parts of the country and beyond.

Ofada rice is considered as African local rice that is believed to be *Oryza glaberrima*. Most improved rice varieties are referred to as *Oryza sativa* (Asian rice). Ofada rice has been able to maintain its uniqueness as both improved and local African rice. Ofada rice is taxonomically documented as *Oryza sativa* var: ofada .

Bottom-top approach was used in the screening, selection and release of the 2 Ofada rice varieties. Ofada rice accessions were collected based on the farmers' preference from Farmers fields, and scientist that worked on Ofada rice were consulted and useful information was obtained from them. The bulk Ofada rice (mixtures or source population UOM4A11) was subjected to recurrent selection based on 5% selection intensity with bias for acceptable characters. Desired morpho-agronomic, adaptive and nutritional characters were used as markers of improvement.

Repeated cycles of selection was done, resulting in four distinct Ofada rice genotypes but two outstanding and dual purpose Ofada rice varieties; UORG 311 and UORW 111 were given detailed attention. UORG 311 and UORW 111 were returned to the farmers for acceptability, adaptability and stability tests/trials across all south western states, and Edo and Delta States of Nigeria. The National Variety Release Committee visited FUNAAB, had meetings, also visited the farms of some selected farmers farms along with FUNAAB research farms. Four out of the 8 distinct Ofada rice genotypes were presented as proposal for variety release. I made advocacy for 2 Ofada genotypes and both of them were approved and released as FUNAABOR 1 and FUNAABOR 2. The DUS and VCU of both varieties are given below (Table 9)

Table 9: Profile of 2 Open Pollinated dual purpose Ofada rice varieties

S/No	**Variety Name**	**Original Name**	**Year of Release/ Registration**	**Developing Institute**	**Breeder/ Collaborating Scientists**	**Outstanding Characteristics/ Potential Yields**
1.	FUNAABOR-1	UORG 311	2011/2011	IFSERA, FUNAAB	***Breeders*** Showemimo, F.A., Gregorio, G., Maji, A.T., ***Collaborating Scientists*** Olowe, V.I.O., Ukwungwu, M.N., Adigbo, S.O., Olaoye, O.J., Akintokun, P.O., Bodunde, J.G., C.A. Awe & Idowu, O.T.H.	Good yield, gold colour grains with red strips, very high swelling capacity and good nutrient acceptable, excellent stay green attribute, high ratooning ability. Good yield (2.7t/ha) bred for Forest Transition/Derived Savanna
2.	FUNAABOR-2	UORW 111	2011/2011	FUNAAB	***Breeders*** Showemimo, F.A., Gregorio, G., Maji, A.T., ***Collaborating Scientists*** Olowe, V.I.O., Ukwungwu, M.N., Adigbo, S.O., Olaoye, O.J., Akintokun, P.O., Bodunde, J.G., C.A. Awe & Idowu, O.T.H.	Good nutrient, yield (2.5t/ha), pure white, smooth, long, sweet grains, acceptable. Bred for Forest Transition/Derived Savanna

5.4.1. *FUNAABOR-1 (OFADA GOLD)*

It is a result of cycles of recurrent selection towards desired characters acceptable to all stakeholders. It has high stay green attribute, medium maturing, high rationing ability, dual purpose (lowland and hydromorphic) can also survive in swampy condition. Good yield, gold colour grains with red strips, very high swelling capacity, very good grain appearance, medium length grains, acceptable taste, aroma and texture, and very high swelling capacity. Good nutrient profile and the yield is 2.7t/ha (Table 8). It was bred for Forest Transition and derived Savanna agro-ecology, but it's currently doing well in Northern and Sudan savannah agro-ecologies of Nigeria

5.4.2 *FUNAABOR-2 (OFADA WHITE)*

It is tall but not lodging, late maturing, also dual purpose variety, average stay green attribute, low rationing/tillering ability. Good nutrient profile, high antioxidants, 80% swelling capacity, good aroma and taste, grain texture is smooth, pure white grains, salt tolerant, smooth and long grains, sweet grains, acceptable for health. It was bred for Forest Transition/Derived Savanna and the grain yield is 2.5t/ha,

6.0. CURRENT RESEARCH INTERESTS

All available methods of crop improvement especially to create genetic variability are employed to increase yield, introduce resistance, achieve high nutrient dense genotypes, adapt and stable to target environment and also to gain socio-cultural acceptance. Based on the above, my research interest shifted to the use of mutation, molecular and genomic tools to enhance my plant breeding activities and focus.

i. Use of Mutation in OFADA Rice Breeding

Two of my Doctoral students were placed on Ofada mutation breeding with the objectives of breaking the yield ceiling, reduce height and improve nutritional profile without compromising desirable characters. One worked on Phenotyping and the other on genotyping of Ofada rice varieties. They have both graduated with their Ph.D. Currently, I have 3 MSc students working on various aspects of mutated Ofada rice.

The released Ofada rice varieties (FUNAABOR 1 and FUNAABOR 2) seeds were irradiated using ^{60}Co gamma rays to elicit variation towards selection for grain improvement in 2013 at Ghana Atomic Energy Commission (GAEC), Accra, Ghana.

The result of the mutation study showed between 50-80% yield increases from $M_{0,}$ pedigree. Recurrent and early generation selections were practiced to achieve recombinant and gain improved Ofada rice genotypes at M_8 stage. The mutated Ofada rice have reached homozygous status, their genes are already fixed for the desired characters. There are 10 M_8 Ofada genotypes with 50% yield advantage to their respective M0 , 6 M_8 Ofada genotypes had 80% yield advantage over the released cultivars. The selected mutated Ofada rice genotypes have very good nutritional profile and antioxidants. Their culinary and organoleptic characters are yet to be conducted.

ii. Use of Molecular Marker Technology

Molecular tool had been used by my graduated Ph.D. student to assess, map out and identify resistant genes present in rice varieties. FUNAABOR 1 and FUNAABOR 2 were included in the study accidentally, but the result showed they were 2nd and 3rd best variety with salt tolerant attributes and genes, though the genes for salt resistance had not been identified. Further studies are going on for such identification, mapping and documentation.

iii. Nomination of mutated OFADA rice into National CSP and RIPT

Ten mutated Ofada rice genotypes are already nominated in to the Collaborative Seed Programme (CSP) and Rice Innovative Pilot Team (RIPT) in the ongoing pilot farmers participatory trials under farmers' field condition in preparation for another set of Ofada rice variety release for commercialization.

iv. Farmers' Participatory Evaluation of Foxtail millet

I am in partnership with some Plant Breeders in the northern part of the country and some had contacted some farmers in transition zone and derived savanna to evaluate Foxtail millet for adoption and adaptation. Foxtail millet (*Setaria italica*) is more of an orphan crop, not popular in Nigeria but its closely related family, fonio millet, (*Digitaria exilis* Stapf) is well known and grown in Northern Nigeria for its nutrition and often called 'hungry millet'. I came across Foxtail millet in China in 2017. Apart from normal evaluation and maintenance of seeds, nothing much had been done. The institute I visited in China requested I send a proposal to them for multi-locational testing for adaptation and stability studies. Foxtail millet is the crop for the future due to climate change and high nutritional profile. I have made request for funding and more genotypes of Foxtail millet to accommodate more farmers and agro-ecological zones.

7.0 BREEDING IS BUSINESS

Plant Breeding is big time business with several product lines that meet the emerging needs of humanity. Some parts of the business are advocacy, consultation, short and long-term training and impact assessments. Public and private breeders are partnering for better recognition and gains. Thus, services rendered must be adequately compensated.

7.1 Plant breeding in society

As long as the world population is expected to continue to increase, there will continue to be a demand for more food. However, with an increasing population comes an increasing demand for land for residential, commercial, and recreational uses. Sometimes, farm lands are converted to other uses. Increased food production may be achieved by increasing production per unit area or bringing new lands into cultivation. As an active Plant Breeder, my view is that Plant breeding is affected and will also affect the society in the following ways:

7.1.1 *Seeds*

Seed is defined as fertilized, matured ovule consisting of an embryonic plant together with a store of food, all surrounded by a protective coat. A seed (in some plants, referred to as a kernel) is a small embryonic plant enclosed in a covering called the seed coat, usually with some stored food. In botany, seed is an undeveloped plant embryo and food reserve enclosed in a protective outer covering called a seed coat. More generally, the term "seed" means anything that can be sown, which may include seed and husk or tuber.

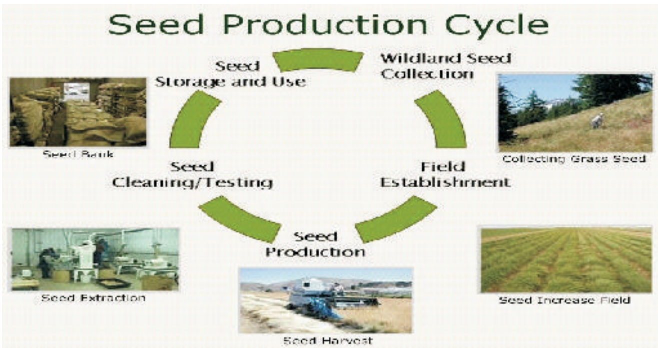

Figure 26: Process of seed production and process for commercialization

7.1.2. *Clients and Stakeholders*:

i. Client is a customer, buyer, purchaser or receiver of a new crop variety, its crop produce or processed material from a seller, vendor or supplier in the value chain for a monetary or other consideration.

ii. Stakeholders: The term stakeholder is broader and includes clients and any other person or organization with an interest in a given crop situation, action or enterprise.

7.1.3. *Market segments*

i. Clear segment: Each product line are profiled for specific sector of the market, thus, there is need to create specific market segments of clients, product and related outlets within the value chains

ii. Understanding clients: An understanding of clients is central to demand-led variety design, release and adoption. It is essential to be clear on who the clients are and what affects their buying decision

iii. Value chains: Breeders need to understand value chains and the relative importance of different clients in the chain, as well as their requirements in new variety design.

iv. Different clients: Different clients in value chains have different requirements and not all of these requirements can always be satisfied with the same variety, especially when there are specialist properties required for processing. Breeders should have regular contact with clients in all parts of the value chain and involve them in new variety design.

vi. Client location and scale: The geographic location of clients is important, as is knowledge of whether the benefits and value of new varieties are also applicable for potential clients across national borders. The analysis of agro-ecological zones should be given particular attention. The more clients that can benefit from each new variety, the greater the investment case for a breeding programme, especially when it can have a multi-country impact.

7.1.4. *Understanding markets and market research*

i. Best market research practices: Breeders need to access key information from farmers and all clients in crop value chains. The best quality market research methods, those that remove bias should be used. This requires skilled third parties, such as social scientists and independent market research agencies, to gather information and conduct interviews on behalf of their plant breeder clients.

ii. Partnering with social scientists: Breeders should liaise closely with the social scientists that are conducting ex ante impact assessments and seek to include additional questions that can be used to influence new variety design and plant breeding programmes.

iii. Participatory appraisals: Participatory rural appraisals (PRAs) are a starting point for gathering market research information. PRAs focus on farmers, but they also need to be extended to many other clients in the value chain.

7.1.5. Difference between demand-led breeding and current/conventional breeding approachə

I. Client focus: Breeding goals and objectives are set based on what clients want and need, thus, marketable problem solving breeding as against breeding based on only breeders' objectives. So it is not what technology can offer, but what technology can solve for specific or individual trait improvement.

ii. Value chains: Greater understanding is required about the structure of crop value chains to form a niche for market sector. Demand-led approach will be targeted towards industrial uses of such product instead of breeding several varieties for end users to accept or reject. This will curb fund wastages. The buying and selling factors of different clients, together with their relative priority will assist in setting new variety designs.

iii. Demand-led breeding: This approach puts more emphasis on regularly consulting and understanding the needs and preferences of all clients and stakeholders in a crop value chain, not only farmers.

iv. Variety design and benchmarking: There must be consultation and possible agreement between end users and breeders in redefining and redesigning new product and product lines. Stronger emphasis is placed on the systematic and quantitative assessment of varietal characteristics in the creation of new product profiles performance and line progression as against just yield improvement in the current breeding programmes.

v. Market research: Stronger emphasis is placed on gathering unbiased, reliable, independent information on clients' needs and preferences. That forms the basis for crop improvement under demand driven approach with the aim of replacing an existing variety that was bred out of the stakeholders' interest

vi. Market and business knowledge: A demand-led approach requires breeders to have greater knowledge about crop uses, markets and business. It takes the best practices from breeding and integrates these with the best practices in business.

7.1.6. *Implications for the Plant Breeder*

1) The business of plant breeding requires Plant Breeders to understand the rudiment of business enterprise to be able to gather and assimilate information from multiple clients and many market sources to properly situate crop value chains.

2) Partnering and collaboration is the ability of Plant Breeders to network with both the public and private sectors to extend their reach, influence and technical know-how for improving their technical competencies and delivery system in the art and science of plant breeding.

7.2.1. *Breeding and business Models*

Innovative plant breeding plays an important role in a number of public objectives, such as food security, environment, sustainability, and a number of transitions in the rural area, such as 'biobased or knowledge-based economy'. The plant breeding sector is of high economic significance with a steadily growing export value and a significant 'spin off' of final products. The Nigeria plant breeding sector holds a very strong position in cereals, tubers and legume, vegetable crops. Nigerian plant breeders play leading role in fundamental, strategic and applied research in plant genetics and plant breeding.

Innovation in plant breeding is dependent on specific knowledge, the development and application of new technologies, access to genetic resources, and capital to utilize those factors. Access to technology as well as genetic material is essential for the development of new plant varieties. Competition and profitability of the plant breeding sector play a major role in the sustainability of the total food chain (Figures 27, 28 and Table 10). Farmers and growers have an interest in competition in the seed market.

One significant result from the development in molecular biology, was in the introduction of patent rights in the breeding sector. This system of intellectual property rights (IPR) certainly not only applies to genetic modification but to an ever broadening range of new techniques that make plant breeding more efficient and effective. Patent positions in combination with technological developments have in recent, decades, led to a large consolidation move among breeding companies. For most crops, only a few companies are controlling the Nigerian market. Thus, very few Nigeria seed companies cater for the ever-increasing seed and grain requirement of Nigerians and African countries.

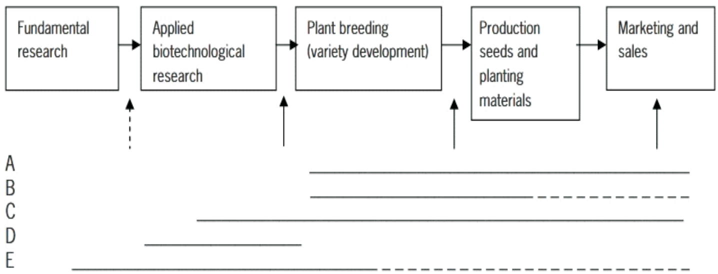

Figure 27: Demand driven participatory plant breeding scheme

Table 9: Interpretation of Figure 27; crops and institutional responsibilities

S/No.	Type	Remark	Example
1.	A	Company/Institute involved in primarily selling o f seeds and planting materials	bulbs, cuttings and seed
2.	B	Granted licenses for propagation and production of propagation material for the size of market	Vegetables, horticultural crops
3.	C	Involvement of biotechnology in their breeding programmes to generate income by selling seed, planting materials and licenses on patents.	Cereal, legumes and tuber crops
4.	D	Biotechnology company focusing on income from contract research for seed, protocols and patients.	All crops of interest to the company
5.	E	Multinational biotechnological companies with the production and marketing of seed while at the same time licensing technologies to other breeding companies	All crops of interest to the company

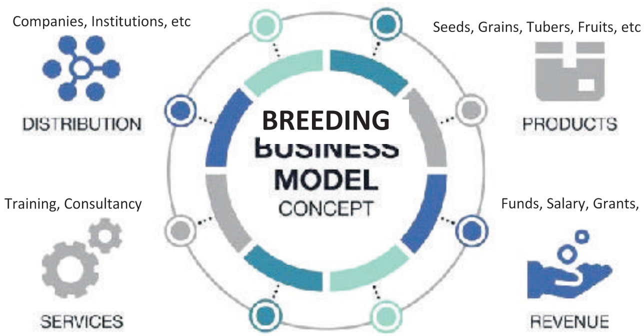

Figure 28: Breeding business model to meet all stakeholders' needs

7.2.2. *Economic aspect of breeding*:

The world of plant breeding is changing rapidly, in response both to scientific developments and to economic forces. In particular, there is a growing trend to widespread privatisation of crop breeding. Economic outcomes in the "plant breeding industry" are being driven by interactions between advances in scientific knowledge, changes in the legal framework for intellectual property rights, and competitive forces in the market. While extended property rights have created the foundation for new markets, the opportunities arising from scientific discoveries have provided powerful incentives for firms to enter these markets and invest in plant breeding Figure 28. The competitive forces unleashed by these developments are likely to transform the production of new plant varieties.

The advantage that modern plant breeding has is to help create value in the supply chain and it is one of the driving forces behind the increasing privatisation and commercialization of plant breeding products, Plant Breeder's Right and protocols. Plant breeding outfits in partnership with international research centres and government agencies appropriate a sizeable share of the benefits from improved varieties sales to themselves.

Public plant breeding programs have not been immune to government pressure to generate revenue from their activities. Like private business, their capacity to capture a high proportion of the net benefits of new varieties depends on:

- a legal basis to establish ownership of the intellectual property embodied in the variety,
- the capacity to exclude potential users who are not willing to pay the nominated price,
- the costs of monitoring and enforcing compliance,
- the capacity for price discrimination.

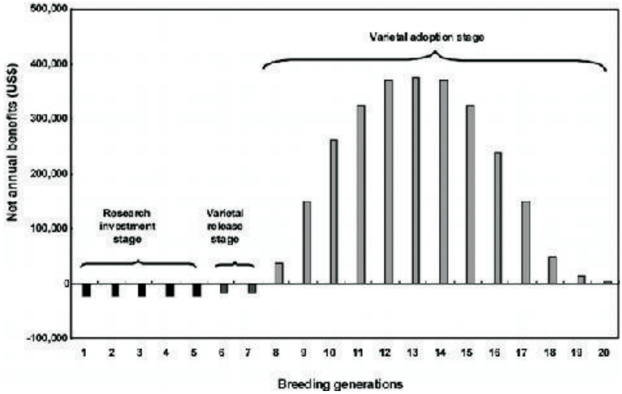

Figure 29: Economics of Plant breeding and commercialization of varieties

7.2.3. *Coexistence of Plant breeder's right and patent rights*

Mr. Vice Chancellor, Sir, in May 2021, the President of the Federal Republic of Nigeria, His Excellency President Mohamodu Buhari, assented to the Plant Variety Protection (PVP) Act 2021, which grants exclusive intellectual property rights to Plant Breeders over new plant varieties ("Plant Breeders Rights"). This act is the legal aspect of the science behind the art of Plant Breeding, and the visual art showcasing plant breeding science, strategies and successes.

Important highlights of The Nigeria Plant Breeders Right are listed below:

a. *Establishment of the Plant Variety Protection Office*: The Act establishes a Plant Variety Protection Office, through which breeders will be granted rights, and information on plant breeders' rights issued in Nigeria can be obtained. The Office would facilitate transfer and licensing of plant breeders' rights, collaborate with local and international bodies whose functions relate to plant breeders' rights, as well as perform other necessaryfunctions.

b. *Conditions for Plant Variety Protection (PVP)*: The Act provides for the Registrar to grant protection to plant varieties that are new (novel), distinct, uniform, and stable.
i. Novelty: A plant variety would be considered new if at the date of filing, there had been no propagating or harvested material of the plant variety commercialized with the consent of the breeder earlier than one year before filing in Nigeria and four years in any territory other than Nigeria and six years for trees and vines in such territories.

ii. Distinctness: The requirement of distinctness is fulfilled if such variety is easily identified and differentiated from other known existing varieties at the time of filing.

iii. Uniformity: Uniformity is deemed, where aside from the variation that may be expected from the features of such propagated plant variety, it is sufficiently uniform in its relevant characteristics.

iv. Stability: The requirement of stability is fulfilled if after repeated propagation or after a particular cycle of propagation, the relevant characteristics remain unchanged.

c. *Nature of Plant Breeders' Rights (PBR)*: A plant breeder has exclusive rights to propagate materials of a protected variety. Authorization must be obtained from such breeder for the production and reproduction, conditioning for propagation; offering for sale; selling or marketing; exporting; importing and stocking in relation to any of the mentioned purposes.

d. *Duration of Plant Breeder's Rights*: A plant breeder's right will expire after 20 years from the date of grant except for trees and vines whose breeder's right shall expire 25 years after the date of grant. Grant for the above breeders is extendable for an additional 5 years each, upon notice to the Registrar 6 months before the expiration of the original term. The Act makes provision for the holder of a plant breeder's right to assign or authorize any activity in relation to a registered plant variety. The assignee shall notify the Registrar of the assignment for record purposes.

e. *Benefits of Plant Variety Protection to Plant Breeders and Nigeria's Economy*

i. The introduction of the PVP Act would create access to collaboration and access to high-quality new varieties from foreign plant breeders. Hitherto, the absence of regulatory framework protecting new plant varieties had discouraged foreign collaboration and partnerships with plant breeders in Nigeria because of the lack of Intellectual Property (IP) protection for plant breeders.

ii. IP protection granted to plant breeders will result in increased investment in plant breeding and the development of new plant varieties capable of increasing yield and productivity. This is because investors are now assured of a structured IP protection system to underpin the commercialisation of new plant varieties.

iii. Given that the PVP Act confers IP rights on registered plant breeders, this would serve as an incentive to plant breeders for the development of new varieties and encourage more farmers to engage in plant breeding, thereby leading to an increase in the availability of more improved crop varieties with better yielding potentials.

iv. The signing of the PVP Act will eradicate existing scepticism in investing in plant breeding by private companies and encourage more investment from the private sector.

v. The PVP Act will encourage applications from non-residents or foreign plant breeders, as plant breeders are unlikely to release valuable varieties into a country without adequate protection of their plant varieties, and this will enhance access to foreign plant varieties.

vi. During the evaluation of new plant varieties, breeding entities get to collaborate with farmers and local institutions. This would serve as capacity building for local farmers and institutional staffs involved and create employment opportunities.

vii. International plant breeders will be encouraged to incorporate their companies in Nigeria to produce and market their varieties locally.

viii . It is expected that the proper implementation of the provisions of the PVP will encourage research and development by breeders, thereby leading to higher agricultural productivity, and a boost in the agricultural sector would have a reverberating effect on Nigeria's economy.

ix. The Act stipulates that harvested material or products obtained through the unauthorized use of a protected variety would require the authorization of the holder of the breeder's right unless there has been a reasonable opportunity to exercise such right in relation to the referenced plant variety. However, it is ambiguous what reasonable opportunity to exercise right entails, as a plant breeder might have exercised such right by declining the offer and the user goes through to use such propagated or harvested material, this certainly would not automatically be seen to be justified just because the breeder had reasonable opportunity to exercise his right.

x. By the provisions of the Act, any decision of the Registrar as regards refusal, nullification, or cancellation of a breeder's right can be appealed to the Minister of Agriculture. However, the Act provides that any decision emanating from the Minister is final. The finality of such a decision deprives an appellant of the right to seek remedy in a court of law.

8. CONCLUSION:

Plant Breeders' are special kind of people that are consumed with zeal to provide solution to the ever-increasing agricultural challenges that bedevil humanity. Complexities and challenges are overcome by inward reach before outward reach. Large and broad-based genetic variation, the science and art of plant breeding are our major strength, providing good choices for breeding acceptable varieties. Creativities following imaginations need natural, hybridization, mutation, molecular and genomic tools to achieve set breeding objectives. It's unbelievable the stress Plant Breeders go through in this part of the world due to lack of good protective government policies. Funding and lack of adequate infrastructure are major problems militating against breeding breakthroughs. Plant breeders must self-motivate themselves for successful plant breeding endeavours. The joy of all Plant Breeders is to create, redesign, remodel and produce new crop cultivars for commercialization; “that is the artistic design of intricate science of plant breeding”. Development of ideal new varieties combining good yield with resistance to pest, diseases and other stressors is an economic relief to all stakeholders.

Plant breeders must partner with each other and other related specialists to access data and resources they need to quickly identify target genes and evaluate new varieties. The exchange of information or bioinformatics is important in Plant breeding as business. Breeders must be involved in all aspects of agro-commercialization of end product of breeding activities. The IPR and PVP are very good steps towards protecting the Plant Breeders, and the commercialized varieties in their name. The issue of royalty for Plant Breeders is an aspect that needs to be pursued vigorously to preserve the art and science of breeding and breeders.

The perception that science interfaces art provides an understanding towards successful plant breeding endeavours because it require skills and talents (artfulness), salesmanship and scientific background of breeding. By providing access to scientific data, resources, and collaborative platform, breeders are able to quickly and efficiently identify the genetic variations that will allow them to develop new varieties with improved traits. In this way, this platform has the potential to contribute to sustainable crop production and help to ensure food security for future generations.

9. RECOMMENDATIONS

1. There can never be enough funds for research, especially agricultural research, however, the government should create a special intervention fund dedicated to agriculture, especially to train Plant breeders and related discipline.

2. The assented Plant Variety Protection and Intellectual Property Right by the Federal Government of Nigeria should be enforced, particularly the royalty for the public breeders involved in the commercialized varieties.

3. Partnership and networking amongst public, private Plant Breeders, national agricultural research institutes, universities and international research organizations should be

encouraged. Plant breeders and relayed specialists should freely exchange data and other relevant information to enhance plant breeding activities.

4. There is need to establish Plant Breeding Institute to cater for administering all that concern Plant Breeding activities, plant Breeders, and all other related matters for the advancement of Plant Breeding as an established profession.

1. Federal University of Agriculture, Abeokuta should establish Seed Unit and register Seed company that will be headed by professionals to key into the business of Plant Breeding and other related agro-commercialization of property rights. The case of FUNAABOR 1 and FUNAABOR 2 (as seeds and grains) should be taken very serious for income generation.

2. Rapid training and retraining of Plant breeders must be encouraged particularly in the utilization of the new biotechnological, molecular and genomic tools to enhance crop improvement aimed at solving food crises.

3. Plant Breeding courses should not be to earn degrees alone, but must be taught from practical point of view to achieve scientific manipulations, artistic impression and business mindset to improve economy and wellbeing of humanity.

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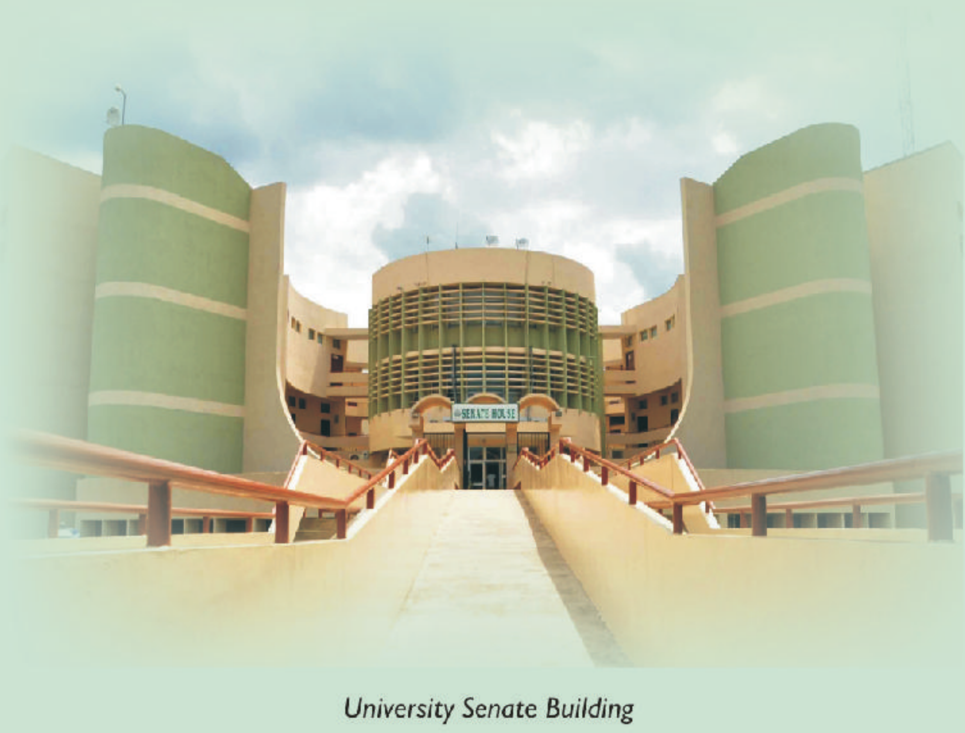

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