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Genetic Improvement of Rice in Nigeria for Enhanced Yeild and Grain Quality - A Review

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Authors' contributions

This work was carried out in collaboration between all authors. Author ABO wrote the first draft of the manuscript. Authors DN and SBZ reviewed all drafts of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

The development of rice with high yield and grain quality is one of the main goals of rice breeding programs all over the world. In Nigeria, Rice breeders have been successful in improving the crop for different characteristics, tolerance to biotic and abiotic stresses. An example of rice variety developed for early maturity, high grain yield and quality is FARO 44(Sipi-692033), for tolerance to iron toxicity is FARO 52(WITA 4), for tolerance to African Rice Gall Midge is UPIA 2 (IWA 2) amongst others. A number of breeding methods such as Conventional Hybridization, Recurrent Selection, and Mutation breeding and Varietal Introduction from other countries can be used to create variability in rice to make improvement possible. Different research institutes in Nigeria, in collaboration with international NGOs have been intensifying efforts to improve the crop for different characteristics particularly for grain quality and high yield, adaptable to the country's varying

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ecology. The development and introduction of tools of biotechnology into plant breeding have enhanced the breeding capacity of breeders, but these tools have not been fully integrated into rice breeding programs in the country. This paper highlights different breeding methods that can be used to develop new rice varieties, modify or improve already existing ones. Recommendations are also given in the direction of future research for enhancement of rice in Nigeria.

Keywords: Rice; grain quality; conservation; hybridization; mutation breeding; recurrent selection; biotechnology, Nigeria.

ABBREVIATIONS

AFLPs	:	*Amplified Fragment Length Polymorphisms*
AfricaRice	:	*Africa Rice Center*
CGIAR	:	*Consultative Group on International Agricultural Research*
CIAT	:	*International Center for Tropical Agriculture*
CNRRI	:	*China National Rice Research Institute*
DArT	:	*Diversity Array Technology*
DNA	:	*Deoxyribonucleic Acid*
FARO	:	*Federal Agricultural Released Oriza*
IRRI	:	*International Rice Research Institute*
IITA	:	*International Institute of Tropical Agriculture*
MAS	:	*Marker Assisted Selection*
NACGRAG	:	*National Center for Genetic Resources and Biotechnology*
NERICA	:	*New Rice for Africa*
NCRI	:	*National Cereals Research Institute*
NGOs	:	*Non-Governmental Organizations*
RAPDs	:	*Randomly Amplified Polymorphic DNA Markers*
RFLPs	:	*Restriction Fragment Length Polymorphisms*
SSLPs	:	*Sequence Length Polymorphisms*
SNPs	:	*Single Nucleotide Polymorphisms*
TEs	:	*Transposable Elements*
VRC	:	*Varietal Release committee*
WARDA	:	*West African Rice Development Association (old name of AfricaRice)*

1. INTRODUCTION

The value of food crops is increased when the quantity of the crop is increased through increase in yield per hectare and when quality is increased to meet basic nutritional and processing requirement to satisfy consumer demand. Rice (*Oriza sativa* L.) is one of the world's oldest domesticated staple foods. It supplies 2808 calories /person/day which represents 21% of the total calorie supply and it is a source of income to more than 100 million household around the world [1]. The consumption of rice is growing faster than that of any other staple in Africa and the world at large, simply because it has become convenience food for the growing world population. It is cultivated on almost 11% of the earth's cultivated land area and a wide number of ecosystems [2]. Of the twenty two species of rice that there are, two species, *Oriza sativa* and *Oriza glaberrima* are cultivated while other species are wild. It is one of the crops responsible for the so-called green revolution that happened in the 1960s and 1970s. In addition to having strong breeding programs in all different regions around the world, this crop has three Consultative Groups on International Agricultural Research (CGIAR) centers with the mandate to work with rice: the International Rice Research Institute (IRRI), with global mandate; The Africa Rice Center (AfricaRice), with mandate to work in West Africa; and the International Centre for Tropical Agriculture (CIAT), with the regional mandate for Latin America.

Nigeria has a potential land area of between 4.6 to 4.9 million hectares suitable for rice production, but only 1.7 million hectares is being cropped [3]. The small number of hectares under cultivation is an indication that food sufficiency through rice production has not yet been fully realized as rice production is left in the hand of peasant farmers whose output is inadequate and paddy processing is substandard [4,5]. The domestic production is also constrained by low-input, inadequate crop management techniques as well as lack of water.

The diversity of rice offers a valuable resource to understand grain quality and how different agronomic backgrounds alter those traits. Rice is consumed mainly as milled, white grains or as brown grains (unpolished), and also as ingredients in food products. The cooking and sensory properties of a variety are key components that affect its acceptability by consumers [6]. Enhancing yield without concurrent enhancement of quality may not be fruitful as the rice must be acceptable to consumers hence the need to improve grain quality. Consumer preferences shifted from low-quality to high-quality rice with increased income and market liberalization that allowed the importation of high quality parboiled rice. Improvements in post-harvest technologies can reverse this shift in consumer preference by decreasing the price difference between low- and high-quality rice.

2. RICE IN NIGERIA

Nigerian agriculture has made possible through the diverse agro-ecological production systems in the country the availability of an array of staple food crops that are of great importance to food security of households. Among these commodities are; Cereals (Rice, Maize, sorghum, wheat, millet etc), Legumes (Cowpea, soya bean, groundnut etc), Roots and Tubers (Cassava and Yam) and various vegetables. Out of all these staple crops, rice has in the past years up till date taken a domineering position as a major source of household calorie.

The demand for rice has risen rapidly over the decade as a result of various factors; aside the increase in population growth, rapid urbanization has posed to be the most influencing factor in the shift in consumer preference toward rice consumption. As men and women get more engaged at work the ease and timeliness of rice preparation has made rice a preferred staple over all other staples and domestic production has never been able to meet this demand, escalating importation of rice into the country over the years. In 2002, 1.9 million tons of rice was imported into Nigeria amounting up to approximately 500 million US dollars [7]. These imports which are procured on the world market and paid for in foreign currency amounting up to $259 million in 1999 [8] represents a substantial and outrageous capital expenditure (which can be greatly reduced or avoided) for the Nigerian economy. Nigeria produces the largest quantity of rice in west Africa, producing 20 million tons of milled rice or 3.2 million tons of paddy rice on the average [9]. Nigeria also recorded the highest rate of consumption of rice in west Africa up to 4.1 million tons of rice in 2002 with only around half of this quantity catered by domestic production. Government policies, Acts and Initiatives on rice in the past years have not helped the economy of rice in Nigeria; they have been inconsistent and have included unstable import tariffs and restrictions. From 1986 to the mid 90s, rice imports into the country were illegal; imports were allowed in 1995 but at 100% tariff. The tariff was brought down to 50% in 1996 and was raised to 85% in 2001. When the outright quantitative ban was placed on rice in 1985, it was anticipated to stimulate domestic production through increase in the price of the imported commodity, the belief was that the ban would create an increased demand for local rice which would serve as a push for local producers to increase production. But the reverse was the case; Nigerians still craved the already banned imported rice, encouraging smugglers to bring bags of rice into the country through the countries porous borders.

It is then obvious that Nigerians are drawn toward and have developed a high taste and acceptance for the quality presented by foreign rice imported into the country because of its palatability and wholesomeness and would adjust to any price at which it is offered provided the aforementioned is maintained. The answer to the question of why locally produced rice is not well accepted by Nigerians lies in the state of the technology involved in the development of the planting materials through processing to the final grain quality presented to consumers. Nigerians will continue to measure the quality and competitiveness of domestic rice against the standard and quality found in imported rice. With this situation, there is an urgent need to improve or modify the existing varieties with farmers for higher yield and better grain quality; these must be achieved under the prevailing conditions of declining and deteriorating land, soil and water resources and at the same time preserving environmental quality. Rice improvement requires the inspired application of new and already existing plant breeding knowledge to create additional value.

3. RICE RESEARCH EFFORTS IN NIGERIA

Several governmental and non-governmental organizations in Nigeria are responsible for rice varietal development and germplasm maintenance. They include;

4. THE NATIONAL CEREALS RESEARCH INSTITUTE

The National Cereals Research Institute (NCRI) is one of fifteen (15) Agricultural research institutes under the federal ministry of agriculture. The institute has a long history dating back to 1898 when the first precursor of the department of agriculture was established, by the then British colonial administration. The institute has undergone several metamorphoses and now has national research mandate on Castor, Rice, Soya bean, Sesame, Sugar cane and Acha throughout the country. In addition to the above stated, the institute has mandate for the overall farming system research and extension into all aspect of agriculture within the North Central Zone of Nigeria. On rice, The National Cereals Research Institute has a national mandate for genetic improvement and improvement in rice processing.

Over sixty improved varieties of rice and its recommended best practices have been released by NCRI in collaboration with other research institutes, universities, agricultural NGOs and departments for commercial production through the National Committee on registration and release of crop and livestock breeds which (since the establishment of The National Center for Genetic Resources and Biotechnology (NACGRAB) in 1987) meets in the conference hall of the center in Ibadan, Oyo state, Nigeria. (With the Director/CEO of the national Center for Genetic Resources and Biotechnology as the registrar of the committee.) To deliberate on varieties of crops presented by breeders from research outfits all over the country for approval and release to farmers. Some rice genetic diversities are kept in short term storage in the institutes head quarters in Badeggi, Bida, Niger State, Nigeria.

5. AFRICA RICE CENTER

The Africa Rice center (AfricaRice), formerly West Africa Rice Development Agency (WARDA) was created in 1971 by eleven (11) African countries to be the leading pan-African research organization working to contribute to poverty alleviation and food security in Africa through research, development and partnership activities. It is one of the fifteen (15) members of the Consultative Group on International Agricultural Research (CGIAR). AfricaRice is an autonomous intergovernmental research association of African member countries which is made up of 24 countries, covering West, Central, East and North African regions including Nigeria

In recent years, rice varietal development/improvement in Nigeria has benefited greatly from significant and increasing high level of collaborative research activities. These activities include the concept of collaborative research between AfricaRice and the National Programs within the Sub region through task forces, under this initiative some production constraints are identified and a task force is allocated to develop technologies aimed at solving such constraints.

The activities of Rice breeding task forces in Nigeria involves research into Upland, Rain fed Lowland and Irrigated Low Land. Through the task forces, lines bred for different ecological problems are composed into nurseries of nominations from AfricaRice and National Programs. The National Agricultural Research System (NARs) that share similar production constraints in a given ecology evaluates these nurseries and the results from these evaluations are discussed at Africa Rice Center headquarters at the end of each cropping season after which some varieties from these nurseries are then identified for national use. AfricaRice at full incorporation into the Consultative Group on International Agricultural research system (CGIAR) established a lowland breeding station at The International Institute of Tropical Agriculture (IITA), when IITA ceased its rice research work. The national program benefited agricultural research scientists in Nigeria because scientists could enjoy closer collaborations with their AfricaRice counterpart at the station.

6. THE NATIONAL CENTER FOR GENETIC RESOURCES AND BIO-TECHNOLOGY

The National Center for Genetic Resources and Biotechnology was established in 1987 by the Federal Ministry of Science and Technology to be the lead center in Nigeria for plant genetic resources and relevant matters relating to research, data collection, conservation and dissemination of technological information. Activities of NACGRAB include;

- Conservation, preservation and maintenance of Nigeria's valuable plant genetic resources for immediate utilization including genetic resource storage for the future.
- Networking and coordinating activities in the development of capabilities in genetic engineering and biotechnology.

In addition to the above activities, NACGRAB is assigned the duties of managing the quality of the seed industry through its varietal release committee (VRC). Its third activity thus include the servicing of the activity of the National Committee on Registration and Release of Crop varieties and Livestock breeds. The gene bank in the center's head quarters at Moor Plantation in Ibadan, Oyo State, Nigeria holds hundreds of rice accessions in cold long term storage and working collection with copies also conserved in the snowy depths of Svalbard, Norway.

7. CONSERVATION OF EXISTING RICE BIODIVERSITY

There are two basic conservation strategies, each composed of various techniques that the conservationist can adopt to conserve genetic diversity once it has been located. The two strategies are *Ex situ* and *In situ*. *Ex situ* conservation means the conservation of components of biological diversity outside their natural habitat. It involves techniques such as Seed Storage, Field Gene Banks, In Vitro Storage, DNA Storage, Pollen Storage and Botanical Gardens. While *In situ* conservation means the conservation of ecosystem, natural habitat and maintenance and recovery of valuable populations of species in their natural surroundings where they have developed their distinctive properties. On-farm conservation and genetic reserves are forms of In situ conservation [10].

The existing rice biodiversity in Nigeria can be properly conserved by giving unwavering attention to careful management and proper documentation to bridge the gap between germplasm available and germplasm utilized in breeding programs. There should be rice germplasm collection with a sense of mission to unexplored and under explored regions of the country while effort to conserve genetic resources such as released varieties, breeding lines, land races etc at research institutes is accelerated. Rice germplasm should be assigned national accession numbers after eliminating the duplicates through systematic evaluation. Also, attribute based core collection of indigenous rice should be developed. A practical mechanism for in situ conservation through farmer participatory breeding approach and through proper incentives to farmers should be put in place.

8. RICE GENETIC DIVERSITY IN NIGERIA

The success of the breeding strategies relies heavily on the genetic diversity of the crop. Rice gene banks around the world exhibit a very large amount of genetic diversity present in farmers' cultivars, landraces, as well as in the genetic makeup of the 22 *Oryza* species. At the National Center for Genetic Resources and Biotechnology, moor plantation, Nigeria. There are over a thousand rice accessions conserved in the center's long and short term gene bank. In addition, there are safety duplicates of these accessions held in trust in the snowy depths of Svalbard, Norway. With this, rice breeders in Nigeria have useful genetic diversity to draw on for many generations to come as long as there is a good choice of germplasm. Out of the 22 species of rice, only *O. sativa* and *O. glaberrima* are cultivated. The number of chromosomes of the cultivated rice and its related species varies from 24 to 48, with the ''n'' number equal to 12. According to Morishima (1984), based on the chromosome paring in the meiosis, rice has the following genomes: AA, BB, CC, EE, and FF for the diploid species and BBCC and CCDD for the tetraploid species. The two cultivated species, which are diploid (2n = 24), were domesticated under different environmental conditions. *O. sativa* was domesticated in South and Southeast Asia and has the species *O. rufipogon* and *O. nivara* as its direct ancestors. *O. glaberrima* comes from tropical West Africa and has *O. barthii* as progenitor. The former is cultivated throughout all the rice growing environments around the world. However, cultivation of the African species is confined to its region of origin. The three main sources of genetic diversity for rice in Nigeria are; *Oriza sativa*, *Oriza glaberrima* and wild species e.g. *Oriza bathii*.

O. sativa germplasm consists of land races and improved germplasms, generally they are yet to be fully exploited to improve varieties for upland ecologies and rain fed deep water ecologies. The deep root nature and heavy panicle that combines big and strong Culm can be utilized to develop materials for drought tolerance and lodging resistance that characterize upland ecologies particularly in the high rainfall areas of the rain forest zone. The tall nature of these materials and their photo period sensitivity can also make them ideal for the development of rain deep water ecology materials for the flood plains of the Niger, Benue and Kaduna rivers in Nigeria.

O. glaberrima originates from West African subregion. It is well adapted to the adverse African rice growing soils, harsh climatic conditions and biotic stresses such as drought, Rice Yellow Mottle Virus (RYMV), competition from weed, soil acidity etc. [11,12]. They are however characterized by very low yield potential, grain shattering before full maturity and many other undesirable traits that makes them unappealing to agronomists and consumers alike. Inspite of all its undesirable traits, it offers great potentials for genetic improvement because of its wide adaptation to various rice growing ecologies ranging from upland to deepwater.

The use of glaberrima germplasm has a major constraint in that the F_1 plants in 90 percent of crosses is sterile and two or three back crosses may not have a major impact on the high sterility situation. Anther culture can be used to salvage the situation as the production of double haploids that may be fertile and fixed is possible. A series of back crosses were made by the National Cereals Research Institute in its sativa-glerbarrima interspecific hybridization and it was discovered that there were only a small number of compatible lines that can give a high percentage of fertile individuals after two or three back crosses. The use of *O. bathii* as genetic resource is constrained by a number of factors. *O. bathii* is found in almost all rice fields in Nigeria. Given the genetic distance between this wild germplasm materials and cultivated species, the success of cross hybridization is low and requires advanced breeding techniques such as embryo culture.

In 1991, The Africa Rice Center initiated a program to combine the two cultivated rice species *O. sativa* and *O. glaberrima*. Their genetic dissimilarity needed the use of a different breeding approach. Embryo rescue technique was employed to obtain viable segregating populations [13]. The newly developed materials were called ‘‘new rice for Africa’’ and were popularized as NERICA varieties. The NERICA varieties were the first wide-scale success of crossing of the two cultivated species. The upland varieties were derived from *O. sativa* subsp. *Japonica* (Known in Africa as ‘upland rice’) and the low land varieties from subsp. *Indica* (‘lowland rice’). The main features of these new varieties, when compared to the traditional *O*. *glaberrima*, cultivated by farmers, are their improved ability to compete with weeds, their larger panicles with around 400 grains and a higher yield potential. In addition, shattering is reduced, stems are stronger thus preventing lodging, maturity occurs around 30 days earlier than other conventional cultivars, and they have greater resistance to the most common biotic and abiotic stresses, as well as improved adaptability to the poor African rice growing soils.

During the period 2002-2006, AfricaRice designated 18 upland NERICA and 60 lowland NERICA-L varieties. The success of the NERICA varieties cannot be denied. Particular highlight include Nigeria in which close to 200,000 hectares of NERICA 1 and NERICA 2 were cultivated. The strong participation of the farmers in the process of evaluation of the breeding lines as well as in the development of the materials contributed greatly to the success of the program [14].

9. CHOICE OF GERMPLASM

One of the most difficult tasks in carrying out a successful breeding program is the choice of germplasm. To be able to develop a variety with a set of desirable characteristics rice breeders need to be sure that the source germplasm has desirable genetic variability. After the parents are chosen and the crosses are made there are almost no chances of new alleles appearing in the segregating populations. To make the right choice of parental material to be used in a breeding program, breeders must clearly know the type of product to be developed; the characteristics of the species to be bred; the combining ability of the parents in case of hybrid cultivars; the environmental conditions of the target area; the social and economic aspects of the farmers and markets; and the different breeding approaches available to achieve the proposed goals. An additional element to be considered is the legal aspect in relation to the materials to be used as parents.

In general, rice breeding programs have two major different end products. The first and the most common one is a pure line, which will be evaluated and released as a commercial variety. The second one is an inbred line that will be the parent of a commercial hybrid. An intermediate product may be a population with certain desirable characteristics that could be used for further improvement.

10. PRINCIPLES OF GENETIC IMPROVEMENT IN RICE

Increase in grain yield potential and grain quality is one of the most important goals of almost all rice breeding programs. The focus is mostly geared toward the application of plant breeding techniques to increase grain yield and grain quality of existing varieties. Some of the principles revolving around these breeding techniques include;

10.1 Conventional Hybridization

One of the traditional methods of crop improvement is sexual hybridization. This involves making a deliberate cross between two plants with desirable attributes; in hybridization program, pedigree selection among the F_2 derived progenies is the most popular method and sometimes, bulk population selection is used by breeders but usually in combination with pedigree method [15]. In the development of the improved varieties released in Nigeria, The National Cereals Research Institute (NCRI) and its partners adopts mostly pedigree method in combination with single seed descent selection. The method is combined to speed up the process of having pure lines for agronomic evaluation. After crossing, a successful fertilization brings about the recombination of genetic information of the two parents and the offspring arising from such a cross inherits the characters associated with the parents. Selection is done after the creation of variability that accompanies hybridization, desirable individuals are selected on the basis of field observation and yield trials. The success of a hybrid depends on the level of heterosis *i.e*. hybrid vigor (the superiority of the F_1 hybrid over the parental genotypes). It is expressed after crossing parental Varieties. Another method of producing hybrid rice is the three-line method, which requires careful seed production [16]. The combination between different varieties is the first step to obtain heterosis, but its expression improves as combinations between varieties belonging to different groups are explored.

11. THE PEDIGREE METHOD

Pedigree selection is a widely used method of breeding self-pollinated species (and even cross-pollinated species.

Such as corn and other crops produced as hybrids). It is a breeding method in which the breeder keeps records of the ancestry of the cultivar. The base population is established by crossing selected parents, followed by handling an actively segregating population. Documentation of the pedigree enables the breeder to trace parent–progeny back to an individual F_2 plant from any subsequent generation. To be successful, the breeder should be able to distinguish between desirable and undesirable plants on the basis of a single plant phenotype in a segregating population. It is a method of continuous individual selection after hybridization. Once selected, plants are reselected in each subsequent generation. This process is continued until a desirable level of homozygosity is attained. At that stage, plants appear phenotypically homogeneous. The breeder must develop an effective, easy to maintain system of record keeping. The most basic form is based on numbering of plants as they are selected, and developing an extension to indicate subsequent selections. For example, if five crosses are made and 500 plants are selected in the F_2, a family could be designated 5-112 (meaning, it was derived from plant 112 selected from cross number 5). If selection is subsequently made from this family, it can be named, for example, 5-112-8. The breeder may include letters to indicate the parental sources (e.g., SP-5-112-8), or some other useful information. The key is to keep it simple, manageable, and informative.

12. BULK POPULATION SELECTION

The procedure in bulk selection allows natural selection to operate on segregating populations. Individual plants are selected in F_5 and in later non-segregating populations. This method allows a large number of crosses to be evaluated and large population sizes to be maintained. Plants which are more competitive emerge as the material is more densely seeded. Progeny resulting from this method are those which were favored by natural selection.

13. SINGLE SEED DESCENT

Single seed descent method is a modification of bulk method of breeding that has attracted many plant breeders. It is a breeding procedure in which fixation with minimum bias from potential variability is the major aim. The modification is in such a way that it allows the equal survival of segregates. In this method, only one seed is selected randomly from each plant in F_2 and subsequent generations. The selected seed is bulked and is used to grow the new generation. This process is continued up to F_5 generation. By this time desired level of homozygosity is achieved. In F_6, large number of single plant, 200-500 are selected and their progeny are grown separately. In F_7 and F_8, selections are practiced between progeny and superior progeny and are isolated based on preliminary replicated trial. The superior progenies are then tested in multiplication trails and the best progeny is identified for release.

14. THE THREE LINE METHOD HYBRIDIZATION

The three line method is a common form of hybrid rice technology. The key to the system is the cytoplasmic male sterile, or CMS line in which the fertility of the nucleus (the major player in sexual reproduction) is suppressed by factors in the cytoplasm of the cell. Thus the CMS line cannot pollinate itself-i.e., it is sterile. The two other lines required to make the system work are the maintainer and the restorer. The Maintainer is generally identical to the CMS, except that it does not have the cytoplasmic sterile factors, but these are not dominant over the ‘normal’ fertility factors of the nucleus; however, the Restorer is genetically dissimilar to the CMS so that seed from the resulting cross (F_1) has as much heterosis as possible.

Both Maintainer and Restorer lines can be self-pollinated and breed true. However, the CMS must be crossed with either the Maintainer, to maintain the CMS line, or the Restorer, to generate the F_1 seed that is grown by farmers. The hybrid (F_1) seed typically grow into plants with vigorous roots, strong tillering, large panicles and heavy grains. Certain characteristics are required of good CMS lines: good agronomic characters; stable male sterility (100%); floral structure; and flowering habits. CMS lines must maximize their reception of pollen (e.g., by having a large stigma).Meanwhile, the Restorer lines needs: strong restorer ability; good agronomic characters; to be taller than the CMS line (to maximize dispersal of pollen over recipient CMS rows in the field); and appropriate flower structure and habit (e.g., large anthers with much pollen, long filament to exerts the anthers, closed floret to protect it from self-pollination).

Hybrid-rice technology exploits the phenomenon of ‘heterosis’, or hybrid vigor and involves raising F_1 hybrid seeds. The three line method of hybridization is widely used in China, and has been championed in Africa by the Chinese, with various exchange visits for African researchers to learn hybrid rice growing techniques in china or on their home soil. The advantage of hybrid rice is that it almost guarantees a 20-30% yield increase over the parent varieties (as a result of heterosis). There are two major disadvantages however: seed yield (as opposed to grain yield) are only about 70% of ‘regular’ varieties; and farmers have to buy fresh seed every year because hybrid grain will not breed true if saved as seed.

15. RECURENT SELECTION

Population improvement through recurrent selection is a traditional breeding method that has been used in rice all over the word for several years back. [17] Suggested its application in rice using male sterility. Population improvement through recurrent selection in rice is a methodology widely used in Latin America; however, it is not as popular in Nigeria. In rice, as probably happens in almost all self-pollinated crops, breeders tend to use pedigree selection which is a complement to recurrent selection if well managed. The genetic improvement process is cyclical; the aim of having such cycles is to capitalize on the genetic gains made in previous years; however, through pedigree selection this is done in a non-systematic way. In general, each year breeders select the best breeding lines to make new elite crosses between them and/or with new germplasm. The main feature of recurrent selection is to increase the frequencies of the favorable alleles, as was pointed out by Hull, [18], when describing the process of recurrent selection. Thus, by applying the recurrent selection method in rice, breeders are following the same principle but in a systematic and long-term way. Hand crossing in rice is a laborious task as described by [19]. Some of the requirements when using recurrent selection method is to produce progenies (sometimes crossing when using full or half-sib families) and recombine the selected ones after replicated experiment trials across environments. Therefore, the utilization of population improvement methods in rice only became feasible after the discovery of the male sterile gene obtained by [20] through induced mutation of the rice variety ''IR36''. The recessive male sterile gene was employed in 1984 by Embrapa and Cirad to create populations with broad genetic bases [21,22] Moreover, the simplification of the crossing method developed by [23] and described by [24] made a significant contribution to promoting the use of breeding methods that require a large number of crosses Therefore, recurrent selection allows defined and shorter breeding cycles, the possibility of a more precise follow-up of genetic gains, and opportunities to develop breeding lines with a wide genetic make-up.

16. MUTATION BREEDING

Mutation breeding is an effective means for inducing variants to improve quality traits, particularly those controlled by major genes. According to [25] during the period 1966–1990, there were 78 varieties released in China originated from mutation breeding. More recently, from 1991 to 2004, there was a similar number (77) of new releases coming from application of mutation [26]. The most popular mutagen is the gamma ray and the mutated characteristics are the ones responsible for the expression of agronomic (e.g., resistance to pests) and grain quality phenotypes. The use of different sources derived from induced mutations was a popular choice to generate genetic diversity for specific traits in rice in the 1980s. Today the technique has become part of the tool kit breeders have to enhance specific rice Characteristics in well-adapted varieties. Reports from [27] indicated that during the period 1990 and 2002 the Agricultural Genetics Institute in Vietnam developed and released 10 varieties, most of them have better grain quality, in addition to other agronomic trait. The Gama ray is usually applied in physical mutagenesis. This has been widely practiced in china, mostly as a means to accelerate improvement efforts with small populations and limited objectives [28].

17. INTRODUCTION FROM OTHER COUNTRIES

Varietal introduction from other countries coupled with multi location testing is one method of developing new varieties in a short space of time according to [29]. With strong collaboration between rice breeders in research institutes and universities across the country, hundreds of rice accessions and lines can be evaluated and screened every year and adopted for release for different agronomic traits including grain quality and yield characteristics and for different production systems. Often times, selection from introduction may not provide the particular agronomic and quality traits needed for a particular area, adapted local cultivars with desirable traits can be crossed with selected introduced lines to have the complementary characteristics followed by pedigree and back cross method. Promising uniform lines can be evaluated in yield trials. A number of crosses can be made with the objective of developing quality rice with characteristics such as short stature, photoperiod insensitive, high yielding, good eating and milling quality and good aroma.

18. APPLICATION OF BIOTECHNOLOGY

The development of DNA-based techniques and their application to crop plants has opened up new possibilities for enhancing rice yields beyond the limits imposed by conventional breeding and to stabilize yields. Various options for application of biotechnology in rice improvement are briefly discussed below.

The first and most important aspect to successfully take advantage of the variety of biotechnology tools available to rice breeders is to have a well structured, efficient, and effective breeding program. In the past recent years, Nigeria has made investments in the area of biotechnology, but without reinforcing breeding activities and/or having a well-structured operational breeding program that can incorporate biotechnology tools, very seldom has Nigeria ensured linkages between biotechnology efforts and breeding priorities or strategies.

Biotechnological techniques that have been used in rice breeding include Anther culture, Cell culture, Protoplast fusion and Wide hybridization. Anther culture is a simple biotechnology tool that has been used for quite a long time. The technique allows the development of double haploid lines or true Breeding lines, which shortens the breeding cycle and helps produce new rice Varieties. One of the main uses of double haploid lines is for the development of mapping populations for molecular analysis and mapping of DNA markers [30]. With Somatic cells culture, Heizhenmi, a dark black rice was obtained from the non-colored variety, Basmati 370 in china by the China National Rice Research Institute (CNRRI) [31].

Rice has a series of species that can and have been used to address specific breeding problems such as resistance to pests and tolerance to abiotic stresses. However, one of the main limitations on the use of wild relatives in breeding programs is the lack of crossability between cultivated and wild species due to chromosomal and genetic differences. One alternative to overcome this sexual Barrier is to use embryo rescue and protoplast fusion, which are biotechnology techniques that have been used successfully in rice. The NERICA varieties provide a good example of how these techniques were used to help address some specific breeding objectives. Several different types of markers are being used in rice, among which one may find the following: restriction fragment length polymorphisms (RFLPs); randomly amplified polymorphic DNA markers (RAPDs); amplified fragment length polymorphisms (AFLPs); diversity array technology (DArT); simple sequence length polymorphisms (SSLPs) also known as SSRs or microsatellites; transposable elements (TEs); and/or single nucleotide polymorphisms (SNPs). If genes of interest are identified and linked to some of these markers they can be used to aid selection in a process known as Marker –Assisted Selection (MAS). Knowledge of gene and marker location, linkage strength, and stability is essential. Therefore, basic information is required and molecular linkage maps may play a major role. Rice maps have been developed to that end; the first RFLP map was published in 1988 and was constructed at Cornell University by [32]. Breeders are interested in transferring genes of interest from one parent to the other. This process can be facilitated by tagging such genes, which means identifying a tight linkage between the targeted gene and a molecular marker. By selecting the marker the breeder is indirectly selecting the trait of interest. In hybrid rice, [33] transferred a resistance gene for bacterial leaf blight into a widely used parent. [34] Successfully pyramided four bacterial blight resistance genes through MAS into a rice variety. The rice genome is one of the most studied by scientists around the world. [35] Described it as having 430 Mb. [36] described it as 400 Mb once re-evaluated. [37] sequenced the japonicas genome and [38] did the same for the indicas. The introduction of an alien gene into rice through genetic engineering allowed breeders to target problems that without this technology it was not feasible. The golden rice is the most well known case of application of genetic engineering in rice in the 1990s. This specific project genetically engineered the provitamin A pathway into rice. Most cases, however, were related to the production of transgenic rice for resistance to diseases, insects, and abiotic stresses.

19. THE NEWEST RICE PROJECT

Soil nitrogen deficiency is a major constraint to rice production. Nitrogen deficiency is mostly high in highly weathered upland areas where an average yield of only one tone per hectare which is about 25 percent of yield potential has been recorded. Nitrogen is difficult to retain when applied to low land areas due to floods and flowing water that characterize such areas. Improving the nitrogen use efficiency (NUE) of rice is one means of overcoming these limitations. Similarly, drought is a major limiting factor in rice production in Nigeria and Sub-Saharan Africa where about 80 percent of rice farmers depend on rain fall. Farmers are often resource constrained and cannot afford irrigation systems. With the utilization and application of water use efficient (WUE) component, rice will require less water and this will offer an appreciable coping mechanism against drought. Also, high salinity is increasingly becoming a major problem in rice growing areas of the coastal lowlands and mangrove swamps of Nigeria and Sub- Saharan Africa in general.

The Nitrogen-Use Efficient, Water-Use Efficient and Salt-Tolerant (NEWEST) rice is a transgenic rice developed by plant transformation mechanism using *Agrobacterium tumefaciens* as vector to infuse the nitrogen efficient, water efficient and salt tolerant gene by electroporation into WITA 4 (FARO 52). The resulting events developed from the transformation are under screening on the confined field trial (CFT) site of the National Cereals Research Institute (NCRI) badeggi, Nigeria for trait gain. The goal of the NEWEST rice project is to develop and disseminate farmer preferred and locally adapted rice varieties with enhanced nitrogen use efficiency, water use efficiency and salt tolerance.

20. POTENTIALS AND COSTRAINTS IN RICE IMPROVEMENT IN NIGERIA

Rice varietal improvement has come a long way in Nigeria over the past decades with evidences of success in the development of early maturing varieties having higher grain yield, better grain quality, high milling recovery and nutrient content much more than what was obtained in the local unimproved varieties. Examples of such improved rice varieties include FARO 44(Sipi 692033), a cross between Sipi 661044 and Sipi 651020. It has a potential yield of 4-8 tons per hectare and it has become the variety of choice of late in most low land ecologies across the North Central and far North of Nigeria because of its high yield, short duration, long grain characteristics and its ability to reach optimum production under low management. FARO 52(WITA 4) is another well cultivated improved rice variety in Nigeria with potential yield of 3-7 tons per hectare. It is an evidence of success in rice improvement program in Nigeria for high yield and tolerance to abiotic stress such as iron toxicity and drought. UPIA 2(IWA 2) is high yielding with long slender grains, tolerant to iron toxicity and is a more recent evidence of success in improvement of rice in Nigeria for tolerance to African Rice Gall Midge.

However, further and speedy improvement of rice varieties in Nigeria has been hampered by a number of constraints. The effect of climate change can be seen with incessant flood disasters witnessed every year in the country. Several rice production fields and farm lands get destroyed and farmers experience terminal drought on the same production field where flood had occurred. Nutrients in these areas are also seriously leached after the incidence. There is also the serious problem of weed competition which if left uncontrolled leads to a 100% loss. The control of these weeds leads to increased production costs and crop yield is reduced drastically as a result of delayed weeding due to competition for labor at the early stage of crop growth.

It is against this background that the hope of survival and continued increase in production of rice with still higher yield and grain quality than even the currently available improved varieties must be sourced in more effective, efficient and timely methods of rice varietal development. This hope is held in the introduction and application of biotechnology to rice improvement. Following the signing into law of the national biosafety agency bill in April of 2015, the country has made some strides in investment into this new technology to shorten and hasten the time taken to develop new varieties but there is the challenge of lack of personnel and infrastructures to fully incorporate the technology into breeding programs. The issue of safety has been of utmost concern to consumers and environmentalists who feel that adequate effort has not been made to understand the dangers inherent in the use of transgenic crops and their potential long-term impacts. There is limited information, at times misinformation, about the health and environmental implications of transgenic crops. The issue of allergens and toxins arising from consumption of genetically modified crops and animal products has not been adequately studied. Adequate checks to ensure that the levels of naturally occurring allergens in foods made from transgenic organisms have not significantly increased above the natural range found in conventional foods have not been put in place. Also of great concern is the fear that techniques used to ensure that gene transfer in the course of genetic modification is successful can also lead to the emergence of anti-biotic resistant strains of bacteria. This may lead to rise in the incidence of diseases that are resistant to treatment with common antibiotics. It is possible that once transgenic crops have been released into the environment they could produce unforeseen and undesirable effects.

Unless transgenic crops are rigorously tested before they are made commercially available they may produce.

Some undesirable environmental side-effects. Farmers and other stakeholders are also very concerned about loss of biodiversity in our natural environment as a result of increased adoption of conventionally bred crops.

21. IMPROVED VARIETIES OF RICE IN NIGERIA

Over sixty (60) varieties of rice has been released and registered in Nigeria, these varieties had varying genetic contribution from across the world. For example, the high level of resistance to blast in Tjina was used for developing high yielding blast-resistant varieties such as FARO 16 and FARO 25, as well as semi-dwarf FARO 28. Most varieties bred in the country since 1986 have parents originating from IRRI. IR8 was used in crosses to incorporate its gene for earliness, traceable from early IRRI lines into FARO 15, a high adaptable and High-Yielding variety, in order to obtain stiff strawed early maturing, high yielding varieties. FARO 15 had the high yielding stiff straw from its IR8 parent. The other parent of FARO 15 is BG 79, used because of its wide adaptability to Nigerian ecosystem. This combination resulted in the development and release of FARO 30, 31 and 32 as early maturing high yielding varieties for irrigated schemes in Nigeria.

FARO 12, a long duration (140-160 days) variety is photo period-sensitive with long grains. The selected and released lines from this cross (FARO 33 and 34) were weak-strawed (like the FARO 12 parent) but inherited the long grain of FARO 12 and earliness of IR28. They performed well under moderate levels of fertilizer and are grown in most of the irrigated schemes of the North. Another promising variety of rice is FARO 44(Sipi 692033), an early maturing variety (110-120 days) derived from the cross between Sipi 661044 and Sipi 651020 has gained a high popularity among farmers as a variety of choice across different low land ecologies in the country since its release in 1992 due to the long grain, high quality rice paddy that it offers. In a study on the adoption of rice technologies introduced by the United States Agency for International Development in Anambra and Ebonyi States, Nigeria [39]. Reported that FARO 44(Sipi 692033) had the highest mean adoption score of 5.00 among other compared varieties which were; FARO 52(WITA 4), FARO 46(ITA 150), and FARO 55(NERICA 1).With mean adoption scores of 2.02, 1.14 and 1.16 respectively. The afore stated further indicates the acceptance of FARO 44 as a high quality variety and a variety of choice among farmers. In line with [40] which noted that availability of high quality rice paddy is a sure way to compete with imported rice and farmers must therefore grow long grained, high quality rice paddy for processors to produce high quality rice. FARO 52(WITA 4) combines drought resistance, iron toxicity tolerance with high yield and yield stability under low impute conditions. Its short coming however is its susceptibility to African Rice Gall Midge (AFRGM). FARO 46 (ITA I50), a cross between 63-83/ (Dourado recoce/ROK1/SE363G is the most widely adopted improved upland rice variety in Nigeria today. with a moderate yield potential of 2-3 tons per hectare, it is an intermediate to tall plant type, depending on the water and fertility condition of the soil. Paddy grain is golden, easy to thresh and long grained. The variety is widely grown in the south west of Nigeria where two cropping cycles of the rice are cultivated a year. It is also grown in the northern part of the country: Kano, Adamawa and beyond, where it is intercropped with sorghum, maize and millet.

22. RICE IMPROVEMENT PROGRAMES

An increase in productivity is always one of the main goals of any crop breeding program including rice. However, a long list of goals can be identified for this crop varying in importance from region to region across the country. A few examples of breeding goals are described below.

Increase grain yield potential is the major goal of almost all rice breeding programs around the world. The major impacts are related to the development of new strategies to increase the genetic grain yield potential of varieties.

Resistance to blast disease has been among one of the most researched rice breeding goals for decades. This disease is a widespread pest of rice in Nigeria. It is present in almost all agro-ecological zones where rice is grown across the country. It causes leaf and panicle damages. Improvement strategies have to rely either on gene pyramiding or multiple long-term resistance and/or tolerance because the fungus has a complex set of races and single gene resistance is frequently overcome in a very short time by the pathogen.

Drought tolerance is another trait highly researched in rice. The increase trend in global water scarcity, the gradual seriousness of water shortage around the world due to climate change, and the high water demand of rice varieties make this a highly important objective of rice breeding programs. The complexity of the trait and the difficulties in developing a reliable and simple screening system make the development of tolerant varieties an important challenge. The use of biotechnology tools is making a significant contribution to identify genes and strategies to incorporate them in new varieties. However, the progress is still below the required level to produce significant impact in rice production due to the genetic complexity of the trait.

Grain quality characteristics vary from region to region and country to country. In Nigeria, consumers discard locally produced rice grains derived from the indigenous varieties simply because of the high quality and palatability standard set by rice imported into the country. Speciality grain quality rice types are a major objective of breeding programs in Nigeria.

African rice gall midge is a serious biotic stress on rice in low land rice producing areas across Nigeria. So far success has been actualized in developing varieties tolerant to the stress. Examples of the tolerant varieties are UPIA1 and UPIA2.

Table 1. Some improved, released and registered rice varieties in Nigeria

Variety name	Original name	National CODE	Origin	Developing institute	Outstanding characteristics	Year of release	Year of registry	Agro-Ecological zones	Cultivation status
FARO-33	FAROX-233-1-1-1	NGOS-91-33	Nigeria (NCRI)	NCRI, Bida	Long grain type, (4-7t/ha)	1986	1991	Derived Savannah, Humid Forest	Moderately cultivated
FARO-37	I ITA 306	NGOS-91-37	Nigeria (IITA)	NCRI,Bida	Long grain type(5-8t/ha)	1986	1991	Derived Savannah, Humid Forest	Moderately cultivated
FARO-44	SIPI-692033	NGOS-91-44	Taiwan	AfricaRice/ IITA/NCRI	Long grain ,optimum production under low management, (4-8t/ha)	1990	1991	Derived Savannah, Humid Forest	Most cultivated
FARO-46	ITA-150	NGOS-91-46	IITA, Ibadan	IITA, Ibadan	High yielding, early maturing, blast resistant and drought tolerant	1990	1991	Northern and southern Guinea Savannah	Moderately cultivated
FARO-52	WITA 4	NGOS-01-52	AfricaRice & IITA, Ibadan	AfricaRice& IITA, Ibadan	High yielding, (3-7t/ha), tolerant to iron toxicity and drought.	2001	2001	Derived Savannah	Well cultivated
FARO-55	NERICA1 WAB 450-1-P38-HB	NGOS-03-55	AfricaRice, Bouake	NCRI, Badeggi	Early maturity, weed competitiveness, tolerance to disease, high grain yield,(3-7t/ha) and good cooking quality, resistant to lodging.	2003	2003	Northern and Southern Guinea Savannah, Sudan Savannah	Moderately cultivated
FARO-57	TOX4004-43-1-2-1	NGOS-05-57	AfricaRice/IITA	NCRI, Badeggi	High yielding, (6-8t/ha) medium maturing, long slender grains, resistant to blast, drought, iron toxicity and rice yellow mottle virus.	2005	2005	Northern and Southern Guinea Savannah, Sudan Savannah	Moderately cultivated
FARO-58	*NERICA7 WAB450-1-B-P-20-HB*	*NGOS-11-58*	*AfricaRice*	*Africa Rice Center and NCRI*	*Early maturing, High grain yield, .(5t/ha) good cooking quality*	*2011*	*2011*	Northern and Southern Guinea Savannah	Moderately cultivated

Variety name	Original name	National CODE	Origin	Developing institute	Outstanding characteristics	Year of release	Year of registry	Agro-Ecological zones	Cultivation status
FARO-59	NERICA8 WAB450-1-BL1-136-HB	NGOS-11-59	Africa Rice	*Africa Rice Center and NCRI*	Early maturing, golden grain colour, weed competitiveness and tolerance to lodging.(5t/ha)	2011	2011	Northern and Southern Guinea Savannah	Moderately cultivated
FARO-60	NERICA L-19 WAS 122-IDSA-1-WAS-6-1	NGOS-11-60	Africa Rice	*Africa Rice Center and NCRI*	High yielding, .(8t/ha) long slender grains and tolerant to iron toxicity	2011	2011	Derived savannah	Moderately cultivated
FARO-61	NERICA L-34 WAS 161-B-6-3-FKR-1	NGOS-11-61	Africa Rice	*Africa Rice Center and NCRI*	Early maturing, submergent tolerant.(7t/ha)	2001	2001	Derived savannah	Moderately cultivated
FUNAABO R-1	UORG 311	NGOS-11-63	Selection from farmer's field	*FUNAAB(IFSERAR) and NCRI Badeggi*	Good yield, gold colored grains with red srips, very high swelling capacity and good nutrient, acceptable, excellent stay green attribute, high ratooning ability	2011	2011	Derived savannah	Moderately cultivated
UPIA 2	IWA 2	NGOS-13-65	IRRI	IRRI, Africa Rice Center and NCRI, Badeggi	High yielding, .(8t/ha) Long slender grains, tolerant to iron toxicity and African rice gall midge	2013	2013	Derived savannah	Moderately cultivated

Source: Catalogue of crop varieties released and registered in Nigeria. Volume No.6

Iron toxicity in some low land ecologies in Nigeria is very high. However varieties have been developed to withstand or tolerate iron at toxic level and still produce commercial quantity and quality seeds and grains for consumption. WITA 4(FARO 52) is one of such varieties among others.

23. CONCLUSION

With the demand for quality rice increasing in the country, the prospects of improving the quality and yield of locally produced rice through breeding research are very promising. Conventional breeding approaches have been hugely successful in developing new varieties in the past. However, screening and selecting for good plant traits through these methods is time consuming and expensive. With the introduction of biotechnology and close interaction between molecular biologists and breeders, molecular genetic information can be used to enhance breeding strategies through techniques broadly referred to as Marker Assisted Selection (MAS). Since most of the local varieties in the country generally have low yield, breeding for improved quality will focus on increasing yield potential without unduly sacrificing rice quality characteristics. The combination of quality characteristics such as long grains, dry fluffy texture when cooked and pleasant aroma etc is preferred by consumers. Breeders and Agronomists are conducting collaborative research in an effort to produce the best quality rice for the Nigerian market and the world at large.

The National Cereals Research Institute, Africa Rice Center and other rice mandated research outfits across the country have programs to develop quality rice with early growth duration, long, slender translucent grains, pleasant aroma, high acceptable yield and excellent milling quality. However it will be difficult to surmount the challenge of improving the rice cultivars and varieties available to farmers in the country in record time with just the application of conventional plant breeding techniques, modern tools of biotechnology will in no doubt be helpful in surmounting the challenge as it presents more advanced and more precise exploration of genetic resource for varietal improvement to research scientists in coming up with varieties with better yield and grain quality and better adaptation to the different production ecologies in the country.

24. FUTURE PROSPECTS AND RESEARCH NEEDS

Significant to rice development in recent years in Nigeria is the increasing high level of collaborative research activities from which rice varietal improvement in Nigeria has greatly benefited. The impact is already being felt, but the greater part is to be witnessed in the near future. Nigeria has a tremendous diversity of indigenous rices with valuable genes for desirable cooking quality and taste which are adaptable to the different ecological zones with tolerance/adaptation to prevailing biotic and abiotic stresses in the country. On account of these unique qualities, farmers have grown and conserved them over generations in spite of their low yields. A lot of research has been carried out and is going on in the area of breeding for rice cooking quality and taste as they are becoming irrevocably lost due to the extensive adoption of short duration or early maturing high yielding varieties and population induced problems. The NEWEST rice is an ongoing project in an attempt to develop transgenic rice which on completion and full incorporation into farmer’s field will come with solutions to nitrogen deficiency and water shortage problems as well as salinity toxicity hampering rice production in the country. However further research should be carried out on application of genetic engineering to rice improvement e.g., biofortification of rice to combat iron deficiency in infants and adult Nigerian population.

A range of value added rice products can be developed following careful evaluation of the unique quality traits for use in rice based products and cross matching the available appropriate genotypes based on knowledge of rice varietal diversity in the country. Top priority should be given to collection, purification, agronomic, physiological, biochemical and molecular characterization, evaluation and maintenance of indigenous rice germplasms. Hundreds to thousands of rice germplasm collections are maintained in various mandated research institutes across Nigeria, however no precise information exists about these rice collections. A large number of indigenous rice are grown by farmers in different parts of Nigeria and at such, there is an urgent need to develop a detailed data base on all indigenous rice for which there is enough morpho-agronomic and grain quality variation. This will not only be of immense use to the scientists involved in the improvement of locally produced rice but it would also help preserve Nigeria's rice biodiversity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. IRRI. Rice almanac, source book for the most important economic activity on earth. Third edition. Maclean JL, Dawe DC, Hardy B, Hettel GP, (Eds). International Rice Research Institute Manila, Philippines. 2002;1–253.
2. Khush GS. What it will take to feed 5.0 billion rice consumers in 2030. Plant Molecular Biology. Maclean JL, Dawe DC, Hardy B, Hettel GP, (Eds). 2005;59(1): 1–6.

   Rice Almanac. International Rice Research Institute, Los Banos, Philippines; 2002.
3. Ojehomon VET, Adebayo SB, Ogundele OO, Okoruwa, et al. Rice data systems in Nigeria: National rice survey 2009. Building a Rice Data System for Sub-Saharan Africa; 2009.
4. Longtau SR. Multi-agency partnerships in West African agriculture: A review and description of rice production systems in Nigeria; 2003.

   Available:http://www.odi.org.uk/resources/download/3045.pdf

   (Retrieved on 16th September, 2011)
5. Federal Republic of Nigeria (FRN). Accelerated rice production in the Niger River basin, tcp/nir/3303. Main Report and Working Papers, Federal Ministry of Water Resources and Food and Agriculture Organization of the United Nations – Rome. 2006;1-12.
6. Cramer GL, Wailes EJ, Shui S. Impacts of liberalizing trade in the world rice market. American Journal of Agricultural Economics. Dawe DC, Slayton T. 1993;75(1):219–226.
7. USDAFAS. United States Department of Agriculture and Foreign Agricultural Service, Nigeria Product brief rice. Gain report N13026. USDAFAS: Mistowa; 2003. Available:Org/files/corpao/2006/CRPAO320064/RIFAN/ Nigeria.Pdf
8. Tunji Akande. An overview of the Nigerian rice economy. Agriculture and Rural Development Department, The Nigerian Institute of Social and Economic Research (NISER) Ibadan, Nigeria.
9. Daramola Biyi. Government policies and competitiveness of Nigerian rice economy. Paper presented at the workshop on rice policy and food security in Sub-Saharan Africa. WARDA Cotonou, Republic of Benin; 2005.
10. Ajiboye TO. Biotechnological Application and Genetic Resource Management Training Manual, National Center for Genetic Resources and Biotechnology, Moor Plantation, Ibadan, Nigeria; 2013.
11. Maji AT, Singh BN Drought tolerance in African rice, *Oriza glaberrima* Steud. Proc. 17th International Congress of Genetics, International Convention Centre, Birmingham, UK. 1993;73.
12. Paul CP, Ng NQ, Ladeinde TAO. Dialel analysis of resistance to virus in African rice *Oriza glaberrima.* J. Gen and Breeding. 1995;217-272.
13. Jones MP, Aluko GK, Semon N. Characterization and utilization of *Oryza glaberrima* in upland rice improvement. In Jones MP, Dingkuhn M, Johnson DE, Fagade SO, (eds). Interspecific hybridization; Progress and Prospects, Bouke WARDA. 1997;43-60.
14. Africa Rice Center (AfricaRice). New breeding directions at AfricaRice: Beyond NERICA. Cotonou, Benin. 2010b;1.
15. Tang S, Wang Z. Breeding for superior quality aromatic rice varieties in China: Speciality rices of the world. Breeding, Production and Markeing. FAO. 2001; Chapter 4:43.
16. Africa Rice Center (AfricaRice). New breeding directions at AfricaRice: Beyond NERICA. Cotonou, Benin. 2010b;11.
17. Fujimori H. Recurrent selection by using male sterility for rice improvement. Jpn. Agric. Res. Qua. 1979;13:153–156.
18. Hull FH. Recurrent selection for specific combining ability in corn. J. Am. Soc. Agron. 1945;37(2):134–145.
19. Guimara˜es EP. Hibridacao em arroz. In: Borem A, (Ed.) Hibridac¸a˜o artificial de plantas. Universidade Federal de Vicosa (UFV), Vicosa, Brasil. 1999;101–120.
20. Singh RJ, Ikehashi HI. Monogenic male sterility in rice, induction, identification and

inheritance. Crop Sci. 1981;21(2):286–289.

21. Taillebois J, Guimara˜es EP. CAN-IRAT5 upland rice population. Int. Rice Res. Newsl. 1989;14(3):8.
22. Rangel PHN, Neves PCF. Seleccio´n recurrente aplicada al arroz de riego en Brasil. In: Guimara˜es EP, (Ed.) Seleccio´n recurrente en arroz. Centro Internacional de Agricultura Tropical, Cali, Colombia. 1997;79–97.
23. Taillebois J, Castro E, da de M. A new crossing technique. Int. Rice Res. Newsl. 1986;11(6):6.
24. Sarkarung S. A simplified crossing method for rice breeding. Fondo Latinoamericano de Arroz de Riego (FLAR) and CIAT, Cali, Colombia. 1991;1–32.
25. Wang LQ. Advances in plant mutation breeding in China: A full analysis. Bull. Nucl. Agric. Sci. 1992;13:282–295.
26. Chen X, Liu X, Wu D, Shu QY. Recent progress of rice mutation breeding and germplasm enhancement in China. Plant Mutat. Rep. 2006;1(1):4–6.
27. Tran DQ, Dao TTB, Nguyen HD, Lam QD, Bui HT, Nguyen VB, Nguyen VX, Le VN, Do HA, Phan P. Rice mutation breeding in Institute of Agricultural Genetics, Viet Nam. Plant Mutati. Rep. 2006;1(1):47–49.
28. Tang S, Wang Z. Breeding for superior quality aromatic rice varieties in China: Speciality rices of the world. Breeding, Production and Markeing. FAO. 2001b; Chapter 4:43.
29. Khin Than Nwe, Tin TinMyint, Garcia AG. Breeding and cultivation of superior quality rice in Myanmar, speciality rices of the world. Breeding, Production and Markeing. FAO. 2001;Chapter 11:124.
30. Tang S, Wang Z. Breeding for superior quality aromatic rice varieties in China: Speciality rices of the world. Breeding, Production and Markeing. FAO. 2001c; Chapter 4:43.
31. Lu C, Shen L, Tan Z, Xu Y, He P, Chen Y, Zhu L. Comparative mapping of QTLs for agronomic traits of rice across environments using a doubled haploid population. Theor. Appl. Genet. 1996; 93(8):1211–1217.
32. McCouch SR, Kochert G, Yu ZH, Wang ZY, Khush GS, Coffaman DR, Tanksley SD. Molecular mapping of rice chromosomes. Theor. Appl. Genet. 1988;76:815–829.
33. Chen S, Lin XH, Xu CG, Zhang QF. Improvement of bacterial blight resistance of 'Minghui 63', an elite line of hybrid rice, by molecular marker-assisted selection. Crop Sci. 2000;40:239–244.
34. Huang N, Parco A, Mew T, Magpantay G, McCouch S, Guiderdoni E, Xu J, Subudhi P, Angeles ER, Khush GS. RFLP mapping of isozymes, RAPD and QTLs for grain shape, brown planthopper resistance in a doubled haploid rice population. Molecular Breeding. 1997;3(2):105–113.
35. Arumuganathan K, Earle ED. Nuclear DNA content of some important species. Plant Mol. Biol. Rep. 1991;9:208–218.
36. Chen M, Presting G, Barbazuk WB, Goicoechea JL, Blackmon B, Frang G, Kim H, Frisch D, Yu Y, Sun S, Higingbottom S, Phimphilai J, Phimphilai D, Thurmond S, Gaudette B, Li P, Lui J, Hatfield J, Main D, Farrar K, Henderson C, Barnett L, Costa R, Williams B, Walser S, Atkins M, Hall C, Budiman MA, Tomkins JP, Luo M, Bancroft I, Salse J, Regad F, Mohapatra T, Singh NK, Tyagi AK, Soderlund C, Dean RA, Wing RA. An integrated physical and genetic map of rice genome. Plant Cell. 2002;14:537–545.
37. Goff SA, Ricke D, Lan TH, Presting G, Wang R, Dunn M, Glazebrook J, Sessions A, Oeller P, Varma H, Hadley D, Hutchison D, Martin C, Katagiri F, Lange BM, Moughamer T, Xia Y, Budworth P, Zhong J, Miguel T, Paszkowski U, Zhang S, Colbert M, Sun WL, Chen L, Cooper B, Park S, Wood TC, Mao L, Quail P, Wing R, Dean R, Yu Y, Zharkikh A, Shen R, Sahasrabudhe S, Thomas A, Cannings R, Gutin A, Pruss D, Reid J, Tavtigian S, Mitchell J, Eldredge G, Scholl T, Miller RM, Bhatnagar S, Adey N, Rubano T, Tusneem N, Robinson R, Feldhaus J, Macalma T, Oliphant A, Briggs S. A draft sequence of the rice genome (*Oryza sativa* L. ssp. japonica). Science. 2002;296:92–100.
38. Yu J, Hu S, Wang J, Wong KS, Li S, Liu B, Deng Y, Dai L, Zhou Y, Zhang X, Cao M, Liu J, Sun J, Tang J, Chen Y, Huang X, Lin W, Ye C, Tong W, Cong L, Geng J, Han Y, Li L, Li W, Hu G, Huang X, Li W, Li J, Liu Z, Li L, Liu J, Qi Q, Liu J, Li L, Li T, Wang X, Lu H, Wu T, Zhu M, Ni P, Han H, Dong W, Ren X, Feng X, Cui P, Li X, Wang H, Xu X, Zhai W, Xu Z, Zhang J, He S, Zhang

J, Xu J, Zhang K, Zheng X, Dong J, Zeng W, Tao L, Ye J, Tan J, Ren X, Chen X, He J, Liu D, Tian W, Tian C, Xia H, Bao Q, Li G, Gao H, Cao T, Wang J, Zhao W, Li P, Chen W, Wang X, Zhang Y, Hu J, Wang J, Liu S, Yang J, Zhang G, Xiong Y, Li Z, Mao L, Zhou C, Zhu Z, Chen R, Hao B, Zheng W, Chen S, Guo W, Li G, Liu S, Tao M, Wang J, Zhu L, Yuan L, Yang H. A draft sequence of the rice genome (*Oryza sativa* L. ssp. indica). Science. 2002;296:79–92.

39. Nwalieji HU, Madukwe MC, Agwu AE, Umerah MI. Adoption of rice technologies introduced by the United States Agency for International Development in Anambra and Ebonyi States, Nigeria. Journal of Agricultural Extension. 2014;18(1):148.

40. Nigeria Markets. Rice; 2012.
Available:http://www.nigeriamarkets.org/Rice.mht
(Retrieved on 10th September, 2011)

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