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Review

Breeding dynamics of rice (*Oryza sativa*) for enhanced adaptation and grain quality

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Rice is a very important crop feeding half of the world population. Its importance is becoming increasingly high due to high nutritive value and high returns per given land area than any other cereal crop. However, its production is facing major challenges such as degraded soil, need for high grain quality, population growth, high input costs, climate change and variability threats and plateauing yields. There is now more urgent need to think about how to increase rice yield to feed an ever growing population, and this is largely to come from increased yields per given land area, rather than expansion of new area and committing them for rice production. More importantly, the reproductive resource is under threat and thus this increased productivity must enhance the conservation of the productive land resource base for sustainability. This article explores some of the avenues available to meet some of the challenges.

Key words: Climate change, growing population, rice (*Oryza sativa*).

INTRODUCTION

This part of the paper reviews the existing information available for meeting the objectives of upland rice (*Oryza sativa*) research aimed at developing rice varieties well adapted to low soil fertility conditions especially nitrogen and phosphorous prevalent in potential upland production regions of Kenya and rest of the world. In the light of this objective, this is a review of various topics in the literature in order to provide the theoretical and practical framework for further research for interested scientists. The areas covered are: a) breeding rice for low soil nitrogen (N) and phosphorous (P) and high yields, b) critical genetic review and opportunities for upland rice development, c) breeding for high grain quality especially fragrance, and d) farmers perception and preferences for rice varieties and traits. The review also gives important definitions in the main topic areas. This part of the paper builds up a reference base for the research study for now and in the future.

THE GENUS *ORYZA*

Rice belongs to the genus *Oryza* and family Poacae tribe Oryzeae. It originated in Asia (*O. sativa* L.) and West Africa (*Oryza glaberrima* Steud) (Vaughan et al., 2003). According to Vaughan et al. (2004) the genus *Oryza* is made up of 23 species, with two species being cultivated (*O. sativa* and O. *glaberrima*), while the other 21 are not domesticated. The *O. sativa* has further three subspecies; *indica* Kato, *japonica* Kato and *javanica* (Roschevicz, 1931).

The subspecies *japonica* has two strains, namely *tropical* and *temperate* which is commonly sticky rice due to high amylopectin content. *Indica* are found in tropical

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and sub-tropical regions, while *javanica* are mainly grown in Indonesia and *japonica* are found in temperate regions. In terms of grain characteristics; the *indica* varieties have long grains. While, *japonica* have short grains and *javanica* have broad grains.

The breeding pattern in rice can be easy or complex depending on whether the hybridization is intra- or inter-specific. The crossing within the *O. sativa* has few hybridization incompatibilities likewise, within *O. glaberrima* group. However, any hybridization between *O. sativa* and *O. glaberrima* (Jones et al., 1997; Khush, 2000), and *O. sativa* and *O. officinalis* has to involve embryo rescue (Khush, 2000) in order to have successful crosses.

GENERAL NITROGEN DYNAMICS IN RELATION TO RICE

There exists enormous potential for upland rice production in Kenya. However, various constraints namely low soil fertility especially in terms of nitrogen (N) and phosphorous (P) minerals, lack of adapted and high yielding varieties with desirable grain qualities, and high cost of inputs has contributed to low productivity. High labour costs, especially for irrigated paddy rice, drought, insect, pest and diseases, poor agronomic practices that do not entail soil conservation and nutrient recycling have also negatively affected rice production. Production activities are done manually due to lack of simple implements such as hydro tillers, seedlings transplanters, rippers, threshers and winnowers to aid agronomic practices for increased productivity. The low soil fertility, drought, high input costs and lack of certified seeds have been identified as the major constraints (Kimani et al., 2011). Nitrogen constitutes one of the primary nutrients for effective rice crop growth and productivity as it is involved in many internal metabolic activities (De-Datta and Broadbent, 1990).

Function and mobility of nitrogen

Dobermann and Fairhurst (2000) have observed that nitrogen is an essential constituent of amino acids, nucleic acids, nucleotides, and chlorophyll. It is responsible for rapid growth and increased leaf size, spikelet number per panicle, percentage filled spikelets in each panicle, and grain protein content. It therefore, affects all components contributing to yield. They observed leaf N concentration to be closely related to the rate of leaf photosynthesis and crop biomass production; and that when sufficient N is applied to the rice crop, the demand for other macronutrients such as potassium (K) and phosphorous (P) is increased. The major forms of N available for uptake by plants are NO_3-N and NH_4-N, and most of absorbed NH_4-N is incorporated into organic compounds in the roots, whereas NO_3-N is more mobile in the xylem and is stored in the vacuoles of different plant parts (Dar et al., 2006). The NO_3-N is involved in maintaining cation-anion balance and osmo-regulation, and its greatest requirement is during early to mid tillering and panicle initiation stages. Sufficient N supply during ripening is necessary to delay leaf senescence, maintain photosynthesis during grain filling, and increase the protein content in the grain. Nitrogen is one of the mobile nutrients within the plant being translocated from old senescent leaves and stems to younger leaves and grains, and thus deficiency symptoms tend to occur initially in older leaves (Shukla et al., 2004).

Nitrogen deficiency symptoms

According to Dobermann and Fairhurst (2000) nitrogen deficiency is the most commonly detected nutrient deficiency symptom in rice characterized by old leaves and sometimes all leaves turning light green and chlorotic at the tip. Under severe deficiency leaves may die except for young leaves, which are greener, narrow, short, erect, and lemon-yellowish green. The whole or affected field may appear yellowish, and N deficiency is known to often occur at critical growth stages such as tillering and panicle initiation when the demand for N is high. The overall effect of N deficiency is reduced tillering, small leaves, short plants and reduced grain number. They have indicated that plant tissue and crop based estimates provide the most reliable estimates of the indigenous N supply in intensive rice systems. However, in irrigated rice systems, most of the commonly used soil tests cannot be relied upon to predict soil N supply under field conditions. Therefore reliable general critical levels or ranges cannot be given, and soil organic carbon or total soil N content are not reliable indicators of soil N supply in irrigated rice systems, but are more important in upland rice systems.

General method of nitrogen management

The correction of N deficiency is not difficult because response to N fertilizer is rapid where farmers can afford N fertilizers and the crop is of high value. Once the N is applied response may be evident after five days by greening and improved vegetative growth, but this is highly dependent on the rice variety, soil type, weather conditions, used N fertilizer, applied amount and time the method of application (Zhi-You et al., 2006).

RICE BREEDING FOR LOW SOIL NITROGEN (N)

Fageria and Baligar (2003) and Hou et al. (2007)

reported that nitrogen is the most important nutrient for crop production, and its deficiency occurs in most rice growing regions of the world. They cited the main reasons for nitrogen (N) deficiency as (i) N leaching, volatilization, and denitrification; (ii) Lower rates of N application than rates of N removal in the harvested portion of the crop; (iii) Low N-use efficiency by the crops; (iv) Use of high yielding and N responsive cultivars; and (v) Soil degradation due to continued crop production. Roder et al. (1995), George et al. (2001) and Kimani (2002) have similarly noted that nitrogen and phosphate deficiencies are the most important nutrient disorders in the upland production environments. Delseny et al. (2001) as a result have estimated the resultant yield loss due to nutrient stress to be 2000 kg ha^{-1}. They argued that this loss can be mitigated by use of well adapted genotypes to various soil N conditions in order to increase farm yields. This can be done by exploiting genotypes that have traits for low soil N adaptation.

Definitions of nutrient-use efficiency terminologies and their application

Nutrient efficiency has been widely used as a measure of the capacity of a plant to acquire and utilize nutrient for biological and grain yield. Nitrogen-use efficiency (NUE) has been defined as the amount of biomass produced per unit of N applied. Fageria and Baligar (2003) and Singh et al. (1998) have further defined nutrient(s) use efficiency as the maximum economic yield produced per unit of nutrient applied, absorbed or utilized by the plant to produce grain and straw. While plant genetic variability has been defined as the heritable character of a particular crop species or cultivar that exhibit varying responses in growth or production when compared to other species or cultivars of the same species under limiting and non-limiting growth conditions. However, Shaver and Melillo (1983) expanded nutrient-use efficiencies further and categorized them as agronomic, physiological efficiency (PE), agro-physical efficiency (APE), apparent recovery efficiency (ARE) and utilization efficiency. Nitrogen response efficiency (NRE) is defined as the production per unit N available. N-use efficiency is also defined as the ability of a genotype to produce superior grain yields under low soil N conditions in comparison with other genotypes.

The subject of NUE has been widely studied (Fageria and Baligar, 2003; Ishimaru et al., 2001; Lawlor, 2002; Mae, 1997; Zhi-You et al., 2006). High NUE value is generally important under conditions of low soil N availability, as it entails high biomass production per unit of N uptake (Aerts and Chapin, 2000) and it is a useful index that combines both plant physiological and morphological responses along nutrient availability gradients. Vitousek (1982) has reviewed nitrogen dynamic terminologies as follows: NRE is the net primary production (NPP) as a proportion of available N in the soil (Nav) and N-uptake efficiency (NupE) as the proportion of available soil N acquired by plants. As defined, NUE is the total net primary production per unit N absorbed or lost. Thus nutrient response efficiency can be defined as the product of nutrient uptake and use efficiency. A reduction in cultivar productivity with decreasing soil N can thus be mitigated if NRE (NPP/Nav) is increased through higher (N_{ac} is the N taken up by the plant (N_{ac}/N_{av} (N_{av} is the N available in soil) (NupE), N-use (NPP/N_{ac}) or both. Pastor and Bridgham (1999) observed that the application of nutrient response efficiency, nutrient-uptake efficiency, and nutrient-use efficiency may give important information about the competitive abilities of different genotypes under different N available gradients. Use of NupE may be particularly important, as it has been found that N concentration in plant tissue and indices of soil nutrient availability do not show a clear relationship.

Classification of genotypes in relation to N-use efficiency

Genotypes response to different levels of soil N conditions is widely varied. Genotypes that do not respond to increasing rates of N due to either poor adaptation to high N supply environment or inherently low-yield potential are identified as inferior. Under low soil N supply, certain genotypes have been observed to respond well and give high grain yield, but they do not respond to additional N application. Singh et al. (1998), and Shrestha and Ladha (1996) observed that the higher N uptake observed in the long-duration genotypes may be attributed to the longer period of N accumulation at the vegetative and the higher associative nitrogen fixation, as opposed to the short duration ones. Inefficient genotypes in their study were observed to require higher N supply to achieve similar grain yields. They therefore, concluded that genotypic differences were either due to poor adaptation at high N or poor N-use and or uptake efficiency at low soil N supply. By using nitrogen productivity index (NPI), which integrates both grain yield (GY) and nitrogen physiological use efficiency (PNUE) as an effective parameter, they were able to rank genotypes into efficient, inefficient, and inferior ones in both growth duration groups. They reported the relationship between N-uptake and tiller number, spikelets number, which explained 73 and 86% of total variation in genotypes. They observed that 75% of the variation in grain yield was explained by N-uptake, genotypic differences remained, with the N-efficient genotypes having a consistently higher physiological N-use efficiency (PNUE). These are identified as N-efficient genotypes as they consistently produce high grain yield at all soil N levels. Cooper (1999) reported that such differences have Important implications in both plant performance, high yield being achieved by lines with high nutrient uptake, high nutrient-use efficiency, high harvest index, and high nutrient harvest index.

Based on N-use efficiency and grain yield at a low soil N level, rice genotypes have been classified into four groups. Fageria and Baligar (2003) have categorized crop genotypes according to their nutrient use efficiency. The first genotype group is the efficient and responsive (ER), these are genotypes that produced above the average yield compared to all the genotypes tested in the experiment at low soil N level and have higher N-use efficiency than the average of all the categorized genotypes. The second classification is genotypes that are efficient and non-responsive (ENR). These genotypes produce more than the average yield of genotypes tested at low N level, but N-use efficiency is lower than the average of all genotypes classified in this group. The third type is referred to as non-efficient and responsive (NER) genotypes. These genotypes produce less than average grain yield at low soil N level. The fourth group of genotypes are those that produced less than the average yield of genotypes tested at low N level and response to applied N (N-use efficiency) is also less than the average of those genotypes. These types are classified as non-efficient and non-responsive (NENR) genotypes.

Fageria and Baligar (2003) argued that the genotypes which fall into efficient and responsive (ER) group are the most desirable, because they can produce more grain yield at low soil N conditions and also respond well to applied N. Thus, this group can be utilized for both low as well as high input production conditions and give reasonably good yield. The second most desirable group consist of efficient and non-responsive (ENR) genotypes. They can be planted in low soil N environments and still produce more than average yield. The NER cultigens can be used in breeding programmes for their N-responsive characteristics (higher N use-efficiency trait). They finally concluded that the most undesirable genotypes were those that were non-efficient and non-responsive (NENR).

Nitrogen productivity index (NPI) ranking of genotypes is consistent with N-efficient genotypes exhibiting high NPI. Cooper (1999) has concluded that PNUE, agronomic N-use efficiency (ANUE) and apparent recovery (AR) indexes are biased either toward soil or fertilizer N supply. Because of significant genotype, N supply, and genotype by N-supply interactions; germplasm evaluation for N partitioning, recovery, and efficiency; requires that N-supply to be at least at a low and a high level. He also observed that use of NPI for evaluating genotypic differences in N-use also requires field evaluation of genotypes at low N (or zero N fertilizer) and a high N level (N application or soils with sufficient N). Edmeades et al. (1997) also observed that the use of NPI is the most promising parameter for quantifying and ranking genotypes for soil N fertility environments.

Mechanisms for genotypic differences in nutrient use efficiency

Fageria and Baligar (2003) have observed that large differences occur among cultivars of the same species in absorption, translocation, and utilization of mineral nutrients. They have given the soil, plant mechanisms and processes including other factors that have great influence on differences of genotypes in their nutrient-use efficiency as indicated in Table 1. The main mechanisms cited were nutrient acquisition, nutrient movement in root, nutrient accumulation and remobilization in shoot among other factors. Nitrogen has also been described as the most difficult to manage due to its volatile nature and mobility. Nitrogen harvest index is a measure of N partitioning in rice, which provides an indication of how efficiently the plant utilizes the acquired N for grain production.

Genetic variability for N harvest index exists within the small grain genotypes and a high N harvest index in the genotypes is associated with efficient utilization of N. Variation in the N harvest index is a characteristic of genotype and such trait may be useful for selecting for higher grain yield. Importance of this trait is also indicated by a highly significant correlation between N harvest index and grain yield (Britto and Kronzucker, 2004).

Rice yield potential

Among all the important cereals, rice has the highest yield expressed in food and energy (Juliano and Villareal, 1993). However, there appears to be a barrier preventing yield increases above approximately 10 t ha^{-1}, as this ceiling-yield has remained unchanged in the tropics for more than 20 years (Khush, 2005). Amano et al. (1996) by contrast, have reported that grain yields of 13 to 15 t ha^{-1} have been observed for the temperate environments of Yanco, Australia and Yunnan China, and that this yield required an uptake of 250 kg N ha^{-1}. They observed that there is need to identify and quantify component parts of the tropical ceiling-yield barrier for rice, and develop ways to overcome that barrier. The imbalances between demand and supply of plant nutrients, in particular N, are the main common causes for yield limitations. The issue of how the plant can control the rate of deployment of its N resources for the construction of metabolic, structural and storage components has been cited as crucial in improving yields (Sheehy et al., 1996). Akita (1989) and Sheehy et al. (1996) estimated that maximum grain yield for the dry season at IRRI would be 15 t ha^{-1} at 14% moisture content. Scobie et al. (1993) estimated that at least 30% of the projected 70% increase in the global rice demand by the year 2030 must come from yields realized from increased rainfed rice productivity.

Breeding opportunities for low soil nitrogen environments

Nitrogen fertilization is expensive to the ordinary rice farmers. Furthermore, it has been observed that even for

Table 1. Summary of soil and plant mechanisms and genotypic variability in nutrient-use efficiency.

Parameter	Characteristic
Nutrient acquisition	1. Diffusion and mass flow. 2. Root morphological factors. 3. Physiological factors. 4. Biochemical factors.
Nutrient movement in the root	1. Transfer across endodermis and transport in the root. 2. Compartmentation. 3. Rate of nutrient release to xylem.
Nutrient accumulation and remobilization in shoot	1. Demand at cellular level and storage in vacuoles. 2. Re-transport from older to younger leaves and from vegetative to reproductive parts. 3. Rate of chelates in xylem transport.
Nutrient utilization and growth	1. Metabolism at reduced tissue concentration of the nutrient. 2. Lower element concentration in supporting structure (stem). 3. Elemental substitution. 4. Biochemical nitrate reductase.
Other factors	1. Soil factors. (i) Soil solution. (ii) Physico-chemical properties. 2. Environmental factors. (i) Intensity, amount and quality of light. (ii) Temperature. (iii) Moisture. 3. Plant diseases, insects and allelopathy.

Source: Baligar and Fageria (2001).

those who apply them they are not efficiently utilized by the rice plants thus need for breeding efficient varieties (Saito et al., 2006). One reason attributed for this is that rice is grown in environments that are conducive to N loss through nitrification-denitrification, ammonia volatilization, runoff, and leaching. It has also been observed that imbalanced use of fertilizers and occurrence of other macronutrient deficiencies combine to give rise to low N-use efficiency.

There are however, opportunities in rice improvement for low soil N conditions through development and deployment of varieties with enhanced N-use traits for grain yield. Zhi-You et al. (2006) reported that the net primary productivity (NPP) increased with N and water availability in their study on rice. The efficiency of whole plant N use, uptake, and response was observed to increase with decreasing soil N and water, and was higher on infertile than fertile habitat. It has been suggested that NUE theory rests on the premise that plants on poor soil N are less productive than those on N rich soils. High NUE is therefore, considered to be indicator of good adaptation to low soil N, because it shows high biomass production per unit of N-uptake. Ishimaru et al. (2001) and Mae (1997) have observed that the ratio of Rubisco to total leaf N is a factor determining N-use efficiency in rice yields and that this is one of the main targets in development of N-use efficient varieties. They have indicated that by controlling N-use efficiency this can be a valuable tool for maintaining high yields under low input agricultural systems. This is the principle objective of large yield production of high quality with minimal agricultural inputs especially N.

Genotypes have been observed to vary in their ability to utilize N efficiently and partition N between various rice plant components. Zhi-You et al. (2006) and Singh et al. (1998) have observed great variability in rice for grain yield, N-uptake efficiency and partitioning parameters such as; physiological N-use efficiency (PNUE), ANUE, AR, partial factor productivity of applied N (PFPN), N productivity index (NPI), and N harvest index (NHI). They reported existence of significant differences among genotypes and N-levels for rice total biomass, total N-uptake, tillering ability, panicle numbers and total number of spikelets (m^{-2}). Straw and grain N concentration was also variable within rice genotypes. Singh et al. (1998) on the other hand, observed that differences in physiological efficiency may occur because of differences in critical concentrations (internal N requirement) for expansion, growth, mass accumulation, organ formation and differences in the ability to translocate, distribute and redistribute the absorbed N in various organs, and the efficiency of N-use in photosynthesis. N-use efficiency though largely dependent on interactions between nutrient balance, water availability, light intensity, disease pressures, and genotypes; can be improved through appropriate genetic manipulation. Selection and plant breeding techniques can be utilized to develop and deploy rice varieties that are resistant to pests, diseases, and adverse environmental conditions such as drought, nutrient deficiencies, toxicities, and salinity (Nguyen and Byun-Woo, 2006; Singh et al., 1998). However, selection to improve the rice crop's N-use efficiency remains viable and one to be exploited because it is sustainable and environmentally friendly.

The wide genotypic variability for low soil fertility environment offers great opportunity for rice improvement. In this regard, Saito et al. (2006) observed that traditional cultivars were less responsive to N application, and grain yield for these cultivars increased only by 16% with N application (a 0.1 to 0.4 t ha^{-1} increase in grain yield), while grain yields of improved cultivars were increased by 37% with N application (a 0.9 to 1.2 t ha^{-1} increase in grain yield) in their study. Inthapanya et al. (2000) observed that breeders often select their plant materials under high productive environments assuming strong genetic correlations with low productive environments. If this is so, lines selected in high productive environments are likely to perform well in low productive environments (Atlin and Frey, 1989). Ceccarelli (1994), Holland et al. (2003) and Kimani et al. (2007) have however, argued that breeding for target environment is the best approach as genotype performance under different fertility conditions are controlled by different gene systems. Several authors have reported that the potential exists for exploiting genotypic differences in rice for low N responsiveness (Broadbent et al., 1987; De-Datta and Broadbent, 1993) during rice improvement for low soil N conditions.

Genotypes have been shown to differ in their nitrogen use-efficiency thus breeding for low soil N adaptation is of great advantage. Socolow (1999) reported that although N application increases yields, its use is known to have negative impacts resulting from N-compounds on the atmosphere, the ground water, and other segments of the ecosystems. One way to alleviate this problem has been cited as the use of low soil N-efficient cultivars, restriction on use of nitrogen fertilizers and rising the areas under organic farming (Presterl et al., 2003). Ohnishi et al. (1999) by combining the breeding objectives of yield improvement for both conditions of high and low N input environments were able to make progress in developing genotypes adapted to both low and high soil N conditions. A similar approach was advocated by Atlin et al. (2006b) who cited the following two breeding strategies; (i) indirect improvement where selection is done at only one N level, and the performance at the other N condition being obtained by correlated response; or (ii) combined evaluation where selection is based on an index of the weighted cultivar performance means at both high and low N levels as useful strategies for varietal improvement. They concluded that if combination of the two breeding objectives is not effective, then it would be important to breed for the high and low N conditions independently. In order to make a decision on to which of the two strategies would be the most effective, understanding of the quantitative genetic variances such as coefficients of genotypic correlation, genotypic variance components, heritabilities, and economic weights for yield under high and low soil N conditions is crucial.

Lawlor (2002) has argued for increased food production without expansion of agricultural land and with less fertilizer use in order to feed the growing population and save fossil fuel energy used in its production. The use of less N fertilizer will lower the cost of production, pollution, environmental problems that result from methods of synthesis, inefficient use and uptake by crops and attainment of this objective is urgent (Kimani, 2002). The production per unit area with less fertilizer use is an option to be pursued as this will give more yields at a lower cost for farmers. Sheehy et al. (2000) as reported by Lawlor (2002) observed that it is desirable to improve the genetic potential of rice yields which have been stagnant for decades through breeding and achieving better yields with less N and other resources. Lawlor (2002) reported that increasing the effective live of the leaves (stay green trait) through breeding is a proven method for increasing yields. Productive rice varieties have greater root size, length and root surface area per volume of soil (Veeresh et al., 2011). These traits are genetically controlled and are important in N-uptake from low soil nitrates (NO_3^-) concentrations. Nitrogen content per unit biomass is used as the indicator of how adequate N supply is for crop growth. The shortcoming of this value is that it changes with crop age and environment. Nitrogen deficiency reduces the %N as leaf:shoot ratio decreases with crops development. In rice, yield production depends on the number of plants per unit area, tillers plant^{-1}, number of spikelets tiller^{-1}, grains panicle^{-1} and 1000 grains weight. However some of these traits have negative correlation with one another and hence their breeding is not straight forward. Baligar et al. (2001) argued that when N-supply is limiting to achieve genetic potential, then it is N-uptake that must be enhanced to obtain greater biomass. This can be done by breeding for roots traits that enhance N-uptake coupled with more efficient metabolic utilization of available N into useful products. This can be realized by expanding the period for light absorption for its effective use by breeding for rice with enhanced stay green-traits.

De-Datta (1981) observed that rice plants when grown at low N level (20 kg ha^{-1}) use fertilizer most efficiently for grain production during maximum tillering stage and flowering stage (between flowering and milk stages). High N supply reduces number of filled spikelets and 1000 kernel weight. The author argued that N application should be split with one dose at transplanting and another at panicle initiation especially for medium and long duration rice. Nitrogen absorbed from tillering to panicle initiation tends to increase the number of tillers and panicles, while that absorbed during panicle development (panicle initiation to flowering) increases the number of filled spikelets per panicle, while N absorbed after flowering tends to increase 1000-grain weight.

It has generally been observed that late maturing rice varieties accumulate a large amount of N in the plants due to increased N mineralization, and they produce higher grain yields. This is in contrast to early maturing lines that tended to have higher N concentration in the grains and stems thus are less efficient in N-use. Fukai et al. (1999a) have suggested that NUE for grain production may be a more useful trait in developing new low soil fertility conditions adapted cultivars. Seedling tests for screening genotypes adapted to low soil fertility suffer from inability to pick genotypic variation in reproductive traits such as HI, nutrient HI and grain nutrient concentration. It has been argued that small genotypic and fertilizer interaction justifies the use of moderately high levels of fertilizer rate in breeding programmes.

Utilization of remobilized internal N for breeding high yielding rice

The mobilization of N from areas of less active growth to regions of active development of the absorbed N within the plant can play a key role in breeding N-efficient rice plants. Mae et al. (1983) observed that major source of N for developing leaves of mature rice plants was N mobilized from older, senescing leaves. Studies with ^{15}N revealed that mobilized N accounted for 64% of the total N in the youngest leaf blades of rice. Ladha et al. (1998) similarly concluded that efficiency in N mobilization from old leaves affected physiological efficiency (PE) in the process of grain production. The concept that tropical rice suffers high-light stress during grain filling in the dry season may help to explain why the maximum yields of inbred cultivars are higher under temperate conditions (12 to 13 t ha^{-1}) than they are under dry-season tropical conditions (9 to 10 t ha^{-l}). They reasoned that lower straw N concentration may be an indication of higher PE-biomass. Grain N concentration may have also an effect on physiological efficiency, although most lines they studied, 93% of them had grain N concentration of 0.95 to 1.2%. On average, grain -N concentration decreased by only 0.1% when PE-grain increased by ten. Therefore, they concluded that human nutritional value of rice was not really changed with the improvement of nitrogen-use efficiency.

Harvest index (HI) is defined as the ratio of grain yield to the total biomass. This index is not constant but varies between sites and years due to differences in environment and N-supply among the genotypes (Lawlor, 2002). The genetic potential is defined as the total capacity of the plant, to form yield when environmental stresses are removed. Both inter- and intra-specific genetic potential variations in N nutrition have been recognized among cereal species and genotypes. This therefore, offers great potential to develop cultivars that are efficient at low nutrient levels or are capable of using N more efficiently when applied as fertilizer.

Genetic variability for N harvest index exists within the small grain genotypes and a high N harvest index in the genotypes is associated with efficient utilization of nitrogen. Variation in the N harvest index is a characteristic of genotype and such a trait may be a useful variable for selecting rice genotypes for higher grain yield. Importance of this variable is also indicated by a highly significant correlation between N harvest index and grain yield.

BREEDING RICE FOR LOW SOIL PHOSPHORUS CONDITION

Phosphorous is an important nutrient in many crop species for development and growth, as it is involved in many metabolic functions.

Functions and mobility of phosphorous (P)

Phosphorous is an essential major element in many plants among them rice crop and it is involved in various metabolic reactions. It is an important constituent of adenosine triphosphate (ATP), nucleotides, nucleic acids, and phospholipids. Its major functions are in energy storage and transfer and the maintenance of cell membrane wall integrity. Phosphorous is mobile within the plant and promotes tillering, root development, early flowering, and ripening especially where temperatures are low. It is particularly important in early growth stages (Dobermann and Fairhurst, 2000). The addition of mineral P fertilizer is required when the rice plant's root system is not yet fully developed and the native soil P supply is low. Phosphorous is remobilized within the plant during later growth stages if sufficient P has been absorbed during early growth.

Phosphorous (P) deficiency symptoms and effects on rice crop

Deficiency may be acute, occurring when a nutrient is suddenly no longer available to a rapidly growing plant or chronic deficiency that occurs when there is a limited but continuous supply of a nutrient, at a rate that is insufficient to meet the growth demands of the plant.

Most of the classic deficiency symptoms described in textbooks are characteristic of acute deficiencies. The most common symptoms of low-grade, chronic deficiencies have been reported to be tendency towards development of darker green leaves and stunted or slow growth. According to Dobermann and Fairhurst (2000) the P-deficient plants are generally stunted with greatly reduced tillering. The leaves are in most cases narrow, short, very erect, and have a ‘dirty’ dark green colour. Stems are thin, spindly and plant development is retarded. The number of leaves, panicles, and grains per panicle is also reduced. Young leaves appear to be healthy but older leaves turn brown and often die. Lincoln and Zeiger (2010) have reported P deficiency in rice is associated with red and purple colors development in leaves if the variety has a tendency to produce anthocyanin. The leaves appear pale green when P and N deficiencies occur simultaneously. Other effects of P deficiency have been reported to be delayed maturity beyond one week and that when P deficiency is severe; plants may not flower at all. Large proportion of empty grains may result. When P deficiency is very severe, grain formation may not occur at all and low 1000 grain weight and poor grain quality result. Normally there is reduced response to mineral N fertilizer application, varieties have reduced tolerance to cold water and there is absence of algae in floodwater. Poor growth results in small leaves and slow establishment of green manure crops.

It has been observed during vegetative growth before flowering that P supply may be sufficient and a response to P is usually very low when P leaf concentration is 0.2 to 0.4%. Yields greater than 7 t ha^{-1} require more than 0.06% P in the straw at harvest and greater than 0.18% P in the flag leaf at flowering. General measures to prevent P deficiency and improve P use efficiency are best based on varieties. This should start with selection of rice cultivars that use P efficiently, particularly on acid upland soils (Li et al., 2005). The P-efficient rice cultivars have either greater P acquisition, increased external efficiency because of better root morphology or increased excretion of organic acids or O_2 or higher internal efficiency of P use such as larger grain yield when P uptake is low. Examples of P efficient varieties are IR20, IR26, IR64, and IR74 (Dobermann and Fairhurst, 2000).

Phosphorus (P) supply is a prerequisite for realization of higher yield potential of modern rice varieties, as it plays a crucial role in energy storage and transfer within cells, speed up root development, facilitates greater N uptake and results in higher grain protein yield. Gill et al. (2004) have observed that the problem of limited phosphorus resource can be mitigated to some extent by reducing phosphorus loss and through better cycling in agricultural production systems and development of P-use efficient crop varieties. The differences in P uptake and use among varieties will help reduce costs of phosphorus fertilization and enhance productivity if more P-efficient varieties are used. In Sub-Sahara Africa the estimated net per hectare loss during the last 30 years is 700 kg N, 100 kg P, and 450 kg K in about 100 million hectares of cultivated land (Breth, 1996). The figures are the balance of nutrient inputs that include fertilizers, minus nutrient outputs, which are harvested by crop removals. This is in total contrast to commercial farms in North America and Europe which have recorded net positive nutrient balance of 2,000 kg N, 700 kg P, and 1,000 kg K ha^{-1}, during the last 30 years is four times the cultivated land resulting sometime in ground water and stream pollution (Frissel, 1978).

Cultivars tolerant to low soil P support sustainable farming systems and reduce production cost and farmers dependence on fertilizers. Fukai et al. (1999a) and Hou et al. (2007) have reported that both N and P and their utilization efficiency (grains yield/unit nutrient uptake) to produce grain yield are important for low soil N and P environments. Genotypic variation in utilization efficiency was observed to be consistent across environments and that efficiency can be improved by development of cultivars that require low nutrient concentration in the plant and a higher concentration in the grain. Grain yield is reduced by both drought and low soil N and P in rice production regions (Shu et al., 2005). The genotypic variation in traits conferring low soil P adaptation must be present and can be incorporated into suitable genetic background (Kimani et al., 2007). The main gene action responsible for low soil phosphorus was observed to be mainly additive in common beans (Kimani and Kimani, 2001). Grain yield increase of 49% and 50% have been reported from application of 6.25 t ha^{-1} and 60 kg ha^{-1} of farmyard manure and N fertilizers, respectively (Fukai et al., 1999a). These results illustrate the magnitude of low soil fertility; however, if drought occurs the use of fertilizer may not result in grain yield increase.

Healthy genotypes are known to better tolerate moderate water stress under low soil nutrient availability. Low soil N and P conditions affects canopy photosynthesis and hence dry matter production and grain yield. Large genotype by environment interaction has been shown to be due to differences in phenology (late maturing cultivars being affected by late season drought), response to drought and low soil P and N. With rising cost of fertilizers and reduced profit in rice production, development of cultivars adapted to low soil fertility is desirable. Ladha et al. (1998) have observed that the ideal cultivars are those that perform well under low soil fertility and respond well to applied N and P fertilizers. Significant interaction between genotype and fertilizer has been observed for grain yield and also significant correlation between grain yield and genotypes.

Adaptation to low and high soil fertility nutrient resource conditions

The adaptation systems for adverse soil fertility conditions can be diagnosed by examining resources that limit yield. Grain yield can be established with regard to acquisition and utilization efficiency of the particular resource. The nutrients that limit yield need to be established and genotypic variation in nutrient uptake and its utilization efficiency for grain production identified. The adaptation traits once identified can be used as selection criteria in plant breeding programme provided a proper screening procedure is developed. Grain yield (Y - kg ha^{-1}) is obtained as total dry matter (TDM) production at harvest in kg ha^{-1}, multiplied by proportion of TDM partitioned to grain (HI) (where HI is harvest index). Y=TDM*HI. This equation is a powerful one in assessing nutrient resource utilization by genotypes. The content of each nutrient in the grain (Y multiplied by the nutrient concentration of the grain) may be considered as a proportion of the total content of that nutrient in the plant biomass. This is obtained as the product of TDM by nutrient concentration of the plant biomass at harvest. Shoot weight has been reported to be the plant parameter most sensitive to P deficiency and can hence be used as an indicator of P-use (Fageria et al., 1988).

Plant species and cultivars within species have been reported to differ in their efficiency in nutrient uptake and translocation into grains. This together with differences in dry matter accumulation per unit time and growth duration leads to differences in nutrient content. Fukai et al. (1999b) also reported that some genotypes are good in use of nutrients for total dry matter production and in the proportion and quantity of nutrients translocated into the grains. Low grain P is a desirable trait as it reduces P-removal from the soil thus contributing to sustainable land use. However, a minimum amount of P in the grain is required for nutritional reasons and for good seed germination (Gill et al., 2004). High grain yield can be realized without reducing grain P concentration by improved translocation of P into grains and increased P uptake.

BREEDING FOR HIGH GRAIN QUALITY

Grain quality traits such as; grain size, aroma, shape, amylose content, gel consistency, swelling properties, cooking properties and milling percentages are important in a rice improvement programmes as they determine the market acceptability of milled rice. In addition, these traits are preferred by consumers including long and slender fine, whiteness, translucency, and strongly scented grains.

Rice is grown in different ecologies with ecological and physio-chemical adaptations and properties. Sanni et al. (2005) identified about five physico-chemical properties that are used in rice quality assessment. These are amylase content, protein content, gel consistency, alkaline spreading value, swelling capacity and water absorption. The major attribute for rice consumption acceptability and hence its adoption is its grain quality traits. Aluko et al. (2004) have reported substantial information for physio-chemical and cooking traits for rice grown in Asia and U.S.A. In Kenya this information is scanty despite the major influence rice quality has on its consumption and marketing.

Some important parameters for consuming attitude and cooking quality, such as amylose content, gelatinization temperature (GT), gel consistency and starch paste viscosity (Bao et al., 2002) have been studied genetically, while other important starch properties, such as gel texture and swelling volume, have received little attention to date. Shi et al. (2000) have identified length and width of rice grain as the two most important quantitative traits closely related to the exterior quality of rice. Rice grain shape has become one of the main goals in rice breeding, because consumers usually prefer milled rice with spindly shape and greater transparency. For rice breeding programmes, understanding the inheritance, specifically gene action, for rice grain shape traits is desirable. Chen et al. (1998) in their genetic analyses of length and width of rice grain reported that rice grain shape is quantitatively inherited. It has recently been shown that rice grain shape is simultaneously controlled by triploid endosperm genes, cytoplasmic effect and maternal plant genes (Shi and Zhu, 1996), and these have a large genotype × environment interaction (GEI) effects, but the genetic effects on the embryo have not previously been demonstrated.

Aromatic rice varieties are economically important as they fetch a premium price in agricultural markets worldwide. The most prominent examples are jasmine and basmati rice varieties. Basmati rice variety is well known for its exquisite aroma and grain quality. However, these grain quality traits inheritance and their interaction with environment behaviour is not known among the Kenyan cultivars. Graham et al. (1999) reported that appearance and taste seem to be the factors that mostly determine quality. In rice, these preferences can be translated into measurable milling and physico-chemical properties. Yajima et al. (1979) identified a total of 114 different volatile compounds that are responsible for rice fragrance. Among them, 2-acetyl-1-pyrroline (2AP) stands out as the main fragrance compound in both jasmine- and basmati-style rice varieties, and the 2AP concentration in fragrant rice is high up to 0.09 mg kg^{-1}, 10 times more than that in non-fragrant rice (<0.006 to 0.008 mg kg^{-1}) (Chen et al., 2006).

Two or three recessive or dominant genes have been reported to be responsible for the fragrance trait (Reddy and Reddy, 1987; Tripathi and Rao, 1979). However, most researchers believed that rice fragrance is controlled by one single recessive gene (Huang et al., 1994; Jin et al., 2003; Sood and Siddiq, 1978) with small gene modifiers. Unlike other traits controlled by major genes, rice fragrance which is a recessive trait is easily influenced by many elements, such as genetic background, environmental conditions and storage time among other factors (Chen et al., 2006). Wongpornchai et al. (2004) noted that jasmine rice variety has gained an increasing popularity throughout the world food market because of its famous reputation in appearance, cooking quality and high aroma level. Rabiei et al. (2004) has given rice grain quality traits as including milling, appearance, cooking and nutritional qualities which have great influence on rice consumers in most countries. Rice grain characteristics such as length, breadth and shape have a direct effect on the marketability, and therefore, the commercial success of modern rice varieties. These characteristics affect the appearance of the rice grain and are quantitatively inherited. Since the economic value of a plant depends on its different traits, plant breeders should consider simultaneous selection for two or more traits to maximize the economic value of a plant along its agricultural production value chain.

An aromatic rice variety emits a definite odour in fields, during harvesting, storage, milling, cooking and eating (Efferson, 1985) and it is best developed in cooler temperatures during maturity. Inheritance of aroma has been reported to vary depending with materials used in the research, but it's inherited. Phosphorous has been reported to favourably influence rice grain quality, aroma, softness, fluffiness, whiteness, and glossiness as these are related to P content in paddy grain and not content in the plant (Suwanarit et al., 1997), and that organic fertilizers have no effect on rice cooking qualities (Jeong et al., 1996). Several components contribute to rice grain quality, and among these, fragrance and taste qualities are the most important to consumers (Myint et al., 2009).

Myint et al. (2009) have noted that rice grain quality affects the nutritional and commercial value of grains, and that it is of great importance to those involved in producing, processing and consuming rice. Rice grain quality includes factors such as processing quality, appearance, nutrition, cooking and taste qualities. However, rice cooking and taste qualities are the most important qualities to consumers. Although preferences vary from one group of consumers to another, rice grains with a pleasant fragrance and a soft texture usually achieve higher prices in national and international markets. Fragrant or scented rice that obtains a premium price in international markets is characterised by its natural fragrance or pleasant aroma and good taste quality. Nagaraju et al. (2002) have observed that in general, traditional fragrant rice varieties are of tall stature, prone to lodging, have low tiller number, high sterility, are sensitive to photoperiods and have poor response to fertilizer application thus leading to low yield potentials. This compound has been isolated from all parts of the rice plant except from the roots (Yoshihashi, 2002). Various techniques have been developed to assist breeders in the selection of individuals with distinctive fragrances. Sensory methods such as chewing seed samples and smelling leaf tissues from individual plants were reported by (Wongpornchai et al., 2004), as well as heating seeds or leaf tissue with water or reacting with 1.7% KOH solution (Sood and Siddiq, 1978). However, these methods are limiting when processing a large number of samples. Chemical methods are possible for the identification and quantification of volatile compounds in the cooking water by using gas chromatography (Lorieux et al., 1996; Mahatheeranont et al., 2001). For example, quantification of 2AP by stable isotope dilution methods (Yoshihashi, 2002) and histochemical localisation of 2AP in thin sections of seeds by reacting with 2,4 dinitrophenol hydrazine (Nadaf et al., 2006). However these methods are not practical during the breeding processes that generate many samples.

A major nuclear recessive gene has been reported to control the formation of fragrance in rice. The molecular marker for grain fragrance was first discovered by Ahn et al. (1992). The RFLP analysis has shown that the fragrance locus is linked to a single copy DNA clone, RG28, on chromosome 8 of rice, at a distance of 4.5 cM fragrance gene. A number of PCR-based markers have been developed to detect fragrance and assist breeders in their selection of this trait through Marker assisted selection breeding programs (Bradbury et al., 2005). Conventional breeding methods combined with marker assisted selection can be more successful in the development of high quality new cultivars. This is because of the quantitative nature of grain quality traits and environmental variations that make it difficult to identify genetically superior lines due to their interferences. Molecular markers facilitate the selection of complex traits during the breeding process because they are reliable and they are unaffected by environmental conditions and thus consistent in their results.

Michael et al. (2009) have reported fragrance in the grain to be one of the most highly valued grain quality traits in rice, yet the origin and evolution of the betaine aldehyde dehydrogenase gene (*BADH2*) underlying this trait remains unclear. Despite multiple origins of the fragrance trait, a single allele, *badh2.1*, has been reported to be the predominant allele in virtually all fragrant rice varieties today, including the widely recognized Basmati and Jasmine types. Fragrance is reported to be produced in all parts of the rice plant except the roots, and it has a very low odour threshold, allowing humans to detect it at minute concentrations in field grown plants, macerated leaf tissue, as well as in the grain before, during, and after cooking. Fragrant accessions have been identified within at least three of the distinct genetic subpopulations of rice, including Group V that include Basmati and Sadri varieties, *indica* that include Jasmine varieties and tropical japonica.

Shu Xia et al. (2008) have observed that rice to be a primary food crop and has an important role both economically and in terms of food security. Aromatic rice varieties constitute a small but special group of rice and have gained greater importance with the worldwide increase in the demand for super rice. Not only is aroma one of the most important traits for determining good quality rice, but fragrant varieties have comparable or superior nutritional values and better amino acid profiles. For example, Basmati-370 rice has higher lysine, phenylalanine, leucine and methionine content than non-aromatic varieties (Sekhar and Reddy, 1982). Consumers are willing to pay higher prices for fine-grained aromatic rice, and therefore, sensory evaluation of grain quality has become an important consideration in rice breeding. There are different flavours or aromas occurring in diverse aromatic genotypes that arise from varied origins and hence there is no consensus yet on the nature of rice aroma (Dhulappanavar, 1976).

At least six chromosomes have been reported to be involved in the mapping process for aroma. Lorieux et al. (1996) have confirmed the close linkage between RG28 and *fgr* (5.8 cM) on chromosome 8 and identified two quantitative trait loci for fragrance, one on chromosome 4 and the other on chromosome 12. Li et al. (2006) and Bradbury et al. (2005) have reported significant polymorphisms between aromatic rice genotypes and non-aromatic genotypes with regard to the coding region of a gene with homology to the betaine aldehyde dehydrogenase 2 gene *BAD2*. However, *BAD2* appears not to be responsible for aroma in all aromatic rice varieties, since this gene is not responsible for a dominant aroma trait of an aroma mutant SA0420, a view also observed by Kuo et al. (2005). Even so, it has been established that in most rice varieties aroma is controlled by a single recessive gene mapped to chromosome 8 of *O. sativa* (Li et al., 2006). Molecular fine mapping for aroma and the subsequent use of this information in the selection process would greatly accelerate the efficiency of aromatic rice breeding programmes. In addition, physical mapping of aroma could be useful for understanding rearrangement in the rice genome and exploring candidate genes for aroma. The identified markers linked with aroma provide a useful avenue for molecular marker-assisted selection of genotypes arising from hybridization in future breeding programmes.

Nguyen and Bui (2002) have identified the two markers RG28, RM223 to be closely linked to extremely aromatic phenotypes. The aroma or fine flavor of cooked rice has been shown to be composed mainly of formaldehydes, ammonia and hydrogen sulfide. Some researchers reported that an increase of propanol, pentanol, and hexanol during storage seemed to be responsible for the stale flavor of cooked rice. As many as 100 volatile flavor components such as hydrocarbons, alcohols, aldehydes, ketones, acids, esters, phenols, pyridines, pyrazines, and other compounds have been identified in cooked rice. A molecular marker that is closely linked to the aroma gene can be used to facilitate early selection for the presence or absence of scent, and to identify the nature of the locus (homozygous or heterozygous condition), it may also be useful for the rapid incorporation of the scent character into breeding lines. Ahn et al. (1992) have reported a DNA marker closely linked to a gene for aroma in rice. It is generally agreed that gene marker and not flanking markers are more accurate in indentifying fragrance locus in breeding lines.

Xiangli et al. (2008) have conducted genetic studies and physical fine mapping to reveal that a candidate gene (*fgr*/*OsBADH2*) homologous to betaine aldehyde dehydrogenase is responsible for aroma metabolism in fragrant rice varieties, but the direct evidence demonstrating the functions of *OsBADH2* is lacking. A number of genetic analyses using reciprocal crosses repetitively showed that the fragrant characteristic trait is under recessive monogenic inheritance without impact from cytoplasmic genes. In a recent study involving eight aromatic hybrid rice maintainer lines, a single recessive locus spanning SSR markers RM210 and RM515 on chromosome 8 was identified to be tightly linked to the fragrant trait (Ren et al., 2004). Physical mapping revealed that several candidate genes including a rice betaine aldehyde dehydrogenase (OsBADH2) homolog on chromosome 8 co-segregated with aroma production (Wanchana et al., 2005). Meanwhile, a study has demonstrated that the aroma production in fragrant genotypes was well correlated with the multiple mutations in the fragrance rice (*fgr*) locus that is identical to betaine aldehyde dehydrogenase (*OsBADH2*) on chromosome 8. The linkage of fragrant cultivars to undesirable agronomic performance and the molecular mechanism of this major weakness occurring in the aromatic rice cultivars is largely unknown. By using RNA interference (RNAi) technique combined with *Agrobacterium tumefaciens*-mediated T-DNA transfer, it has been shown that the directed degradation of *OsBADH2* transcripts resulted in a significantly elevated fragrance emission and 2-acetyl-1-pyrroline accumulation, unambiguously suggesting that *OsBADH2* locus is responsible for aroma production in fragrant rice varieties (Xiangli et al., 2008). In addition, disrupting of *OsBADH2* led to a detectable reduction of crop productivity, implying its multiple functions in secondary metabolism and agronomic performance. The results showed also reduction in plant height as well as 1000 grain weight in the *OsBADH2*-deficient plants when compared to the wild-type plants segregated out from the transgenic progenies.

FARMERS PERCEPTIONS AND PREFERENCES IN RICE VARIETIES

Various methods have been advanced that incorporate farmers participation, such as participatory rural appraisal (PRA), participatory variety selection (PVS) and participatory plant breeding (PPB) (Ceccarelli and Stefania, 2007; Walker, 2008; Witcombe, 2000). In Kenya, none of these methods has been employed and even literature on the same is rare. But elsewhere, various merits and demerits of the three methods have been practiced and widely discussed. Atlin et al. (2006a), Witcombe and Joshi (2003) argued for and against each of the methods. They observed that PRA is mainly used to gather information and share the results with the local people and Chambers (1994) has elaborately looked at its various forms. PRA actually is used to identify farmers' preferences in a variety with the aim of seeking to have wider adoption of a given variety that meets their desires. The PVS involves merely supplying the farmers with finished product to evaluate in their farms, while PPB involves farmers in selecting genotypes from a population that may involve accessions, advanced lines, segregating materials or cultivars; that can be used as parents in a breeding programme. In the later case because of actively involving the farmers in the breeding continuum, the adoption rate has been observed to be high and thus result into early release of the varieties and ensures crop diversity (Ceccarelli and Stefania, 2007; Virk et al., 2003). Sperling et al. (1993), Witcombe et al. (1996) and Thakur (1995) have actually used PPB where farmers were visiting the research station to select suitable genotypes to be used as parents, and best ones from segregating population to develop varieties that were widely adopted within a short period. They have thus observed that PPB as opposed to PRA and PVS is the strongest tool for variety development and it ensures high adoption within a reasonable time frame (Almekinders and Elings, 2001; Walker, 2008). The case for PPB has specifically been advocated for and used by many authors to develop varieties suited to low input environments and for poor resource farmers (Ceccarelli and Stefania, 2007; Kimani and Derera, 2009; Morris and Bellon, 2004).

Since PPB is suitable especially when breeding for low input system as is the case here, where farmers can barely afford inputs like inorganic and organic fertilizers; it was found appropriate as opposed to the conventional plant breeding that favours farmers under high input environments (Ceccarelli and Stefania, 2007; Kimani et al., 2007). It is difficult for farmers' to modify the production environments and alter the poor soil health condition and also they may fear to replace their cultivars with modern high input dependent cultivars. This situation calls for ecosystem breeding (specific adaptability) where varieties suited to particular environments are developed by exploiting the skills of farmers in order to maximize gains in the target environment. This approach can efficiently cater for the various niche based farmers and thus optimise rice productivity by utilizing responsive the existing wide yield gap. This gap between potential and actual yield is a clear indication of the possibility for further shifts in yield character improvement. Yield improvement can be realized by breeding for adaptation and nutrient use efficiency for the prevailing production environments.

Most of agricultural environments have low soil nitrogen (N) and phosphorus (P), and this situation is further complicated by the fact that few farmers can afford the chemical fertilizers to apply for rice production. The cost of fertilizers has been rising steadily due to escalating oil prices, thus resulting in less use of fertilizers. This has lead to dwindling yields as rice continues to be produced on the same fields without soil replenishment despite massive soil depletion and degradation. However, the wide genetic variability that exists in rice varieties can be exploited to develop low soil N and P efficient varieties capable of producing economic yields. Although few studies were reported, improved low soil N and P efficient genotypes had consistently higher yield than unimproved genotypes.

Grain quality in rice is a very important character as it dictates a variety acceptance by farmers, marketing and consumption and a variety of other uses. The appearance and taste has been documented as the main determinants of grain quality. The information on grain quality inheritance especially fragrance in general is lacking in Kenya, but the information gathered indicated that few genes are involved in control of traits such as aroma. Grain size and shape are quantitatively inherited meaning breeding strategy could be to concentrate genes responsible for their control. Gel consistency has also genotype to different low soil N and P conditions. This way potential gains can be exploited through this decentralized and site specific adaptations and genotype by environment interaction is fully exploited. The situations where progress from crop improvement has been dismal and slow in marginal environments can be reversed as is the case in Kenya. Conventional and formal plant breeding programme practiced by national programmes have ignored indigenous germplasm as well as failed to breed directly for conditions faced by resource poor farmers, instead emphasizing selection for broad versus local adaptation. Further, Witcombe and Virk (2001) have argued that ……… (PPB) is most likely to develop cultivars that may perform better than the products of convectional breeding when it is used in low-input systems, because in these situations the genetic gain between high-yield breeding nurseries and low-yield target environments is likely to be low or negative. Overall the low performance situation can be changed and that for this to happen an urgent reversal is required if food self sufficiency and improved livelihood is to be realized now than later.

Although studies on famers preferences have been conducted elsewhere, in Kenya documented information on rice is scanty. For example, a study conducted in Malawi, found out that unsuitable varieties, high cost of inputs and lack of mechanical implements were the major constraints (Mzengeza, 2010), while in Uganda (Lamo, 2010) reported that farmers preferred high grain quality with high yields, however in West Africa farmers preferred tall and early maturing rice varieties (Efisue et al., 2008). Farmers' perception and preference can be used by breeders to develop varieties that might have higher adoption rate and thus higher productivity. This information is not documented in Kenya and farmers' varieties preferences, to guide rice breeding programme objectives, are not well known.

CONCLUSION

From the review, it is evident that little information exists on rice research work conducted in Kenya in particular and Africa in general. The information gathered may not apply directly because environments, varieties adaptation and general farming systems are quite different. This call for more research based solution to develop varieties that are suited to the unique production niches both existing and new ones.

Research is still required to develop genotypes that can yield highly under existing constraints in order to bridge been shown to be a trait greatly influencing the use of rice and therefore, its marketing.

Briefly, the various selected inheritance study methods have been discussed and their use is dependent on the kind of genetic information that is being sought and their ease of application both in design, analysis and interpretation.

In conclusion rainfed rice varieties for the future should be more responsive to mineral fertilizer but should retain the stress tolerance and grain quality built into traditional varieties. Farmers would then be motivated to invest in more productive land preparation and fertility management practices that result in higher yields. It has been shown that breeding for low as well as high input production environments is possible and that use of modern breeding tools like marker assisted breeding (MAB) should be incorporated. This should facilitate faster variety development as selection can be done early, by selecting lines homozygous for the quantitative trait loci (QTL) or genes of interest at seedling stage. This could save time and resources and lead to faster results. Slowly, pyramiding of desirable QTLs and thus development of multitraits varieties could be achieved. This could gradually but eventually result into development of resilient varieties with enhanced yields and grain quality under various environments, climate change and variability scenarios, while conserving the productive resource base.

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