Climate smart rice innovations to reduce the impact of climate change on the livelihood of value chain actors.

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Abstract

Introduction

Rice is a major source of nutrients, largely contributing to the food and nutrition security for millions of people in Africa although most countries still rely on huge imports to meet local demand. Extreme temperatures, drought, flooding, and high salinity are climate change related stresses that negatively affect rice yield and grain quality. Thus, tackling these constraints is a critical action to increasing rice self-sufficiency in Cameroon and Africa in general.

Methods

The Africa Rice Center in partnership with the National Agricultural Research and Extension Services of its 28 member States operating within the framework of the Africa-wide Taskforces has developed, tested, validated, and are deploying breeding, agronomic and post-harvest approaches to mitigate the negative impacts of climate change on rice yield and quality in Africa.

Results

Breeding approaches have led to the development of drought, cold, submergence, stagnation flood, salinity, and anaerobic germination tolerant varieties that are also resistant or tolerant to biotic stresses. These have demonstrated better yields and grain quality under stressed conditions compared to counterparts lacking those specific traits. The system of rice intensification and alternate wetting and drying, mid-season drainage, smart-valleys approach for inland development, solar-powered irrigation system, no-till and rice straw mulching are agronomic approaches developed and these approaches have demonstrated significant increase in yield and grain quality compared to alternative approached under climate change stress conditions. Post-harvest approaches have focused on reducing grain breakages, chalkiness, mycotoxin contamination, insecticide and fungicide use, deforestation and value addition to broken rice and rice milling byproducts using environmentally friendly methods. Post-harvest innovations here include using improved rice parboiling fueled by rice husk, solar-powered hermetic storage systems, processing of fine broken rice into flour for porridges and bakery products and use of rice husk fan-assisted stoves for household cooking and the cottage processing industry.

Conclusions and recommendations

Although climate change is a serious threat to rice production affecting both yield and quality, African governments will have to implement policy measures that enhance the scaling and adoption of climate smart rice innovation developed by AfricaRice to mitigate the impact of climate change if they aspire to reduce rice imports.

Key words: Rice, climate change, stresses, yield, quality, mitigation

INTRODUCTION

Rice is a major source of nutrients, largely contributing to the food and nutrition security for millions of people in Africa. The combined effects of population growth and urbanization accompanied by changing dietary habits have been implicated in growing rice consumption estimated at 6% per year. Rice self-sufficiency in Africa is estimated at 60% with the rest met though importation—this percentage ratio has even been increasing—estimated to cost over US$ 6 billion annually. Food shortages and price hikes due of Covid-19 pandemic lockdowns and the present Ukraine-Russia war has forced most African governments to start taking measures toward attaining rice self-sufficiency in their respective countries. Under the climate change situation, unpredictable and extreme weather patterns augment various biotic and abiotic constraints for rice cultivation and post-harvest handling. Thus, tackling these constraints linked to climate change is a critical action to achieve rice self-sufficiency.

Extreme temperatures, drought, flooding and high salinity are climate change related stresses that negatively affect rice yield and grain quality in Africa.

Meta-analysis by Su et al (2023) show that high nighttime temperature (HNT) had a more detrimental impact on rice yield and quality when compared with the high daytime temperature (HDT). The optimum daytime and nighttime temperatures for best rice yield were approximately 28 °C and 22 °C, respectively. Grain yield showed a decline by 7% and 6% for each 1 °C increase in HNT and HDT, respectively, when e the optimum temperatures are exceeded. Seed set rate (i.e., percent fertility) is the most sensitive trait to HDT and HNT and accounted for most of the yield losses. Both the HDT and HNT affected grain quality by increasing chalkiness and grain breakage rates, which may affect marketability of the rice produced. Additionally, HNT was found to significantly impact nutritional quality (e.g., protein content) of rice grains. On the other hand, low temperature also negatively affects rice yield; especially cold -- less than 18–20 °C – at the reproductive stage directly causes sterility (Alemayehu et al., 2021). Low temperatures often impede rice growth in the cooler seasons of the Sahel or in high-altitude regions with cold irrigation water supplies.

Drought stress poses a significant threat to rainfed rice production in Sub-Saharan Africa (SSA). Climate change is exacerbating this challenge by introducing increased variability in rainfall patterns and prolonged periods of water scarcity in this region where farmers often lack access to irrigation. Rice yields under severe drought conditions can be reduced by up to 65%. This is accompanied by increases of grain breakage and chalkiness that can be associated with post-harvest loss in quality too.

Soil salinity is one of the impacts of climate change in coastal agriculture land, as rises in sea levels has increased salinity from 1 to 33% over 25 consecutive years (Rahman et al., 2018). Salinity is more evident in semi-arid, coastal agriculture lands, and particularly in arid regions of the world – a Sahel region is a typical case in SSA. Irrigation with saline water, low precipitation, and high evapotranspiration are key factors that cause salinization at a rate of 10% annually to agricultural lands. Salinity stress reduced the grain yield by 64.52 %. Salinity increases grain breakage and the chalky rice rate, adversely affecting the grain quality.

Flooding due to heavy rains in production sites of resource-poor growers is prevalent in the era of climate change. The rice plant can grow under flooded conditions different from the other major field crops. However, excess water can negatively affect its growth and yield. There are different types of flooding problems depending on geography and rainfall pattern. Deep water (> 50 cm) continuing a few months (stagnant flooding) can reduce dry matter accumulation. It also accelerates stem elongation causing lodging after water table reduction. Flash flooding can also cause serious yield reduction -- though it does not continue for a long time – when it brings overhead flooding to the rice plants. Recently some lowland farmers adopted direct seeding to reduce labor force. With incomplete water control, seeds sown are sometimes under standing water and their germination is hindered by anaerobic conditions.

Due to the change of weather pattern, the tendency of disease occurrence could also change, and some areas will be more severely affected. Increased air temperature could increase infestation of weeds in general.

Inappropriate harvesting and post-harvest practices accelerate negative environmental effects on grain quality. Such practices under extreme conditions of temperature and humidity result in high post-harvest losses in rice of about 48%. High daytime temperature and low nighttime temperatures after rice is ready for harvest cause expansion and contraction of grains resulting in grain fissures. In addition, repeated wetting and drying of ready to harvest field grains or grains during drying or storage also cause grain fissures. High rate of grain fissures increases grain breakages during milling resulting in low head rice rate. Rice stored in humid zones in jute bags or nylon woven bags can become wet favoring the growth of mycotoxigenic fungi, mycotoxin contamination and 100% loss of rice. Poor disposal of rice husk through open field dumping and burning increases pollution and green-house gas emission. In addition, traditional parboiling uses firewood as a source of fuel. This increases green gas emission due to the energy inefficient stoves used and high rate of deforestation.

In this paper, we present three biophysical approaches taken by AfricaRice to mitigate climate change induced damages in rice production. In addition, we introduce several policy recommendations for the governments of African countries since this is crucially indispensable to materialize the concrete measures with these innovations.

METHODOLOGY

AfricaRice adopted different approaches to address each of the above stresses which include breeding, agronomic and post-harvest approaches.

Breeding approaches

Recently, a population improvement breeding strategy based on elite x elite scheme (carrying favorable alleles for priority traits; drought tolerance, disease resistant superior, grain quality etc.) integrated with rapid breeding cycle (RGA) , use of precise phenotyping and genotyping, marker assisted selection (MAS) and genomic selection (GS) can enhance the potential of genetic gain under drought and non-stress conditions to meet the demand of rainfed rice production in SSA (AfricaRice, 2023). In this context, a set of 45 promising rainfed lowland lines having higher grain yield under drought and non-stress conditions, shown resistance to blast and RYMV and superior grain quality were developed and tested in countries as multilocation breeding trials through the Africa-wide breeding taskforce.

For cold stress, researchers have identified as well as developed rice cultivars with varying degrees of cold tolerance by studying the genetic diversity within rice germplasm. More than 2500 accessions and breeding lines from both Indica and Japonica backgrounds as well as *O. glaberrima* accessions were screened at different locations on station and through the Africa-Wide breeding Task Force. The genotypes were further evaluated in cold prone environments in Tanzania, Burundi, Rwanda, Ethiopia, DRC and Madagascar

For submergence stress, two popular rice varieties in Nigeria known as WITA 4 and NERICA-L 19 were recently improved by introgression of the submergence tolerant (*Sub1*) gene (originally from FR13A), which can make the rice plants tolerate against overhead flooding up to two weeks. Two improved flood tolerant varieties were released by AfricaRice in Nigeria in 2017, namely FARO 66 (WITA 4-Sub1) and FARO

67 (NERICA-L 19-Sub1). To assess the yield and agronomic potential of the improved germplasm, trials were conducted under submergence stress and control conditions on-station and on farm in Nigeria. In the 2022 wet season. The same trials were conducted in Sierra Leone to expand the two varieties beyond Nigeria.

For salinity stress, salinity problems are expected to become more widespread world-wide because of climate change. Research carried out by AfricaRice involved the introgression of the *Saltol* gene, which confers salt tolerance in rice seedlings, into a popular cultivar Rassi. Some 16 Saltol-introgressed lines (ILs) were identified that had 3–26% yield loss under salt stress compared to unstressed controls. Farmers ranked the varieties at various stages throughout the crop cycle and tested them in their own fields.

Agronomic approaches

Lowland rice with sufficient water control is a highly climate smart crop. For instance, transpiration cooling with flooded conditions could alleviate plant damages by heat stress and maintaining high water table during the seedling stage could avoid cold stress to the seedlings. Irrigation could make the rice plants escape from drought and water excess conditions. Thus, improvement of water management practices is a key issue in agronomy measures against climate change. In 'the improvement', saving water and enhancing water use efficiency can be vital components under the climate change situation. To reduce the amount of water required for crop production, the effect of system of rice intensification and alternate wetting and drying on water productivity and rice yield were evaluated compared to continuous flooding using 60 farmers in 9 sites located in five countries (Burkina Faso, Cote d'Ivoire, Mali, Senegal, and Sierra Leone).

For rainfed lowland and upland, the effect of solar-powered irrigation using a borehole as water source on diversification options and farmers net income were evaluated in 22 sites of two countries (Cote d'Ivoire and Mali) with farmer's fields where such irrigations systems were absent as check.

To reduce soil moisture loss, the effect of a combination of no-tillage and rice straw mulching on soil moisture and rice yield were evaluated with 22 farmers in 2 sites located in northern Benin with farmer's practice as check.

The improvement of water management can also reduce some other abiotic stresses than those linked to climate change. For example, in iron toxic soils, which are widely prevailing bottoms in inland valleys, the effect of mid-season draining on iron toxicity score of the plants, rice yield and water productivity were compared with continuous flooding using 30 farmers in 2 sites in Cote d'Ivoire.

In the rainfed lowlands and inland valleys where drought limits rice cultivation, the effect of Smart-Valleys approach, which is a farmers' participatory land and water development technology, on yields and farmers' net income were compared with farmer's practice using 110 sites in six countries: Benin, Burkina Faso, Liberia, Sierra Leone, Benin, and Togo.

Agronomic options for salt-affected soil management which consist of a combined use of nutrient management strategies (nitrogen, phosphorus, potassium, gypsum, and zinc) and salt-tolerant rice varieties (IZRIZ 10, ISRIZ 11, and Saltol) with good land preparation were assessed for the impact on salinity. A series of experiments was conducted in both research station and farmers' fields using farmer participatory approach in the Senegal River Valley to assess the agronomic and economic viability of these options.

Post-harvest approaches.

To reduce grain breakages and chalkiness caused by high temperatures, drought and other non-climate change factors, a rice husk fueled Grain quality enhancer, Energy efficient and durable Material (Mini-GEM) parboiling technology was developed, evaluated for output rate, improved grain quality – head rice rate, chalky rate and impurity rate in 40 sites in 11 African countries.
To reduce mycotoxin contamination in rice to high variability in temperature and humidity when grains are stored in non-hermetic systems, the effects of head rice rate, chalky rate, impurity rate and storage method on mycotoxin contamination of rice in three contrasting agro-ecological sites in Benin, Cameroon, and Senegal were evaluated.
To add value to broken rice due to low head rice rate and chalky rate caused by climate change and to a lesser extend non-climate chain factors, value-addition to low-grade broken rice through the production of flour and bakery products were evaluated for acceptability in 11 African countries.
To add value to rice husk and reduce greenhouse gas emissions due to open field dumping and burning, fan-assisted rice husk stoves were evaluated for workplace emissions, thermal properties, and suitability cooking processes in Africa.

RESULTS

Climate smart varieties.

Drought tolerant varieties.
The performance of seven elite lines were notable when all environments were considered together including the control environment and drought stress environment. ART1453-B-B-1-5 had the highest grain yield of 7,849.2 Kgha-1 when directly seeded and faced reproductive stage drought stress. These results connote a 29% increase in yield of ART1453-B-B-1-5 above the highest-yielding standard check (FARO 67) under drought stress. At least 7 selected lines yielded better compared to the best checks.

Cold tolerant varieties.
Oryza sativa germplasm coming from higher latitude zones or temperate regions have more tolerance to cold. Furthermore, japonica type varieties generally have a higher level of cold tolerance as compared to an indica type. Considering the agronomic traits, the varieties release by AfricaRice have >80% fertility and >5 ton per ha yield and good level of blast disease resistance. For instance, the data for recently released three cold tolerant varieties in Madagascar, FOFIFA 194, FOFIFA 195 and FOFIFA 196 has shown these varieties to have an average of 2t/ha advantage, early maturing by a month, and good levels of blast resistance.

Submergence tolerant varieties.
Under submergence stress, there were significant increases in the yield of rice varieties improved with the *sub1* gene (NERICA-L 19-Sub1 and WITA 4-Sub1) when compared with their unimproved counterparts (NERICA-L 19 and WITA 4) as well as the best performing checks (FARO 44 for Nigeria and INDOCHAIN for Sierra Leone) in all sites tested in both countries.

Salinity tolerant varieties.
Elite irrigated lowland lines were generated that have outperformed the local popular varieties such as Sahel 108, Sahel 210, that produced 15-120kg per ha, while the elite lines generated 2-4ton/ha. Farmers

also selected these lines based on short cycle, and cooking and eating quality. Through this process varieties like ARICA 11, ISRIZ-09-B1-45, ISRIZ-10, ISRIZ-11 are already released, whereas other potential breeding lines are in the pipeline for release in different countries.

Stagnant flooding resistant lines

Stagnant flooding is a key abiotic stress in rainfed lowlands of Africa. From an earlier MAFF funded project genetic variation in *O. glaberrima* for tolerance to stagnant flooding has been characterized, and four accessions have been identified as tolerant. One of the tolerant accessions has been used to develop three interspecific mapping populations with O. sativa. The three populations were Gervex 2674/ART27-79-1-3-B-B-B-2, Gervex 2674/ ART28-126-3-2-2-7 and Gervex 2674/FAROX508-3-10-F44-2-1 consisting of total 392 progenies were further tested for stagnant flooding and some selected tolerant high yielding lines were tested across SSA through BTF-METs. Two of those tested lines are being tested on farms currently.

Lines with anaerobic germination

Through screening whole *O. glaberrima* genetic pool for anaerobic germination (AG) ability initially we identified six *O. glaberrima* accessions with consistent high level of AG (TOG 5485, TOG 5505-A, TOG 5980-A, TOG 7252-A, TOG 8347 and TOG 16704) were identified. Later we used most consistent accession TOG 7252-A for introgression of AG trait to popular *O. sativa* variety WITA-4 and identified few elite lines with high AG ability. Those lines are currently at advanced yield trial (AYT) stage of testing and will be further tested in METs based on performance.

Early morning flowering lines to avoid heat stress.

Early morning flowering (EMF) is a desirable trait in rice as temperatures in early morning hours are lower compared to afternoon and flowering is the most sensitive stage to heat exposure. We characterized *O. glaberrima* accessions for EMF trait and identified 15 accessions with EMF trait. Currently we are developing elite breeding lines with accessions identified with EMF traits for heat tolerance in rice. Those lines will be further tested in heat prone areas in SSA.

Biotic stress resistant/tolerant varieties

Including climate smart varieties mentioned above, no susceptive varieties could enter multi-location trials through the Breeding Taskforce since evaluation of resistance/tolerance to major diseases in Africa is incorporated into the breeding scheme.

Climate smart agronomic practices.

The system of rice intensification and alternate wetting and drying.

In the irrigated lowlands, the system of rice intensification and alternate wetting and drying reduced water use by 15–43% and increased water productivity by 8–87% without significantly affecting rice yield in comparison to continuous flooding.

Mid-season drainage.

Mid-season drainage reduced iron toxicity score by 40%, water use by 20% and increased water productivity by 18% compared to continuous flooding.

Smart-Valleys approach for land and water development.
In the rainfed lowland the Smart-Valleys approach for land and water development in inland valleys increased farmers' yield by 0.9–2.4 t/ha and farmers net income by 267–1157 $USD with a higher yield and income in the inland valleys where drought limits rice cultivation.

Solar powered irrigation system.
Solar-powered irrigation increased diversification options, and farmers net income by US$5,262/ha/year. In the rainfed upland, supplemental irrigation increased rice yield by 37%, fertilizer use efficiency by 54%, and profitability of rice cultivation by 32%.

No-tillage and rice straw mulching.
The combination of no-tillage and rice straw mulching increased soil moisture by 30% and rice yield by 64%.

Mitigation of salinity stress
Agronomic management strategies, such as salt-tolerant varieties, combined with NPK, gypsum, or zinc fertilizer, increased rice yield by 0.8 t/ha and net profit by US$107/ha. This result suggests that there is a great opportunity for increasing rice yield and profitability under salt-affected soils through integrated management options.

Climate smart post-harvest practices

Mini-GEM parboiling.
Mini-GEM parboiling improves milling rate by 5%, head rice rate by 32%, chalky rate by 3400% and slenderness rate by 6% compared to straight milled rice. In addition, parboiling improves the several micronutrient rates and reduces glycemic index by 40%. Replacement of firewood with rice husk saves about US$ 30 per ton of parboiled rice (30% of production cost). The husk stove also produces near-zero smoke and soot, thereby alleviating air-pollution and pot-blackening.

Hermetic storage bags and cocoons equipment with solar powered Ecowise® monitoring system.
This bags and cocoons can store rice seeds for 1 year and paddy for 2 years with seeds having germinative rate of >90%, while paddy will have the equilibrium moisture rate at 13-14%, CO_2 rate > 7% thus eliminating insect, fungal growth as well as mycotoxin contamination. The system does not require construction of a building or does it require temperature control systems and is thus suitable for resource poor rural farmers.

Rice flour and bakery products produced from fine broken rice.
Fine broken rice can be ground into flour and used as a partial substitute for wheat in the production of biscuits, cookies and cakes, as demonstrated in several African countries. The processing of fine broken rice into flour and subsequently bakery products increased its value by more than 20%.

Solar powered fan-assisted stoves.
These solar powered stoves use rice husk or other agricultural waste for clean energy generation. Fan-assisted cookstoves with vent-type burners were safer to use as they produced both lower concentrations of flue gases and particulate matter. The fan-assisted cookstoves also recorded better thermal indices. Rice husk mixed with palm kernel shell at varying proportions burned for a longer time than rice husk only,

but this mixing had no effect on flame temperature. End-users preferred fan-assisted gasifiers to the natural draft gasifier cookstove.

SOME IMPACT STUDIES

With a sample of 1200 rice producers in two production systems in Mali, endogenous switching regression models showed that in the irrigated system, the impact on yield of climate information system (CIS) users was 1.46 t/ha and 1.44 t/ha for non-users if they would have become users. In the lowland system, CIS adoption increased by 2.66 t/ha for users and 0.26 t/ha for non-users if they would decide to become users.
Studies on 641 rice households randomly sampled and interviewed in Sierra Leone and Liberia showed that the adoption of Smart Valleys Approach (SVA) increased the rice yield by 1.7 t/ha (60% increase), income (US$ 560 per ha) and household food security (7.21%). Knowledge of SVA, contact with extension agents and membership of farmer's association drove the adoption of SVA.

The impact of the GEM system is estimated at 14.38 kg of milled rice per 100 kg of paddy (21.46%), which is equivalent to US$7.25 in additional income (17.77%). A significantly lower poverty rate of 26% was observed among households who adopted the GEM system. Improved production rate, nutritional value of rice and lower energy cost are the main advantages of GEM system.

POLICY BRIEFS ON CLIMATE SMART RICE INNOVATIONS

Although climate change is a serious threat to rice production affecting both yield and quality, African governments will have to take the following measures to mitigate the impact of climate change if they aspire to reach rice self-sufficiency.

1. Improve availability and farmers accessibility of smart rice varieties developed by AfricaRice by setting up a sustainable market-driven rice seed system in their respective countries. This seed system should be built around public-public, public-private, and private-private partnership contracts that are based on tangible demand and supply of different categories of seeds – breeder, foundation, and certified seeds.
2. Support private sector-led rice value chain development interventions that use climate smart agronomic and post-harvest practices in rice production. These value chain interventions should also be built around public-private and private-private partnership contracts that are based on tangible demand and supply of different rice products – quality paddy or milled rice (white or parboiled) and value-added products.
3. Setup an agricultural guarantee and de-risking fund to improve access to financial capital for the financing of tangible demand/supply contracts that include climate smart innovations.
4. In partnership with AfricaRice, government should setup a climate smart rice innovation training fund for value chain actors and students form public and private tertiary educational institutions to acquire professional and business skills in climate smart rice production, processing, and marketing.
5. Ensure that some of the revenue generated from rice importation taxes is invested in local rice production with priority given to climate smart rice production and processing.

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