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Prospect of rice development in Africa

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Abstract. Establishing sustainable food security in the midst of a natural environment that is changing on a global scale is one of the major challenges facing humanity. Particularly in tropical and subtropical regions, environmental problems such as desertification, unstable crop production due to drought, and loss of forests, as well as social unrest due to rapid population growth, are increasing. Many developing countries are located in these regions, and it is clear that urgent measures must be taken to solve these problems. Among them, the sub-Saharan region of Africa tends to have stagnant economic growth due to the economic burden of food imports to compensate for rapid population growth. We believe that we must do our utmost to build a sustainable agricultural system that utilizes limited resources in order to contribute to the development of agriculture in this harsh natural environment and economic crisis. The origin of rice cultivation in Africa dates back to 3500 years ago. Recently, the Africa Rice Center has developed interspecific hybrids, NERICAs, which are expected to contribute to food self-sufficiency in the region. The Japanese government and the Japan International Cooperation Agency have been supporting and contributing to the development of rice production in Africa. The author has been conducting various research projects on rice production with various international and domestic research institutes in the region for about 30 years. In this chapter, the history of Japan's technical cooperation for rice development in Africa and the characteristics of the rice ecosystem will be explained. The functions and problems of interspecific hybrids, which have been developed recently and are being promoted throughout Africa, are also introduced. Furthermore, the characteristics and research results regarding African rice, a genetic resource unique to Africa, will be described. Finally, the future direction of rice cultivation in Africa is proposed by introducing examples of current efforts.

Key words: Africa rice, CARD, Farming system, NERICA, TICAD

Environment surrounding rice cultivation in Africa

It is important for the international community, including Japan, to achieve sustainable economic growth and poverty reduction in Africa from a long-term perspective. It goes without saying that the development of agriculture is essential for economic development and poverty reduction in African countries, where approximately 60 to 80% of the population is engaged in agriculture. However, agricultural development in Africa is hampered by various problems such as the vulnerability of agricultural management due to poor environment and disasters, production instability due to problematic soils and low fertility, and low crop productivity due to underdeveloped cultivation technology (Fig. 1). Furthermore, as the population

Fig. 1. Small-scale paddy fields in flood-prone areas of Guinea

grows and the area of cultivable land per capita decreases, reducing poverty requires increasing cropland productivity, introducing promising crop species and varieties, and developing stable production technologies[1].

In Africa, there has been high demand for rice in recent years, and consumption has been increasing rapidly. On the other hand, the increase in rice production has not been commensurate with the significant increase in rice consumption; and imports from Asia, North America, and other regions have tended to expand year by year. The demand for rice in Africa started to increase in the 1970's; at the same time, West African countries that had formed rice-growing regions came together and established WARDA (West African Rice Development Association, now the Africa Rice Center) with the support of the Food and Agriculture Organization (FAO) and other organizations. Japan has been actively supporting WARDA's research and dissemination programs, including the improvement of rice varieties suitable for Africa, and in 2000, NERICA (New Rice for Africa) was developed for upland rice. On the other hand, since farmers in Africa still lack experience and knowledge of rice production, and the research and extension systems that support farming activities are not fully developed, the actual production of rice that meets the needs of farmers has not progressed significantly. We are still waiting for the rice production in certain areas, which is expanding slightly, to gradually spread to surrounding areas. Under these circumstances, at the fourth Tokyo International Conference on African Development (TICAD IV) held in 2008, the Japan International Cooperation Agency (JICA) announced the establishment of the Coalition for African Rice Development (CARD) as one of the Japanese government's agricultural sector partnerships with Africa. This was the beginning of Japan's full-scale support for rice cultivation.

Japan's support for rice cultivation in Africa

African countries achieved national independence one after another around 1960. At that time, the focus of agricultural research inherited from the colonial era was on large-scale farms. In the 1970s, Japan began full-scale cooperation for technology development and dissemination for the agricultural sector, mainly through JICA, in model areas in Africa where large-scale irrigated rice cultivation was possible. Specifically, through grants and grants-in-aid, JICA developed irrigated paddy fields, established technical training centers, and dispatched teams of experts to support the transfer of technology. As a result of the technical cooperation, dramatic yield improvements have been achieved in model areas such as the Moshi Rural District in Kilimanjaro in Tanzania and the Mwea District in Kenya. This rice cultivation technology introduced the transplanting production system, one of the Asian-style methods of cultivation management, and established a high-input fertilizer system. In addition, the introduction of agricultural machinery to improve work efficiency was also promoted. In the latter half of the 1980s, large-scale irrigation facilities in many areas became obsolete, and the number of government employees involved in facility management was drastically reduced under the structural adjustment policy. Subsequently, the focus of agricultural research shifted to small- and medium-scale farms. As a result, since the latter half of the 1990s, the trend of aid has changed drastically to poverty reduction and food security; thus, cooperation in small-scale irrigated rice cultivation aimed at helping poor small-scale farmers plan, construct, and manage their own rice has become common. Since 2009, the National Crop Resources Research Institute in Uganda, East Africa, has been conducting a project to promote rice cultivation and conducting training and research in a wide range of fields with the aim of expanding rice production and transferring appropriate technology.

Establishment of CARD and Japan's efforts

(1) Background of the establishment of CARD

Since the latter half of the 1990s, the consumption of rice has increased rapidly in Africa, greatly exceeding the production growth in the region, necessitating increasing imports; concurrently, consumption is predicted to grow substantially in the future. Since rice is one of the major crops consumed in Africa with high potential for production expansion in various regions, focusing on rice and mobilizing international support will highly impact development and contribute to the promotion of rural areas and the reduction of poverty as well as mitigating food problems in the medium and long terms. In light of this situation, JICA, in collaboration with the Alliance for a Green Revolution in Africa (AGRA), announced the establishment of CARD to work with rice-producing countries at TICAD IV, as mentioned above. The development goal of CARD was to double the region's rice production from 14 million tons in 2007 to 28 million tons in 10 years by 2018.

(2) CARD's approach by growing environment

At CARD, in phase 1, we tried to increase production through three main approaches: the introduction of improved varieties, improvement of cultivation techniques, and development of infrastructure. In addition, it is said that there are 20 million hectares of unused lowland wetlands

Fig. 2. Maturity of NERICA3 in Cote d'Ivoire

suitable for rice paddies in the region; and by properly developing these ecosystems, we can expect to increase production in a sustainable manner. CARD selected appropriate varieties, improved cultivation techniques, and promoted necessary inputs (facilities, fertilizers, etc.) for each type of cultivation environment. For irrigated paddy fields, the project focused on rehabilitating existing irrigation facilities and strengthening water user associations; for rainfed lowlands, the project focused on establishing and disseminating models of rice cultivation development; and for rainfed fields, the project focused on disseminating improved varieties such as NERICAs and developing low-cost cultivation methods (Fig. 2).

(3) Proposed post-CARD activity plan

At TICAD VII, held in Yokohama in 2019, a new CARD phase 2 was launched with the goal of further doubling rice production (from 28 million tons to 56 million tons) by 2030. This followed the successful completion of CARD phase 1 in 2018, which reached its goal of doubling the rice production volume in each country. CARD phase 2 has expanded the target countries from 23 to 32 and focuses on the path to doubling production through the RICE approach (Resilience, Industrialization, Competitiveness, and Empowerment) in order to enhance the competitiveness of domestic rice and to promote further collaboration with the private sector. Specifically, the keys are: improving rice quality by strengthening the value chain, improving post-harvest processing technology, and promoting the participation and utilization of the private sector; developing and propagating the use of irrigation and introducing crop rotation such as alternating field crops and horticultural crops to counter climate change; and improving livelihoods by increasing yields, profits, and nutrition. In addition, gender considerations, such as reducing the workload of women, may also be important.

Evolution and cultivation of rice

The species of rice cultivated are *Oryza sativa* L. and *O. glaberrima* Steud. The former is called Asian rice because its cultivation originated in Asia, and the latter is similarly called African rice and is thought to have evolved in different regions of Africa[2]. Various theories of the origin of rice cultivation are related to the evolution of wild rice to cultivated rice. It is also commonly said that the wild types of cultivated species are genetically *O. rufipogon* Griff. and *O. barthii* A. Chev. Sakagami et al.[3] defined the annual type as those that die within a year despite adequate growing conditions and the perennial type as those that survive longer. *O. sativa* varies from annual to perennial; the subspecies japonica has perennial characteristics, and indica was found to exhibit a wide range of characteristics from annual to perennial types. On the other hand, we conclude that *O. glaberrima* is a single-fruiting annual with none of *O. sativa's* major variations. There are many theories as to how the species evolved during this process of differentiation. For example, Vitte et al.[4] compared the genomic behavior and sequence of transposons and reported that japonica and indica may have diverged about 200,000 years ago. There are various differences in the growth of japonica and indica. As traits closely related to cultivation, indica generally tends to shatter easily, and japonica tends to shatter less easily; however, quantitative trait locus (QTL) analysis using F_2 of the japonica cultivar 'Nipponbare' and the indica cultivar 'Kasalath' detected shattering QTL on chromosomes 1, 2, 5, 11, and 12, and on the long arm of chromosome 1. The QTL detected on the long arm of chromosome 1 was reported to be the QTL with the greatest power of action[5]. In addition, archaeological analysis related to the loss of degranulation in japonica indicates that the cultivation of rice (paddy rice) occurred in the middle reaches of the Yangtze River in China about 7,000 to 10,000 years ago, and that rice (paddy rice) was introduced to Japan about 3,000 years ago[6, 7]. In general, populations that retain genetic variation have high evolutionary potential, while homogeneous populations are prone to extinction when the environment changes and are said to be in an evolutionary cul-de-sac. In the case of wild rice, the perennial type potentially contains a wide variety of mutations and rarely reproduces by seed as long as the habitat remains stable, so there is little opportunity for the release of various mutant types[8]. On the other hand, annuals are highly productive, but their genetic variation is so low that they are unlikely to be able to generate cultivars and differentiate further varieties. Therefore, it is possible that a primitive cultivar with considerable seed productivity and human-friendly characteristics will emerge from an intermediate population of both seed and vegetative propagation breeding. However, as compared to japonica, which has low genetic diversity, indica has greater diversity, i.e., it is better adapted to a variety of environments [9]. Based on these facts, it is reasonable to assume that indica and japonica have evolved in the context of different genetic variations. From this point of view, it is highly likely that indica evolved from an intermediate-type wild species in a population that varied from annual to perennial, while japonica evolved from a wild species with strong perennial characteristics. We also strongly support the theory that *O. glaberrima*, which lacks monogenetic variation, evolved from an annual wild species.

Study of the origin of rice cultivation

The geographic variation of many cultivated plants was studied, and the location with the highest diversity was assumed to be the origin of the crop, which was rice (*O. sativa*) in the southwestern Himalayas [10]. Although this theory greatly influenced subsequent researchers, it is now recognized that various factors are involved in the accumulation of variation in a particular location, and that the center of diversity is not necessarily the origin of the crop. In addition, there have been various theories of the origin of rice cultivation, from isozyme analysis of rice to theories on the origin from Assam and Yunnan [11], to the theory that the center of variation in cultivated rice is in the region including Myanmar and Laos [12]. In any case, the original site of rice cultivation must have had wild rice in the past, and the ecological and genetic conditions necessary for the differentiation of primitive cultivation types must have been present. In order to approach the origin of crops that have evolved in close association with humans, it is essential to study not only biology but also various other fields and integrate them. In addition, the growth of rice is not only influenced by genes, but also by the environment, the so-called gene–environment (GxE) interaction, which may affect the expansion of rice cultivation. In these areas, a large number of QTLs obtained by interspecific hybridization and natural hybridization between wild and cultivated species have been identified [13]. This suggests that some aspects of rice evolution may have undergone a complex process. In Asia, it was commonly believed that rice (*O. sativa*) originated from Assam in India and Yunnan in China [11]. The genomes of 1083 cultivated rice cultivars of *O. sativa* and 446 wild rice lines of *O. rufipogon* collected from various parts of the world have been sequenced to create a comprehensive genome variation map. In addition, indica evolved from crosses between japonica and wild rice lines in Southeast Asia and South Asia [14]. Huang's study was an extremely valuable achievement, demonstrating the theory that rice cultivation originated in South or Southeast Asia [2] using genome analysis, an advanced modern technology. On the other hand, *O. glaberrima*, which evolved in Africa, has never been the subject of modern breeding, and in recent years it has been replaced by common rice, *O. sativa* originating from Asia. Its cultivation area is decreasing [15], and its genetic diversity and geographical conditions suggest that it originated in the Niger River inland delta region of present-day Mali.

In summary, based on the physiological, morphological, and genetic background of the different rice species, it seems that *O. sativa* evolved from the wild species *O. rufipogon* with annual to perennial variation, and the process of evolution is similar to that described by Huang et al. [14], where the subspecies *O. sativa* evolved from the wild species *O. rufipogon* in the middle reaches of the Pearl River in China. This was followed by crosses between *O. rufipogon* and japonica in Southeast Asia and South Asia, which resulted in the annual to perennial variation in indica. This allows us to explain the differentiation of the subspecies using ecological characteristics. On the other hand, the lack of subspecies differentiation in the monocarpic annual *O. glaberrima* and the very small genetic variation as compared to *O. sativa* suggest that it evolved from the wild annual *O. barthii* found in Africa. Since *O. glaberrima* exhibits high flooding resistance [15], this strongly supports the theory that it originated in the inland delta of the Niger River, a flood-prone region.

The beginning of rice cultivation in Africa

The history of rice cultivation in Africa dates back approximately 3,500 years. At that time, rice native to Africa was cultivated (Fig. 3). It is thought that the beginning of its cultivation was in the wetlands of the upper reaches of the Niger River [16]. Even today, more than 130

Fig. 3. Harvest of African rice in an inundation area of Mali

varieties of African rice are known to have been planted in the widespread river delta region, which is a treasure trove of genetic resources [17]. About 500 years after its cultivation in the Niger River Delta, rice cultivation began in the western Gulf of Guinea region (present-day Senegal, Gambia, Guinea-Bissau, Sierra Leone, Guinea, and Cote d'Ivoire) [18]. It is unclear when rice cultivation began in earnest in African countries, but it was probably after 1500, when Asian rice was introduced to the African continent. When rice was first cultivated in Africa, it was mainly grown by direct seeding, but by the time Asian rice was introduced, some areas had already established row cropping and transplanting techniques [18]. Today, although some areas have been mechanized and modern materials such as pesticides and fertilizers have been applied, most farmers in Africa are still engaged in rough rice cultivation, and their cultivation techniques are extremely immature compared to those in Asia.

Fig. 4. Plant of African rice mixed with paddy fields in Guinea

Characteristics of African rice

(1) Morphological, physiological, and ecological characteristics

African rice is one of the cultivated species of the rice genus, as mentioned above, and is mainly cultivated in West Africa. During 30 years of research on rice cultivation in Africa, the author has confirmed the cultivation of African rice in farmer's fields in Niger, Mali, Guinea, Senegal, Sierra Leone, Ghana, Burkina Faso, and Benin. African rice is known to be tolerant of environmental stresses and is adapted to the unique natural environment of Africa. In the past, African rice was divided into deep-water and upland rice types; but in recent years, it has become clear that these traits show continuous variation and are not clearly dichotomized [19]. However, it is clear that the morphological, ecological, and physiological characteristics of African and Asian rice are markedly different when compared. Morphologically, African rice generally has a variation in brown rice color from light to dark red, with fewer bristles on the surface of the paddy and more often a well-developed glume. The surface of the leaf blade also has few hairs, as the species name—glabrous—implies. The leaf ligule of the Asian rice plant is sharp and pointed, while that of its African counterpart is rounded and small, an indicator that distinguishes the two. Another characteristic of African rice is that there are fewer secondary rachis on the panicle than on Asian rice (Fig. 4). On the other hand, ecologically, African rice is a monocarpic annual; this is ecologically different from Asian rice, which can vary from annual to perennial [3]. It also has a relatively low number of tillers, but it has vigorous initial growth. African rice has an extremely high shattering habit, which is one reason for its low yield. Physiologically, the rate of carbohydrate translocation to the panicle after heading rice is higher in African than in Asian rice, resulting in a shorter ripening period [20]. This growth trait is unique to annual rice and may be advantageous for drought avoidance in poor environments in Africa. With regard to drought resistance, there have been reports that African rice has a higher capacity to recover after drought than Asian rice. It is also characterized by extremely high internode and leaf elongation under flooded conditions and by its ability to avoid high-temperatures damage to flowers during the day, such as by early morning flowering [21]. Furthermore, it is highly resistant to African gall midge and rice yellow mottle virus (RYMV) [22]. Although there have been few reports on the difference in yield between African and Asian rice using experimental methods, African rice is generally considered to have low fertilizer responsiveness and low yield. This is because of its high degranulation during the ripening stage, which results in yield losses [23]. African rice is a cultivated rice, but it seems to show some wild characteristics as well. This may be related to the fact that African rice has been selected less frequently by humans than Asian rice in the history of rice cultivation.

(2) Characteristics of grain quality

From a grain quality analysis of a total of 27 African and Asian rice varieties (8 Asian and 19 African) collected in West Africa (Guinea, Mali, Niger, and Senegal), two Mali varieties were found to have particularly high white rice protein content in African rice [17]. Both of these are grown in the inland delta of the Niger River. On the other hand, no significant differences in amylose content and amylopectin short-chain ratio, which are representative of starch characteristics, were observed between African and Asian rice varieties. The high amylose and a low amylopectin short-chain ratio (L-type) characteristics of the African rice are often seen in indica varieties of Asian rice. It is known that rice with these characteristics generally has a hard texture and is not sticky, both in cooked and cold rice. Therefore, it was thought that the texture of hard rice based on a high amylose and a low amylopectin short-chain ratio would suit the tastes of consumers who prefer African rice. In the future, it is important to refer to the preferences of local consumers when improving African rice for local use.

Rice-harvested area, yield, and production in Africa and Asia

Figure 5-1 shows the harvested area of rice in Africa and Asia from 1961 to 2020. From 1961 to 2020, the harvested area in Africa increased by a factor of 6.2 and in Asia by a factor of 1.3. Also, in 1961, the rice-harvested area of Asia was 39 times that of Africa, but in 2020, the rice-harvested area of Africa decreased by 8.2 times to Asia. During this period, Africa's production increased by about 1,400 hectares and Asia's increased by about 3,300 hectares.

In 1961, rice yields were about 1.6 t/ha in Africa and 1.9 t/ha in Asia, but in 2020, rice yields in Africa increased 1.4 times to 2.2 t/ha and in Asia increased 2.6 times to 4.8 t/ha (Fig. 5-2). Rice yields in Asia increased from 1.2 times those in Africa in 1961 to 2.2 times those in Africa in 2020.

In 2020, Africa produced about 38 million tons of rice, while Asia produced about 680 million tons (Fig. 5-3). This represents an 8.8-fold increase in Africa and a 3.4-fold increase in Asia from 1981 to 2020. Meanwhile, the difference in rice production between Africa and Asia increased from 190 million tons in 1961 to 640 million tons in 2020.

From the changes in each parameter, it can be inferred that rice production in Africa progressed, since the rate of increase in rice production during this period was 3.4 times that of Asia, while it was 8.8 times that of Africa Thus, although the rate of production growth is high in Africa, its production is still very low compared to Asia today. This is related to the expansion of cultivated areas. On the other hand, the level of rice yield in Africa has remained stagnant, and therefore, in order to improve rice production in the future, it will be necessary to increase cultivation area and yield as well.

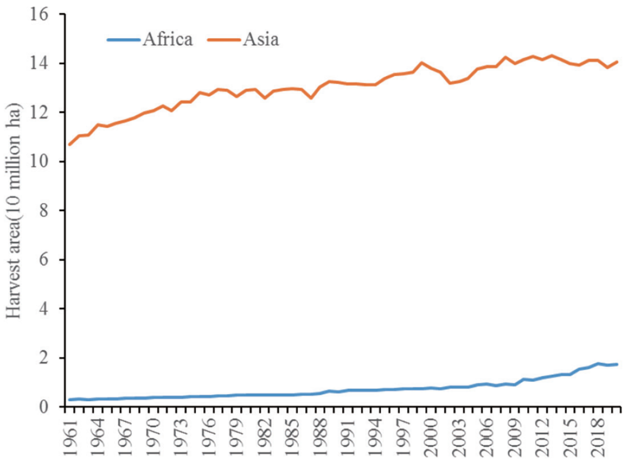

Fig. 5-1. Change in rice harvested area

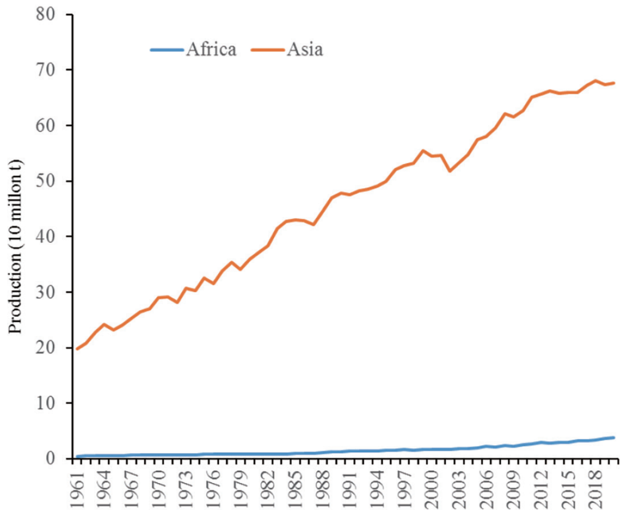

Fig. 5-2. Change in rice yields

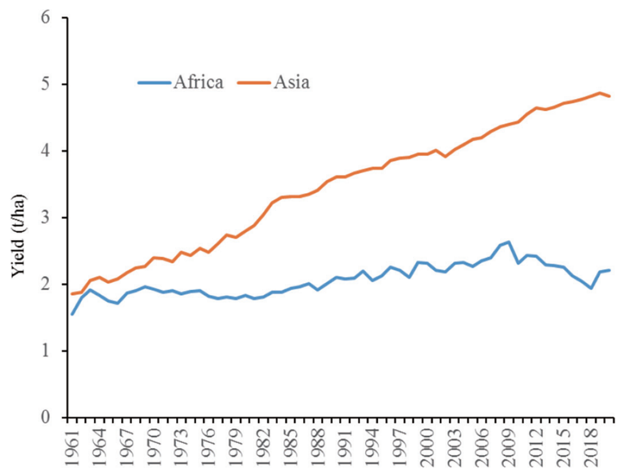

Fig. 5-3. Change in rice production (Data from FAO)

Classification of rice farming systems and issues in Africa

The agricultural systems in Africa can be broadly classified into wetland-adapted agriculture and dryland-adapted agriculture based on differences in the water environment. The former type is found in the Guinea-Sudan savannah climatic zone where there is abundant annual rainfall or in rice paddies where sufficient moisture is available for crop growth during the cropping season; the latter type is found in irrigated land in the Sahel region where rainfall is limited or in fields that depend solely on rainwater and not on groundwater for moisture. Rice is cultivated in paddy fields that are blessed with relatively good moisture conditions and is classified into two types: irrigated rice using river water or reservoirs, and rainfed rice. There are also deep-water rice and floating rice. Land-based rice is generally grown on highlands and slopes and requires sufficient rainfall during the growing period, which limits the growing area.

In West Africa, especially in the Sahel region, agriculture is facing many difficulties due to the harsh natural environment and the economic crisis. In the future, it will be particularly important to establish a low-input, recycling-oriented agricultural system that utilizes limited resources. The challenge of maintaining stable yields must be addressed now.

Rainfed lowland rice cultivation

Rainfed lowland rice accounts for about 52% of all rice cultivation in Africa (2011). Irrigated rice fields account for 16%, and rainfed rice fields 36%. In Asia, irrigated rice fields account for 59% of the total area of rice cultivation, while in Africa, rainfed rice fields are the main form of cultivation (Fig. 6). The average yield of rainfed rice in West Africa is 1.4 t/ha (2011). Asian rice is grown in most of the rainfed paddy fields, but African rice may be grown in some cases, depending on water conditions. The paddy fields are small in size, with a simple ridge or no ridge between rice fields, depending on the topography. The paddy fields in the inland lowlands are fed by runoff from valleys, groundwater, and rainfall. In recent years, an increasing number of regions have adopted Asian-style transplanting cultivation techniques; however, in some regions, direct seeding cultivation is being reevaluated for cost reduction. In this form of cultivation, it is often reported that rice plants suffer from drought damage due to a shortage of water during the late stage of growth. Therefore, in some areas, early maturing varieties with a short growing season have been introduced, but these varieties often have low yields due to insufficient vegetative growth. In such areas, rice varieties with different growing periods are grown in the same area to avoid risk as an insurance crop.

Upland rice cultivation

Upland rice is rice cultivated on flat land or on arable land slopes that are generally not flooded throughout the crop season but rely only on rainwater. It may also be grown on mountain slopes or around wet forests (slash and burn). In both cases, yields are low at 1 t/ha (Fig. 7). In addition to the monoculture of upland rice, maize is intercropped in Guinea, Niger, and Nigeria. In recent years, the introduction of early maturing NERICA rice varieties has been promoted, but the loss of genetic resources such as local indigenous varieties has become a problem. Because of the dependence of upland rice on rainfall, the areas suitable for cultivation are limited. However, unstable rainfall patterns contribute to the problem of water shortage, and adequate measures against water shortage are necessary to

Fig. 6. Rice growth in rainfed paddy fields in Guinea

Fig. 7. Seedling emergence in upland in Cameroon

increase yields. In addition, weed control and maintenance of soil fertility are the major production-limiting factors in cultivation. On the other hand, upland rice areas have some cultivation advantages, such as the availability of solar radiation and temperatures sufficient for healthy rice growth. Cultivation is carried out by direct sowing. There is a method of spreading the seed after plowing with a tractor and then harrowing with the tractor over it. This is intended to avoid bird and drought damage by mixing the sown seeds with the soil. However, in many cases, the soil is not sufficiently leveled, and differences in germination and emergence conditions occur in the field due to differences in soil moisture conditions. There is a wide variety of upland rice varieties, but in general, their panicle weight and number of tillers are lower than those of lowland rice. Drought is a general problem in Africa. Therefore, varieties that are drought tolerant or avoidant are needed. NERICA varieties of upland rice are characterized by a relatively early growth period of 90–110 days in general, of which NERICA4 is said to be drought tolerant. In terms of improving weed-competitive ability, some African rice varieties have excellent foliar development in the early stage of growth.

Irrigated lowland rice cultivation

Rice cultivation in irrigated paddy fields requires that fields be divided into sections by ridges and that water management can be carried out freely (Fig. 8). Large-scale irrigated paddy fields in Africa do not differ greatly from those in Japan, but in most areas, rice is grown by transplanting by hand. When irrigation water is available and the pumping of water from rivers is possible, there are two cropping seasons—wet and dry. In the dry season, atmospheric humidity decreases and water consumption through evapotranspiration increases; therefore, yields are usually higher than in the wet season due to sufficient solar radiation. For example, in the paddy fields of the Niger River Basin, irrigated rice cultivation using large-pump water intake has been widely practiced since the 1960s, and irrigation canals (0.3 to 2 m wide) have been constructed in paddy fields of 0.25 ha per plot. The average yield is over 4 t/ha. In particular, irrigated lowland rice areas are spreading along rivers in Mali, Niger, and Nigeria, and these areas have organized water user associations to contribute to large-scale rice cultivation. The varieties planted in the irrigated paddy fields are diverse, but in general, they are modern varieties of semi-dwarf Asian rice. They are often introduced mainly by the IRRI (International Rice Research Institute), IITA (International Institute of Tropical Agriculture), and Africa Rice Center. In some cases, such as in Guinea, the National Research Institutes have developed varieties through their own breeding programs. Irrigated rice fields in West Africa are often found in rivers and coastal terrain in the Sahel region, making them susceptible to salt damage and iron toxicity. For this reason, salt-tolerant varieties are being introduced. In the coastal mangrove areas of Guinea, seawater is pumped in and out of the paddy fields during the dry season by opening and closing the gates of the flume to reduce the salinity of the paddy soil, thereby making rice cultivation possible. Among the irrigated rice NERICAs, some high-yielding and flood-tolerant lines have been identified in the WAS (West Africa St-Louis) series grown at the Sahel branch of the Africa Rice Center in Saint-Louis, Senegal[24).

Deep-water rice cultivation

Deep-water rice cultivation is practiced in paddy fields where the water table remains at 0.5 to 1 meter for most of the growing period (Fig. 9). The morphological and physiological differences between floating rice and

Fig. 8. Rice growth in irrigated paddy field in Guinea

Fig. 9. Rice growth in a deep-water field in Niger

deep-water rice are ambiguous, because floating rice is also adapted to deep-water areas and is often treated as deep-water rice. In addition, short-stemmed, high-yielding varieties with the added elongation ability of floating rice, which can elongate internodes like floating rice when the rice is flooded, are sometimes referred to as deep-water rice. In Africa, the deep-water rice crop, like the floating rice crop, is a mixture of African and Asian rice. The area under deep-water rice cultivation in Africa is thought to be about 10% of the total area of rice cultivation in Africa. Deep-water rice is generally vigorous in its early stages, and even when the water table is not rising due to flooding, the plants can grow to nearly 2 m in height[25] In Guinea, deep-water cultivation is relatively popular, with water depths rising by up to 1 m, and some rice plants growing more than 2 m in response. Deep-water rice has a relatively long leaf blade, which allows it to avoid flooding and maintain an aerobic metabolism by expanding its leaves above the water surface. Deep-water-tolerant varieties in Africa have been shown to have higher above-ground elongation during flooding and higher net assimilation rates in leaf blades above the water surface[17]. Such above-ground-elongating varieties may be prone to collapse after water withdrawal, so resistance to collapse is important[26]. In deep-water areas of Africa, large seedlings with long grasses are often transplanted to avoid the risk of flooding during early growth. However, in this case, late transplanting often suppresses the increase in the number of shoots. In the deep-water areas of the coastal regions of Guinea, thick-stemmed indigenous rice varieties are often grown, and modern improved semi-dwarf rice varieties are rarely planted.

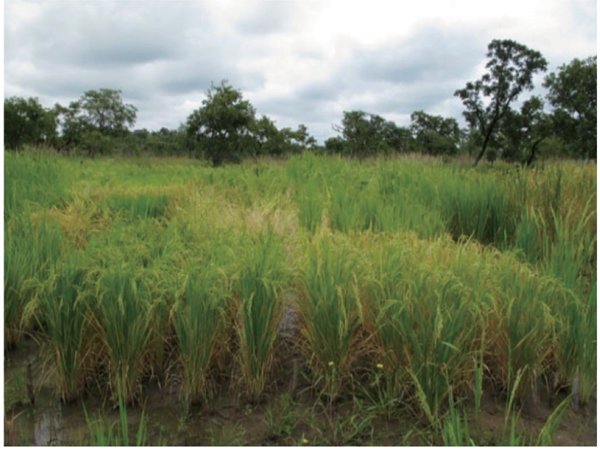

Fig. 10. Interspecific progeny cross between *O. sativa* and *O. glaberrima* in Senegal

The challenge of selecting NERICA rice

(1) Upland NERICA

In 1992, 1130 lines of African rice were evaluated for characteristics related to short growing season, good early growth, and vigorous cropping; 8 lines were selected for crossbreeding at the African Rice Center[27]. Among the resistance traits, they focused on weed competition, trying to produce a rice plant with both the morphology of African rice with horizontally expanding leaves for early vegetative growth and the morphology of Asian rice with high-yielding plants with an excellent light-receiving system in the canopy for reproductive growth. Furthermore, the breeding objective was to shorten the growing season for drought avoidance as well. Interspecific hybridization was started in 1992. As a result, promising lines were obtained from the WAB450 population that showed seed fertility in later generations. The parent variety WAB56-104 is a japonica of Asian rice, and CG 14 is an African rice collected in the Casamance region of Senegal[28]. Several hybrid lines were backcrossed, and promising populations were selected from them (Fig. 10). In the first year, each farmer participated in evaluating the lines. Farmers visited the demonstration plots three different times during the growing season at the active tillering, heading, and harvesting stages and evaluated the lines regarding each of the survey items. In the second and third years, farmers took several lines of their choice to their own farms, cultivated them, and evaluated them. Seven varieties of upland rice (NERICAs 1–7) were disseminated in 2000 and 11 varieties (NERICAs 8–18) in 2005. To date, the results of the pilot studies have revealed several characteristics of NERICA varieties that are so-called high-yielding rice varieties with good fertilizer tolerance and high inputs that translate into higher yields. In addition, as mentioned earlier, these varieties are characterized as early maturing varieties with a growing period of about 90–110 days. On the other hand, the weed-reduction effect is smaller than that of the African rice parent, and, in terms of drought resistance, avoidance due to deep rooting differs among varieties and is not sufficient. At the Africa Rice Center, the number of rice grains per panicle was estimated to be 300–400, but it is unlikely that the number of rice grains obtained can be replicated in the fields of actual farmers. Since it is extremely difficult for African farmers, who generally use low inputs, to obtain sufficient fertilizer for high yields, it is not easy to utilize the growth characteristics of NERICA varieties to achieve high yields for current farmers, except those with fertile soil or who continuously apply a certain amount of chemical fertilizer.

(2) Lowland NERICA

Since 2000, when NERICAs became incentive

Fig. 11. Growth of lowland type NERICA in Senegal

varieties, attention has been focused on the development of rainfed paddy fields in lowland areas with high yield potential in order to further increase yields. Since there are few promising varieties in rainfed lowland fields in Africa in general, the breeding of new varieties was expected. The first objective of breeding rice NERICAs for lowlands was to develop resistance to RYMV, a disease that is unique to paddy fields and for which there were no effective mitigation measures. Crosses were carried out at the Africa Rice Center, mainly at the Sahel Branch (Fig. 11). Asian rice indica type IR64 and African rice TOG5681 were used as crosses. TOG5681 was selected as the parental line for this cross because of its resistance to iron toxicity[29] and RYMV. After two to four backcrosses with the Asian rice parent, selection continued in Burkina Faso, Mali, and Togo, in addition to Saint-Louis, for genetic fixation of the lines. In the selection of lowland rice NERICAs, farmer-participatory methods were used in the same way as for upland rice: 60 varieties were produced in 2005, and their yield potential of 6–7 t/ha effectively reduces major environmental stresses in paddy fields[27]. In 2006, NERICA-L19 was registered in Cameroon; NERICA-L39 and 49 in Niger; NERICA-L19 and 20 in Sierra Leone; NERICA-L19, 34, and 42 in Togo; and NERICA-L19, 41, and 60 in Burkina Faso. In 2006, NERICA-L39 and 49 were registered in Niger, and NERICA-L19 and 20 were registered in Sierra Leone. In Gambia, WAS161-B-9-2, WAS122-IDSA-15-WAS-6-1, and WAS127-B-5-2 were registered as varieties. Later, the variety was further promoted in East African countries.

Future prospects

We are already aware of the impact of climate change on food production. The Sixth Report of the Intergovernmental Panel on Climate Change (2021) warned that global warming will proceed faster than previously assumed and that all regions will face increasing changes. It proposed that "climate-resilient development" is a key phrase in combating global warming, and it predicted that climate change will severely and negatively affect rainfed agriculture in Africa. In rainfed agriculture, farmers have to cope with year-to-year changes in weather even under the current weather conditions; however, climate change in Africa as part of global environmental change will make it even more difficult for farmers to cope.

Rice cultivation is an agricultural practice that developed in Asia and has been established in regions that take advantage of abundant precipitation. In Africa, rice cultivation is vulnerable to climate change, and more-detailed measures are needed. In this respect, the promotion of rice cultivation in Africa needs to be considered differently from that in Asia. It is an important challenge for the international community to achieve sustainable economic growth and poverty reduction in Africa from a long-term perspective. It goes without saying that the development of agriculture is essential for economic development and poverty reduction in Africa, where about 60 to 80% of the population is engaged in agriculture. However, African agriculture is hampered by various problems, such as the vulnerability of agricultural management due to disasters and other unfavorable environments, production instability due to problematic soils and low fertility, and coarse productivity due to underdeveloped cultivation techniques. Furthermore, as the population increases and the area of cultivable land per capita decreases, it is necessary to increase the land productivity of crops, introduce promising crop species and varieties, and develop stable production technologies in order to reduce poverty; however, it is difficult to say that these goals are being achieved presently. On the other hand, tropical Asian countries overcame a rapid increase in population and decrease in cultivable land per capita in the 1960s and increased food production through the "Green Revolution." During Asia's Green Revolution, the productivity of rice increased dramatically due to the spread of high-yielding varieties, the use of chemical fertilizers, the installation of irrigation facilities, and the promotion of mechanization. As a result, urbanites and chemical companies were enriched, but small-scale farmers did not benefit sufficiently, according to some reports; however, there is no doubt that technological innovations dramatically increased yields. In Africa, the Africa Rice Center and the International Agricultural Research Organization have developed a high-yielding interspecific hybrid variety of NERICA, which has been called a miracle rice. This has contributed greatly to the increased rice production in Africa. However, rice production in the region has not been able to keep up with the increase in consumption; as a result, imports from other regions have increased to meet consumption, worsening the region's economy. This section explores reasons the Green Revolution of tropical Asia has not been successful in Africa.

It is important to recognize that Africa is a different continent from Asia. The main differences between Asia and Africa are the natural environment, population density, educational level, religion, acceptance of foreign cultures, and infrastructure. In the agricultural sector, soil fertility is generally lower in Africa than in Asia, which is a major hindrance to improving crop productivity. In Africa, rice cultivation is more susceptible to droughts and other adverse environmental conditions. For example, Africa has a higher percentage of upland rice cultivation than Asia. This is due to the fact that African agriculture has been influenced by European agriculture, which has developed mainly through fields or upland crops in the past. In addition, Asian agriculture is relatively precise, while African agriculture is characterized by coarseness and generally low yields. The stagnation of African agriculture compared to that of Asia is due to a variety of factors, including the natural environment as well as the social and political background. On the other hand, there are various agricultural technologies and traditional methods in Africa that are not seen in Asia, and since crops are cultivated according to the local conditions, it is possible to make the best use of the agricultural environment and genetic resources of each region. Therefore, it is desirable to develop rural areas and agriculture that are suitable for the agricultural environment of each region.

As mentioned above, the majority of people in Africa are engaged in agriculture, and agriculture accounts for a large proportion of income and GDP of the country. This is why it is necessary to focus on poverty reduction in rural areas in order to achieve economic development. This requires support for agricultural and rural development to improve agricultural productivity, increase agricultural income, and improve living conditions. The African region contains about 25% of the world's arable land but produces only about 10% of the world's food. In addition, it has about 60% of the world's uncultivated arable land. From this point of view, Africa's agricultural development potential is high. In West Africa, about 20 million hectares of unused lowland wetlands have potential for rice cultivation[30)]. In particular, in the delta region of the Niger River, African rice, which is endemic to Africa, is grown, and traditional farming methods are practiced. These methods are characterized by the use of chemical-free fertilizers and pesticide-free cultivation management; since rice plants exhibit floating rice characteristics that allow them to grow in response to changes in the water table, we can conclude that they are a cyclical agriculture crop suitable for poor environments with extremely high flood avoidance[17)].

In the 1960s, African countries achieved national independence one after another, and at that time, agricultural research inherited from the colonial era focused on large-scale farms. However, with the subsequent deterioration of the domestic economy and structural adjustments, the budget for agricultural research and development was drastically reduced, and the previous momentum of research and development was lost. For example, in Kenya, the leader of East African countries, 12% of the government budget was used for agricultural research and development in 1965, but since 1990, only 3% of the budget has been used for this purpose. In addition, research and extension organizations now face a serious shortage of human resources and equipment. On the other hand, the numbers of agricultural research institutes and their researchers in African countries are relatively high. This is due to the fact that each country or region has its own agricultural research institute. It is not an exaggeration to say that African agricultural production today is mostly by small-scale farms, although there are differences among regions. From this point of view, it is necessary to promote research and development according to the type of management. In the future, it is necessary to improve the quality of research in Africa's agricultural research institutes by promoting human resource development and to achieve synergy of research results by sharing research among related institutes in neighboring countries. On the other hand, it is extremely important to establish a dissemination system that enables sufficient technological transfer of research results with close cooperation between the research and extension departments.

In order to realize an African version of the Green Revolution, it is important to establish a sustainable and stable technological system, not only from the agronomic perspective of improving yields. Therefore, it is necessary to identify suitable crop species and varieties as well as production technologies that can stably improve yields under various unfavorable environmental conditions in the African region. In addition, it is important to expand the area available for cultivation. On the other hand, in the African version of the Green Revolution, it is important to develop and introduce high-value-added crops with high protein and minerals to supply the nutrients necessary for human life, rather than just increase production through conventional yield and area expansion. This new idea will contribute to the development of high-value-added farming methods that make effective use of limited arable land. In addition, we must (1) establish a production technology system that is resistant to unfavorable environments, (2) develop generally adaptable crops and varieties that can maintain stable yields, (3) develop and introduce high-value-added crops, (4) develop human resources who can lead research, and (5) build a feedback system for research results.

Summary

Will Africa follow Asia in a Green Revolution in rice production? To develop African agriculture and rural areas, which are still vulnerable despite medium- and long-term technical cooperation and economic support from international partners including Japan, it will be necessary to enhance the suitability of progressive agricultural technologies developed in Asia for Africa. However, the current hurdles are high, and it is not easy for African agriculture, which is based on conditions different from those in Asia, to develop dramatically in a short period of time. On the other hand, Africa has valuable plant genetic resources and agricultural inputs that are not available in Asia, so it may be possible to develop them independently. At the TICAD VI held in Kenya on August 27–28, 2016, the Nairobi Implementation Plan was formulated. The plan emphasizes the development of agricultural researchers and capacity building for women and youth. In order to promote Africa's version of the Green Revolution, it is first necessary to develop excellent human resources. This is because the future and direction of Africa are largely in the hands of the African people themselves.

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