Performance of a Number of NERICA Cultivars in Zanzibar, Tanzania: Yield, Yield Components and Grain Quality

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Abstract: The cultivars of NERICA (New Rice for Africa), which are characterized by early maturity and high yield potential under rainfed conditions, have the potential to increase rice production in Tanzania, where rice cultivation is greatly affected by a short rainy season. Trials were conducted in Zanzibar to examine the yield performances of 14 NERICA cultivars at five locations during the long-rains season (Masika) and at another five locations during the short-rains season (Vuli). The NERICA cultivars produced significantly higher yields than local cultivars at five locations. Yields of 12 NERICA cultivars were associated with rainfall ($R^2 = 0.367$ to 0.732) such that they yielded well during Masika (109 to 343 g m$^{-2}$) and poorly during Vuli (11 to 68 g m$^{-2}$). Spikelet number per panicle and percentage of filled spikelets (% filled spikelets) accounted for 70 to 90% of the yield variation in all cultivars, suggesting that yield was determined mainly during the later part of the growth period. In some cultivars, yield was associated with rainfall during the later part of the growth period but the yield of the remainder was associated with rainfall during the early part. A selected group of farmers, extension workers and researchers evaluated grain quality. Some cultivars scored well, especially NERICA 1. We conclude that NERICAs are generally suitable for production during Masika and that NERICA 1 especially should be promoted due to its high grain quality. However, for double cropping of NERICAs, measures must be implemented for increasing or maintaining the water status of the soil during Vuli.

Key words: Early maturing variety, Multi-location trial, Palatability test, Rainfed rice, Upland rice.

Tanzania has a long history of rice (\textit{Oryza sativa} L.) cultivation as the species is thought to have been brought to the coastal area of Zanzibar and Kilwa by sea traders about 2000 yr ago (Carpenter, 1978; Lu and Chang, 1980). In the recent 2010/2011 cropping season, Tanzania produced approximately 1.4 million tons of paddy, ranking fifth in sub-Saharan Africa after Nigeria, Madagascar, Mali and Guinea (USDA, 2011). However, since the demand for rice usually exceeds production in Tanzania, the domestic supply must be supplemented by import (USDA, 2011). In the last decade, Tanzania has imported a total of 1.3 million tons of milled rice to meet its domestic consumption. This production deficit is expected to increase over the next decade due to rapid urbanization and a shift in consumer preference from the traditional staples to rice (Senda, 1999; MAFC, 2009). Thus, the country must increase rice production not only for food security but also to conserve foreign-exchange.

In Tanzania, only a small number of rice fields are irrigated (in the literature the proportion varies from 6 to 30%) and the remainder are rainfed (Kanyeka et al., 1995; MAFC, 2009). The rainfall in Tanzania is characterized as bimodal and unimodal. Bimodal rainfall includes the long-rains season from March to May (3 mo) and the short-rains season from October to December (3 mo) and the unimodal rainfall has just the long-rains season from December to April (5 mo). Rainfed rice is usually grown during the long-rains season in each system. While irrigated fields attain relatively high yields of around 2.1 t ha$^{-1}$, yields of rainfed fields can fall as low as 1 t ha$^{-1}$ in the lowlands and 0.5 t ha$^{-1}$ in the uplands (MAFC, 2009). Thus, an expansion of irrigated production would be the most effective way to increase rice production (MoWI, 2009). However, a lack of finance and of institutional capacity limits this option. In addition, competition for water resources within agriculture (Rajabu et al., 2007) and also
between different industries and the domestic sector (Kadigi et al., 2004; Mwakalila, 2005; Kadigi et al., 2008) is becoming an increasingly serious issue. Therefore, finding ways to increase rainfed rice production is regarded as critically important (Meertens et al., 1999; Young et al., 2002; Mdemu et al., 2004; Hatibu et al., 2006; Raes et al., 2007).

One of the major constraints to rainfed rice production in Tanzania is the range of rice cultivars available. Most producers of rainfed rice grow late-maturing cultivars that can be harvested in 130 – 160 d. For instance, the lowland, rainfed cultivars Supa India and Kilombero are popular among consumers and mature in 140 – 160 d, while the upland cultivars Mulimani and Salama mature in 130 – 140 d (FAO, 2002). Due to the long growth period, the local cultivars often experience terminal drought, and this causes major reduction in yield. Therefore, the introduction of early-maturing rice cultivars that can satisfactorily complete their growth cycles under rainfed conditions should greatly increase production.

The NERICA (New Rice for Africa) cultivars are interspecific hybrids between *Oryza sativa* and *Oryza glaberrima* developed by the Africa Rice Center (Jones et al., 1997a, 1997b; Balasubramanian et al., 2007). These are well adapted to rainfed conditions with potential yields of 4 – 7 t ha\(^{-1}\) (AfricaRice, 2008). Relatively high yields have been recorded under a wide range of climatic conditions such as 2.5 t ha\(^{-1}\) in Benin (Saito et al., 2010), 2.8 – 4.3 t ha\(^{-1}\) in Nigeria (Kamara et al., 2010) and 2.0 – 3.3 t ha\(^{-1}\) in Uganda (Kijima et al., 2008; Kijima et al., 2010). Importantly, the cultivars achieve their high yields by maturing within 90 – 100 d (Balasubramanian et al., 2007; AfricaRice, 2008). Due to their early maturation, combined with their high yield potentials, they are expected to help increase rainfed rice production not only in Tanzania but also in other parts of Africa (Nwanze et al., 2006; Balasubramanian et al., 2007).

In the present study, a series of field trials was conducted in Zanzibar to examine if some of the NERICA cultivars could demonstrate high yields under rainfed conditions in Tanzanian. Zanzibar is an archipelago lying approximately 35 km off the coast of mainland Tanzania. The two, large islands Unguja and Pemba, make up the greater part of the total land area of Zanzibar (2,643 km\(^2\)) and it is here that most of the rice is grown. The climate is typical of the humid tropics and is greatly affected by the trade winds of the tropical monsoon system. While the temperature remains high and relatively constant throughout the year, the rainfall varies with the season with the long-rains season known locally as “Masika” falling from March to June and the short-rains season known as “Vuli” from October to December (Fig. 1). The topography is characterized by three principle landscapes; undulating and elevated, flat valley basins and coral rag. These contribute to marked changes in the rainfall pattern even over quite short distances. The seasonal and spatial variability of rainfall provides a good venue for multi-location trials that examine plant responses to the varied water availability. In addition, Zanzibar has a large number of weather stations for its area because of the semi-autonomy, making available relatively high resolution rainfall data.

First, the NERICA cultivars were subjected to varied rainfall patterns by being grown at different locations in Zanzibar during Masika and Vuli of the 2008/2009 cropping season. Effects of cultivar, location and their interaction on yield and yield components were analyzed and the relative importance of each yield component was determined. Thereafter, contribution of rainfall to yield variability was analyzed using rainfall data recorded at weather stations close to each trial site. The possibility of double-cropping the NERICA cultivars during both Masika and Vuli was also investigated. Second, a grain-quality test
was carried out to compare the NERICA cultivars with some of the popular rice products available in local markets.

**Materials and Methods**

1. **Multi-location trials**

   The trials were conducted at five locations (Kizimbani, Upenja, Cheju, Matanga twani and Msaani) during Masika, from March 2008 to July 2008 and at five locations (Migombani, Mahonda, Koani, Ole and Weni) during Vuli, from October 2008 to January 2009. Details of season, agro-ecology, previous cropping and soil characteristics at each location are presented in Table 1. Soil taxonomy was determined by referring to Calton et al. (1955) and Hettige (1990) while soil texture was determined by the hydrometer method and their textural classes according to the FAO classification. Soil pH and EC were measured using a pH/EC meter. Total-N and P<sub>2</sub>O<sub>5</sub> were determined using the Kjeldahl method and the Bray-1 method, respectively. K<sub>2</sub>O and CEC were determined using ammonium acetate extraction.

   The upland fields in Kizimbani, Matanga twani, Migombani, Mahonda, Koani, Ole and Weni had previously been planted with maize, cassava or rice, while the lowland fields in Upenja, Cheju and Msaani had previously been planted with rice. All fields were unirrigated (i.e., rainfed). The deep, red, ferralsols in Kizimbani, Migombani and Koani are highly-weathered, infertile but very well-draining. The hydromorphic, clay loam, gleysols in Upenja have a permanently-high water table and a peaty top soil. The sandy clay, vertisols in Cheju contain a high proportion of swelling clays and are waterlogged during the rainy seasons but shrink to form deep, wide cracks when they dry out. The light-colored planosols in Matanga twani and Ole have a coarse surface horizon overlying a dense, low-permeability subsoil which results in water-logging during the rainy seasons. The cambisols in Msaani and Weni have an incipient subsurface soil formation. The acrisols in Mahonda are heavily weathered and acid with low base saturation.

Fourteen NERICA cultivars (NERICA 1 – 14) were subjected to trials. As a reference, three local cultivars: BKN SUPA (a lowland rice cultivar developed in a FAO supported irrigation project in Zanzibar and popularly grown in Unguja island and the highest-ranked brand in Zanzibar markets), TOX (a lowland rice cultivar introduced by the International Rice Research Institute in 1980s and popularly grown in Pemba island) and TXD220 (a lowland rice cultivar developed locally in mainland Tanzania and accepted by farmers in Zanzibar after 1999) were also used, but each trial received one or two of the three cultivars depending on their local popularity; Kizimbani (BKN SUPA), Upenja (BKN SUPA), Cheju (BKN SUPA), Matanga twani (TOX), Msaani (TOX),
Migombani (BKN SUPA, TXD220), Mahonda (BKN SUPA, TXD220), Koani (BKN SUPA, TXD220), Ole (TOX, TXD220) and Weni (TOX, TXD220). Although the three local cultivars are all suitable for irrigated lowland conditions, many farmers grow them even under upland conditions due to a lack of good upland cultivars.

Each trial was a randomized, complete block design with two replicates. Individual plot size was 2.1 × 4.0 m. After several days of rainfall, 7 – 10 seeds were planted per hill with a spacing of 0.3 × 0.125 m between hills. Fertilizer was applied at a rate of 20 kg N ha⁻¹, 20 kg P₂O₅ ha⁻¹ and 20 kg K₂O ha⁻¹ 15 d after seedling emergence (DAE) and 20 kg N ha⁻¹ at 28 DAE. Weeds were removed by hand between 10 – 13 DAE and 20 – 23 DAE. At maturity, samples were taken in eight locations (Kizimbani, Upenja, Cheju, Matangatwani, Msaani, Migombani, Mahonda and Koani) but not in Ole or Weni because plants in these trials failed due to severe water shortage.

Twenty hills were sampled from each plot to determine grain yield and yield components. Panicle number was counted from the 20 hills. Panicle number per unit area was calculated based on the hill spacing. The panicles were hand-threshed and filled spikelets were separated from unfilled ones by floatation in water. They were then dried in the sun for a few hr and weighed separately. The moisture contents of the filled spikelets were measured using a grain moisture tester (Ricer m5, Kett Electric Laboratory, Tokyo). Grain yield adjusted to 14% moisture content was calculated from the weighed, filled spikelets, the hill spacing and the moisture values. Subsamples of 5 g and 1 g were taken from the filled and unfilled spikelets, respectively. Numbers of spikelets in each subsample were counted. The 1000-grain weight adjusted to 14% moisture was calculated from the spikelet number of the 5 g subsamples and the moisture content of the filled spikelets. Filled and unfilled spikelet numbers in the 20 hills were estimated from each subsample and the grain-filling ratio (filled spikelet number/total spikelet number) was calculated. Spikelet number per panicle and spikelet number per area were also calculated.

A one-way analysis of variance (ANOVA) was conducted on the yield data collected within each location to compare yield performances of some of the NERICA cultivars (NERICA 1, 2, 10, 12 and 14) with those of BKN SUPA. This trial was also meant to obtain sufficient grains of the five NERICA cultivars for the following sensory test. The trial was a randomized complete block design with two replicates. Individual plot size was 2.1 × 4.0 m. Plants were grown by following the same cultural techniques as those used in the multi-location trials. At maturity, twenty hills were sampled for yield determination as described above.

### 2. Sensory analysis of cooked grain quality

Before the sensory test, a trial was conducted at Kizimbani during Masika from March 2009 to July 2009 to compare yield performances of some of the NERICA cultivars (NERICA 1, 2, 10, 12 and 14) with those of BKN SUPA. The trial was also meant to obtain sufficient grains of the five NERICA cultivars for the following sensory test. The trial was a randomized complete block design with two replicates. Individual plot size was 2.1 × 4.0 m. Plants were grown by following the same cultural techniques as those used in the multi-location trials. At maturity, twenty hills were sampled for yield determination as described above. A one-way ANOVA was conducted on the yield data, and the mean separation between cultivars was determined using the Tukey-Kramer honestly significant difference test.

Thereafter, the sensory test was conducted in October 2009. The extension service unit was consulted to nominate participants and 11 farmers and 4 extension officers were selected across Unguja Island. Three researchers from the research station who were not involved in the study were also invited, so 18 people in total took part in the sensory test. The five NERICA cultivars, BKN SUPA, Mbeya rice (a blend of such local cultivars as Kilombo, Rangimbili, Zambia etc. produced in the Mbeya region and the highest-ranked brand across Tanzania) and Mapembe (an imported rice from Asia and the lowest-ranked brand in Zanzibar markets) were subjected to the test. The five NERICA cultivars were obtained from the trial while BKN SUPA was produced in an irrigated lowland field of the research station during Masika from February 2009 to July 2009. Mbeya rice and Mapembe were obtained from the largest food market in Zanzibar in September 2009. Samples (1,120 mL) of each rice cultivar or brand were mixed with water and the mixtures stirred to wash the grains. After several washes, the samples were mixed with water (1,280 mL)
Fig. 2. Daily and cumulative rainfall values during the 2008 (08) trials recorded at weather stations near the multi-location trial sites. The cumulative rainfalls during the same periods of 2006 (06) and 2007 (07) are also indicated.

Table 2. Yields (g m⁻²) of the NERICA and the local cultivars in the multi-location trials.

| Cultivar | Kizimbani | Upenja | Cheju | Matanga twani | Msaani | Migombani | Mahonda | Koani | Ole | Weni |
|----------|-----------|--------|-------|---------------|--------|------------|---------|-------|-----|------|
| N1       | 362       | 213    | 66    | 322           | 353    | 9          | 38      | 10    | –   | –    |
| N2       | 310       | 139    | 132   | 260           | 348    | 12         | 46      | 9     | –   | –    |
| N3       | 343       | 174    | 100   | 284           | 272    | 16         | 99      | 8     | –   | –    |
| N4       | 340       | 150    | 157   | 129           | 187    | 15         | 95      | 10    | –   | –    |
| N5       | 358       | 135    | 121   | 225           | 263    | 14         | 66      | 12    | –   | –    |
| N6       | 295       | 132    | 102   | 295           | 213    | 6          | 29      | 9     | –   | –    |
| N7       | 355       | 197    | 147   | 140           | 248    | 16         | 54      | 11    | –   | –    |
| N8       | 354       | 145    | 92    | 265           | 289    | 11         | 46      | 12    | –   | –    |
| N9       | 360       | 71     | 77    | 235           | 267    | 5          | 22      | 9     | –   | –    |
| N10      | 347       | 134    | 97    | 299           | 352    | 20         | 94      | 13    | –   | –    |
| N11      | 358       | 83     | 62    | 117           | 223    | 10         | 48      | 10    | –   | –    |
| N12      | 400       | 163    | 105   | 213           | 263    | 17         | 71      | 12    | –   | –    |
| N13      | 276       | 157    | 127   | 249           | 310    | 20         | 96      | 11    | –   | –    |
| N14      | 338       | 128    | 141   | 360           | 262    | 23         | 152     | 13    | –   | –    |
| mean     | 343       | 144    | 109   | 242           | 275    | 14         | 68      | 11    | –   | –    |
| BKN SUPA | 121       | 196    | 140   | –             | –      | 0          | 0       | 0     | –   | –    |
| TOX      | –         | –      | –     | 0             | 0      | –          | –       | –     | –   | –    |
| TXD220   | –         | –      | –     | –             | –      | 0          | 0       | 0     | –   | –    |

ANOVA (F-ratio) 2.78* 0.68 2.26 1.85 4.54** 5.08** 11.98** 11.45** – –

Each value is a mean of the two replicates. N1 = NERICA 1, N2 = NERICA 2 etc. The F tests were significant at *p = 0.05 and **p = 0.01.
and cooked in an electric rice cooker (GRC4304, Geepas, Dubai). A spoonful of cooked rice of each cultivar or brand was given to each participant with its identity concealed. The participants scored each cultivar or brand by color (3: attractive, 2: less attractive and 1: not attractive), fluffiness (3: fluffy, 2: less fluffy and 1: not fluffy), aroma (3: aromatic, 2: less aromatic and 1: not aromatic) and taste (3: tasteful, 2: less tasteful and 1: not tasteful). The participants rinsed their mouths with water after scoring each sample. Each participant summed the scores for each cultivar or brand and ranked them based on the summed scores. Friedman’s ANOVA was conducted on the ranked data set.

Results

1. Moisture conditions in multi-location trials

Fig. 2 shows daily and cumulative rainfall during the growth period. Rainfalls during the same seasonal periods in 2006 and 2007 are also given for comparison. Generally, rainfall events during Masika are more frequent than during Vuli, resulting in larger cumulative rainfall during the former than the latter as in 2006 and 2007. The rainfall events were concentrated in the first part of the growth period (0 – 45 DAE) and declined significantly in the second part. Cumulative annual rainfall during Vuli shows a declining trend from 2006 to 2008.

Kizimbani and Upenja received 815 mm and 849 mm of rainfall during the growth period, respectively. These amounts in 2008 were comparable to those in the same period in 2006 and 2007. In Kizimbani, the surface water drained soon after each rainfall event due to the high permeability of the ferralsols. In Upenja, however, the fields remained waterlogged during the period between sowing and grain-filling due to the high water table of the gleysols.
Table 4. Standardized regression coefficients in multiple regressions of yield on each yield component and percentage contribution of each yield component to yield variation in each NERICA cultivar in the multi-location trials.

| Cultivar | Panicle number per m² | Spikelet number per panicle | % filled spikelets | 1000-grain weight |
|----------|-----------------------|-----------------------------|--------------------|------------------|
| N1       | 0.092 (7.1)*          | 0.339 (26.4)**              | 0.826 (64.3)**     | 0.029 (2.2)      |
| N2       | 0.322 (16.8)*         | 0.693 (35.0)**              | 1.054 (53.3)**     | 0.100 (5.1)      |
| N3       | 0.239 (16.9)*         | 0.321 (22.8)**              | 0.800 (56.7)**     | 0.051 (3.6)      |
| N4       | 0.241 (14.3)**        | 0.527 (19.4)**              | 0.866 (51.4)**     | 0.251 (14.9)*    |
| N5       | 0.210 (15.0)*         | 0.536 (25.5)**              | 0.797 (57.0)**     | 0.036 (2.6)      |
| N6       | 0.120 (8.4)           | 0.363 (25.4)**              | 0.883 (61.7)**     | 0.065 (4.6)      |
| N7       | 0.142 (10.2)          | 0.334 (24.0)**              | 0.872 (62.8)**     | 0.040 (2.9)      |
| N8       | 0.113 (8.4)           | 0.269 (20.0)**              | 0.831 (61.8)**     | 0.131 (9.7)*     |
| N9       | 0.168 (10.5)**        | 0.468 (29.1)**              | 0.812 (50.5)**     | 0.160 (9.9)**    |
| N10      | 0.220 (14.2)**        | 0.301 (19.4)**              | 0.892 (57.4)**     | 0.139 (9.0)      |
| N11      | 0.313 (18.5)**        | 0.504 (29.8)**              | 0.810 (47.8)**     | 0.066 (3.9)      |
| N12      | 0.180 (12.8)**        | 0.272 (19.3)**              | 0.906 (64.5)**     | 0.051 (3.6)      |
| N13      | 0.142 (9.9)*          | 0.439 (30.6)**              | 0.756 (51.3)**     | 0.119 (8.3)      |
| N14      | 0.123 (9.8)**         | 0.149 (11.9)**              | 0.859 (68.6)**     | 0.122 (9.7)*     |

Each value is a standardized regression coefficient and a percentage contribution in parentheses. The multiplicative equation of yield components; Grain yield \((Y) = \text{panicle number per area} \times \text{spikelet number per panicle} \times \text{grain filling ratio} \times \text{1000-grain weight}\) was log-transformed to \(\log Y = \log P + \log S + \log F + \log W\). Each variable was standardized to obtain standardized regression coefficients from which the percentage contribution of each yield component to yield was calculated. \(N1 = \text{NERICA 1, N2 = NERICA 2 etc.}\) The \(t\)-tests on each regression coefficient were significant at * \(p = 0.05\) and ** \(p = 0.01\).

From 912 mm in 2006 and 903 mm in 2007 to 185 mm in 2008. Even with this small amount of rain, the fields were sometimes waterlogged for several days after a rainfall event and soil moisture remained relatively high due to the clay nature of the vertisols.

In Matanga twani and Msaani, the rainfall during the growth period was half those in 2006 and 2007 but still exceeded 600 mm. As a result, the fields in Matanga twani were waterlogged for several days after each rainfall event and soil moisture remained high due to the low permeability of the planosols. The surface water of the fields in Msaani drained well but water running in from higher up the slopes helped to maintain relatively high soil moisture levels.

Migomangi, Mahonda and Koani received approximately 300 mm of rainfall during the growth period but the soil surface at the three sites dried a few hours after rainfall. Ole and Weni received only 202 mm and 100 mm of rain, respectively. The soils in these sites remained dry throughout the growth period.

2. Yield and yield components in Multi-location trials

Table 2 shows yields of the NERICA and the local cultivars in each trial site. In Kizimbani, Msaani, Migombani, Mahonda and Koani, yields were shown by ANOVA to be significantly different between cultivars. In these five trial sites, the yields of the NERICA cultivars were higher than those of the local cultivars; in Kizimbani, BKN SUPA reached its grain-filling period when rainfall drastically declined. As a result, % filled spikelets of BKN SUPA became as low as 38% (data not shown), contributing greatly to the low yield. In Msaani, rainfall declined before TOX reached the booting stage. As a result, this control cultivar dried up before heading and did not yield any rice. In Migombani, Mahonda and Koani, where the trials were conducted during Vuli, the local cultivars BKN SUPA and TXD220 completely dried up during the vegetative stage while the NERICA cultivars managed to maintain some green leaves until grain-filling.

In Upenja, Cheju and Matanga twani, there were no significant differences in yield between cultivars; in Upenja and Cheju, BKN SUPA produced relatively high yields while plant growth of the NERICA cultivars was disturbed by flooding stress. Because BKN SUPA performs well under irrigated lowland conditions (eg. it produced 6.8 t ha\(^{-1}\) in the irrigated lowland field of the research station during Vuli 2007/2008), the cultivar was considered to have taken advantage of waterlogging. In Matanga twani, rainfall declined when TOX reached the panicle initiation stage, and it could not yield any rice. The NERICA cultivars produced fairly good yields as in Msaani. However, unlike Msaani, no significant difference was found between the cultivars. This was due to the large variation between the replications. In Ole and Weni, all the cultivars dried up during the vegetative stage due to severe water shortage. Thus, the two trial sites will be excluded from the following
analyses.

Table 3 shows yields and yield components of the NERICA cultivars in the multi-location trials. Plants of the NERICA cultivars were harvested 85 – 95 DAE. The mean yields across the trial sites were well below the potential yields reported for each cultivar by AfricaRice (2008) but were still above the national average yields for rainfed lowland and upland rice in Tanzania (MATIC, 2009) which ranged from 131 to 177 g m⁻². Mean panicle numbers ranged from 132 to 179 m⁻² and mean spikelet numbers from 60.5 to 88.9 per panicle or from 6,921 to 16,897 m⁻². Mean grain-filling percentages were very low, ranging from 32.6 to 45.6%. Mean 1000-grain weights were relatively high, ranging from 27.7 to 33.8 g.

Mean yields of the NERICA cultivars varied greatly between trial sites and cultivars. Mean yield values in the higher range were obtained from the Masika trials, especially from Kizimbani (343 g m⁻²), Matanga twani (242 g m⁻²) and Msaani (275 g m⁻²). In contrast, values in the lower range were all obtained from the Vuli trials, especially from Kizimbani (343 g m⁻²). In addition, these two components alone account for 70.8 to 90.6% of the yield variations. However, the contribution of % filled spikelets was 1.5- to 5.8-times larger than those of spikelet number per panicle. Regression coefficients of panicle number per area were significant in NERICA 1, 2, 3, 4, 5, 9, 10, 11, 12, 13 and 14, and those of grain weight in NERICA 4, 8, 9 and 14. Percentage contributions of the two components were, however, only 0.1- to 0.4-times the contributions of % filled spikelets. Thus, yield variations in

| Cultivar | Whole | Early | Late |
|----------|-------|-------|------|
| N1       | y = 0.386x - 29.3 (0.367)** | y = 0.502x - 16.9 (0.352)* | y = 0.941x + 20.0 (0.180) |
| N2       | y = 0.369x - 33.9 (0.479)* | y = 0.459x - 15.3 (0.409)* | y = 1.024x - 1.8 (0.358)* |
| N3       | y = 0.323x - 10.1 (0.372)* | y = 0.405x + 5.1 (0.322) | y = 0.87x + 20.5 (0.255) |
| N4       | y = 0.335x - 36.2 (0.647)** | y = 0.413x - 18.6 (0.550)** | y = 0.940x - 8.7 (0.510)* |
| N5       | y = 0.348x - 31.0 (0.449)* | y = 0.436x - 14.6 (0.456)* | y = 0.944x + 1.9 (0.352)* |
| N6       | y = 0.255x - 2.1 (0.239) | y = 0.305x + 14.4 (0.173) | y = 0.773x + 11.9 (0.223) |
| N7       | y = 0.396x - 54.2 (0.732)** | y = 0.503x - 37.9 (0.667)** | y = 1.033x - 12.9 (0.483)* |
| N8       | y = 0.347x - 28.5 (0.415)* | y = 0.441x - 14.2 (0.375)* | y = 0.905x + 8.8 (0.257) |
| N9       | y = 0.328x - 36.9 (0.374)* | y = 0.419x - 24.1 (0.342)* | y = 0.842x - 0.2 (0.218) |
| N10      | y = 0.358x - 19.2 (0.381)* | y = 0.454x - 3.7 (0.339)* | y = 0.946x + 17.8 (0.242) |
| N11      | y = 0.337x - 54.5 (0.560)** | y = 0.448x - 46.7 (0.569)** | y = 0.770x - 4.8 (0.247) |
| N12      | y = 0.380x - 39.7 (0.526)* | y = 0.489x - 25.8 (0.495)* | y = 0.958x + 5.0 (0.307) |
| N13      | y = 0.324x - 15.1 (0.467)* | y = 0.394x + 2.2 (0.389)* | y = 0.915x + 10.7 (0.568)* |
| N14      | y = 0.271x + 24.6 (0.189) | y = 0.311x + 46.2 (0.112) | y = 0.895x + 30.5 (0.230) |

`y = yield (g m⁻²) x = rainfall (mm). Coefficients of determination were adjusted for degrees of freedom (parentheses). N1 = NERICA 1, N2 = NERICA 2 etc. The F-tests on each regression equation were significant at *p = 0.05 and **p = 0.01. Yields and yield components of the NERICA cultivars were shown by ANOVA to be significantly different between cultivars and between trial sites. Among the cultivars, the yield of NERICA 14 was the highest followed (in declining order) by NERICA 1, 10, 3, 2, 13, 12, 8, 5, 7, 4, 6 and 9, with NERICA 11 being the lowest. Among the trial sites, Kizimbani achieved the highest yields followed by Msaani, Matanga twani, Upenja, Cheju, Mahonda and Migombani, with Koani having the lowest. While there were significant interactions between cultivar and trial site in the yield components (except for 1000-grain weight), the interactions were not significant on yield. This indicates that significant interactions in the yield components had no significant influences on yield. Table 4 shows the regression coefficients for yield on yield components and the percentage contributions of each yield component to yield. In all the cultivars, regression coefficients of spikelet number per panicle and % filled spikelets were significant at the 1% level, indicating that in each cultivar the two components are significant variables for explaining yield variation. In addition, these two components alone account for 70.8 to 90.6% of the yield variations. However, the contribution of % filled spikelets was 1.5- to 5.8-times larger than those of spikelet number per panicle. Regression coefficients of panicle number per area were significant in NERICA 1, 2, 3, 4, 5, 9, 10, 11, 12, 13 and 14, and those of grain weight in NERICA 4, 8, 9 and 14. Percentage contributions of the two components were, however, only 0.1- to 0.4-times the contributions of % filled spikelets. Thus, yield variations in
the NERICA cultivars can be explained mainly by the spikelet number per panicle and the % filled spikelets.

3. Relationships between yield and rainfall in Multi-location trials

Table 5 shows regressions of yield on rainfall and their coefficients of determination. When rainfall during the whole growth period was taken as an independent variable, statistically significant equations with coefficients of determination ranging from 0.367 to 0.732 were obtained for all the cultivars except NERICA 6 and 14. This indicates that yields of the NERICA cultivars (except NERICA 6 and 14) can be predicted from rainfall during the whole growth period, and that erratic rainfall accounts for 37 – 73% of the yield variation.

Rainfall events were concentrated in the first part of the growth period (Fig. 2), so rainfall in either the earlier or the later part of growth period was also treated as an independent variable for further analysis. When early rainfall was used, statistically significant equations were obtained from all the cultivars except NERICA 3, 6 and 8, 9, 10, 11, 12 and 14.

In this way, the cultivars can be classified into three groups: cultivars whose yields were determined predominantly by rainfall during both the earlier and the later parts of the growth period (NERICA 2, 4, 5, 7 and 13); cultivars whose yields were determined only by rainfall during the early period (NERICA 1, 8, 9, 10, 11 and 12); and cultivars whose yields were not significantly associated with rainfall (NERICA 6 and 14).

4. Sensory analysis of cooked grain quality

Table 6 shows the results of the yield comparison trial and the grain quality test. Mean yields of each NERICA cultivar ranged from 195 to 253 g m\(^{-2}\) while that of BKN SUPA was 16 g m\(^{-2}\). The multiple comparisons showed significant differences between BKN SUPA and each NERICA cultivar but no differences among the NERICA cultivars. Overall, the yield of the NERICA cultivars was relatively low compared with that obtained from the same field (Kizimbani) in the multi-location trials, which ranged from 310 to 400 g m\(^{-2}\) (Table 2). This was probably due to a difference in rainfall during the growth period; 815 mm in the comparison trial. The vegetative growth of BKN SUPA was significantly lower than that of the NERICA cultivars, which appeared to have also contributed to the low yield. Interestingly, the NERICA cultivars showed no symptom of the disease.

In all the grain quality assessments, both BKN SUPA and Mbeya rice (the popular rice brands in the local markets) scored higher than Mapenbe (the least popular brand in the local markets), suggesting that the results of our blind test were in good agreement with the evaluations made by the local markets.

In the color quality, the NERICA cultivars (and NERICA 14 in particular) scored low compared with Mapenbe. In the fluffiness quality, all the NERICA cultivars scored somewhere between the two popular brands and Mapenbe. In the taste quality, NERICA 1 scored higher than the two popular brands, and NERICA 2, 10 and 12 scored between the two popular brands and Mapenbe while NERICA 14 scored lower than Mapenbe. In the

Table 6. Yields of BKN SUPA and five NERICA cultivars (1, 2, 10, 12 and 14) in the yield comparison trial, and grain-quality scores of BKN SUPA, the five NERICA cultivars, Mbeya rice and Mapembe evaluated by a group of 18 farmers, extension officers and researchers.

| Grain quality | BKN SUPA | N1 | N2 | N10 | N12 | N14 | Mbeya | Mapembe |
|---------------|--------|----|----|-----|-----|-----|-------|---------|
| Yields (g m\(^{-2}\)) | 16 b | 210 a | 195 a | 253 a | 229 a | 238 a | – | – |
| Color         | 50    | 47  | 42  | 45  | 47  | 27  | 52    | 48    |
| Fluffiness    | 44    | 34  | 38  | 35  | 30  | 31  | 43    | 27    |
| Taste         | 40    | 44  | 33  | 35  | 32  | 31  | 40    | 32    |
| Aroma         | 33    | 30  | 30  | 31  | 30  | 24  | 33    | 23    |
| Score total   | 167   | 155 | 143 | 146 | 139 | 113 | 168   | 130   |
| Rank total    | 56.0  | 65.5| 85.5| 76.0| 89.5| 118.0| 53.5  | 104.0 |
| Mean rank     | 3.11  | 3.64| 4.75| 4.22| 4.97| 6.56| 2.97  | 5.78  |

Friedman’s ANOVA: \( \chi^2 = 33.68, P < 0.001 \) (ties: 35, \( \chi^2 \) corrected for ties = 39.35, \( P < 0.001 \))

N1 = NERICA 1, N2 = NERICA 2 etc. Each value in “Yields” is the mean of two replicates. The letters beside the values represent significant differences at \( P = 0.01 \). Each value in “Grain quality” is the sum of scores evaluated by all participants. Grains of the five NERICA cultivars were harvested from the yield comparison trial while those of BKN SUPA were harvested from an irrigated lowland field of the station during Masika 2009. Grains of Mbeya rice and Mapembe were obtained from the largest food market in Zanzibar immediately before the test. Each participant ranked the cultivars or brands based on a simple scoring system (for details, see 5.

Sensory analysis of cooked grain quality). The rank dataset collected from all the participants was analyzed by Friedman’s ANOVA.
aroma quality, all the NERICA cultivars scored between the two popular brands and Mapnebe. Overall, Mbeya rice scored highest followed in declining sequence by BKN SUPA, NERICA 1, 10, 2, 12 and Mapnebe, and NERICA 14 scored the lowest. This ranking was shown by Friedman’s ANOVA to be significant.

Discussion

The NERICA cultivars exhibit their high-yielding properties under Zanzibar conditions (Tables 2 and 6). In Zanzibar, rice producers grow only lowland cultivars even in upland fields due to a lack of cultivars suitable for rainfed environments. The lowland cultivars grown in the islands include, in addition to BKN SUPA, TOX and TXD220 used in the present study, traditional Ringa and SUPA India and locally developed TXD88 (Kanyeka et al., 2004) and TXD306 (Msomba et al., 2004). These cultivars are known to produce fairly good yields under lowland conditions. For instance, in our trial conducted in the irrigated lowland field from November 2007 to March 2008, BKN SUPA and TXD220 produced 6.8 t ha$^{-1}$ and 5.4 t ha$^{-1}$, respectively (data not shown). It is known, however, that yields of lowland cultivars are likely to be reduced under upland conditions (Lilley and Fukai, 1994; Jeerakongman et al., 1995; Naklang et al., 1996; Matsuo and Mochizuki, 2009). In the present study, the yield of BKN SUPA also fell as low as 1.2 t ha$^{-1}$ in the multi-location trials (Table 2) and was further decreased to 0.16 t ha$^{-1}$ in the yield comparison trial (Table 6).

In Zanzibar, the annual consumption of rice per capita is approximately 100 kg of white rice (MALE, 2009, 2010). Nevertheless, the self-sufficiency rate is as low as 20%, and the rest are imported from mainland Tanzania or Asia. At present, the area under rice cultivation is 11,646 ha (MALE, 2010) out of which only approximately 700 ha have been developed for irrigated rice production (MALE, 2004). The great majority of rice fields are still under rainfed conditions. It is believed that the lack of good cultivars suitable for those fields is the cause of low rice production and hence the low self-sufficiency rate (MALE, 2010). Therefore, the NERICA cultivars are expected to replace those local cultivars and to further expand the cultivated area since the potential area for rice production is estimated at 22,600 ha (MALE, 2010).

This study further suggests that the NERICA cultivars could produce high yields even in mainland Tanzania. The single regression analysis revealed that (except for NERICA 6 and 14), the yields of NERICA cultivars were determined by rainfall during the whole growth period (Table 5). The regression equations estimate that with 580–780 mm of rainfall, yields of the NERICA cultivars were as high as 2.1 t ha$^{-1}$, which is the national average yield for irrigated rice. Long-term records from 1992 to 2005 (Rowhani et al., 2011) show that most regions in Tanzania (except Arusha and Kilimanjaro in the north, Dodoma and Singida in the central region and Tabora and Shinyanga in the west) experience more than 550 mm of rainfall during Masika. We infer from this that in an average year, the NERICA cultivars are expected to produce sufficient yield during Masika without irrigation not only in Zanzibar but also in most areas of Tanzania.

The yield performances of these cultivars were poor during Vuli. This suggests that the introduction of a NERICA-based, double-cropping system in most areas of Tanzania is unlikely to be successful (Tables 2 and 3). The five locations in the Vuli trials received 426–869 mm rainfalls during the period in 2006 (Fig. 2). With these rainfalls, the NERICA cultivars are estimated to yield 0.9–3.1 t ha$^{-1}$ (Table 5). In 2008, however, their yields fell below 0.5 t ha$^{-1}$ due to inadequate rainfall. Rainfall in Tanzania varies greatly from year to year, and this affects rice production (Raes et al., 2007; Rowhani et al., 2011). Simulations suggest that intra-seasonal rainfall variability will impact rice production increasingly over the next four decades (Rowhani et al., 2011). In addition, the variability is predicted to be more pronounced during Vuli than Masika (Chan et al., 2008). Thus, measures for increasing or maintaining soil water availability should be employed during the Vuli production if NERICA-based, double-cropping systems are to be introduced. In the past, techniques such as rainwater harvesting (Meertens et al., 1999; Young et al., 2002; Mblinyi et al., 2005; Pachpute, 2010) and soil water conservation management (Makurira et al., 2009; Shemdoe et al., 2009; Mkoga et al., 2010) have been proved effective for crop production in water-scarce climates in Tanzania. These techniques should be further tested with the NERICA cultivars during Vuli. The same techniques may also indicate ways in which yields can be better stabilized during Masika.

Variables other than rainfall may also contribute to cultivar yield variability since the coefficients of determination were only moderately high, ranging from 0.367 to 0.732 (Table 5). Although the present study provides no conclusive evidence for other variables, some observations imply the soil’s physical properties to be one of the candidate variables. For example, Cheju received 185 mm rainfall during the growth period which was much less than 294 mm in Mahonda (Fig. 2). Nevertheless, mean yield at Cheju (109 g m$^{-2}$) was 1.6-times larger than at Mahonda (68 g m$^{-2}$) (Table 3). It seems likely that the sandy-clay soils in Cheju were able to store the limited amounts of rainwater which fell there and even caused waterlogging at times, whereas the loamy soils in Mahonda had inadequate water-holding capacities. The difference in soil water storage of these two soil types might be responsible for the yield differences. Another example is that while there was no great difference in rainfall between Kizimbani (815 mm) and Upenja (849 mm) (Fig. 2), the...
mean yield in Kizimbani (345 g m\(^{-2}\)) was approximately 2.4-times greater than that in Upenja (144 g m\(^{-2}\)) (Table 3). It was observed that the loamy soils in Kizimbani drained the surface water well but the soil in Upenja caused continuous waterlogging until the grain-filling period. Kawano et al. (2008) reported that the yields of the NERICA cultivars were reduced by 10 – 50% by flooding stress during seedling establishment. Oladokun and Ennos (2006) also reported the susceptibility of NERICA 1 to waterlogging. It is thus inferred that the yields of the NERICA cultivars in Upenja were reduced due to flooding stress.

The multiple regression analysis revealed that two yield components, spikelet number per panicle and % filled spikelets alone accounted for 70 – 90% of yield variation (Table 4). It is well known that % filled spikelets is determined during the grain-filling period with allocation of newly assimilated carbohydrates and translocation of non-structural carbohydrates (NSC) stored before heading (Yoshida, 1981). NSC are accumulated in culms and leaf sheaths mainly during a two-week period preceding full heading, and the accumulation occurs rapidly in rice plants having high carbon assimilation rates, i.e., high crop growth rates (CGR), during this period (Yoshida, 1981; Horie, 2001; Horie et al., 2005). The CGR and/or the NSC accumulation during this period are shown to determine simultaneously both the % filled spikelets (Fu et al., 2011) and also the spikelet number per panicle (Horie, 2001; Horie et al., 2005). Thus, the NERICA yields were associated mainly with CGR and/or NSC accumulation during the two-week period preceding full heading and maturity. This is in agreement with a previous report by Matsunami et al. (2010) who found unique characteristics of the NERICA cultivars in their ability to maintain high biomass production rates during the grain filling which probably contributes to their high yields. Due to their early maturity (85 – 95 DAE), this important period occupies almost all of the second part of their growth period. Besides, panicle number per area, which is determined during the early growth period, had no significant relationship with either of the two components in all the NERICA cultivars (data not shown) except the positive correlation with % filled spikelets (\(R = 0.605, P = 0.013\)) in NERICA 3. Thus, NERICA yields may be very strongly affected by environmental factors during the later part of the growth period.

The multiple regression analysis (Table 4) and the simple regression analysis (Table 5) strongly suggested that NERICA yields are greatly affected by rainfall during the later part of their growth period. This seems to be especially true for NERICA 2, 4, 5, 7 and 13 whose yields were strongly associated with rainfall during the later part of the growth period (Table 5). In this group of cultivars, later rainfall events are thought to have had a direct influence on spikelet number per panicle and % filled spikelets and also to have contributed to the between-cultivar yield variations. However, to make the same assumption for NERICA 1, 8, 9, 10, 11 and 12 would be wrong as their yields were associated only with rainfall during the earlier period (Table 5). This is interesting because early rainfall events seem to have influenced the two yield components, spikelet number per panicle and % filled spikelets, which are still to be determined in the later part of the period. In addition, the cultivars NERICA 6 and 14 showed no significant relationships between yield and rainfall (Table 5). NERICA 14 in particular is very interesting because it performed best in the trials (Table 3). It is still unclear why the three groups of cultivars responded to rainfall so differently but elucidation of the underlying mechanism could well provide useful indications for new breeding strategies.

The grain quality of some NERICA cultivars was evaluated highly by the local people (Table 6). NERICA 1, in particular, was ranked as highly as BKN SUPA. In Tanzania, rice is becoming an increasingly important cash crop (Senda, 1999; MAFC, 2009) due to its relatively high market prices (FAO, 2011). With strong consumer preferences for grain quality, the market price of rice varies with cultivar or brand. For example, in August 2011 in the largest food market in Zanzibar, Mbeya rice, BKN SUPA and Mapembe were sold at 1,600, 1,500 and 1,200 shillings kg\(^{-1}\) respectively (US$1 = 1,600 shillings). Similarly, large differences in market price are found throughout the country (Senda, 1999; MAFC, 2009). Therefore, rice farmers in Tanzania often select cultivars for production based on consumer preference rather than on yield potential (Mwaseba et al., 2006; Mwaseba et al., 2007). For example, Mbeya rice is a blend of such local cultivars as Kilombero, Rangimbili and Zambia produced in the Mbeya region. Farmers in this region also grow a local cultivar, Mwangulu, which yields better than the popular cultivars. However, they grow it only in small parts of their fields for emergencies because of its poor grain quality. In the Kilimanjaro region, a high-yielding cultivar, IR54, was commonly grown in large-scale irrigation schemes in the 1980s and 1990s, but nowadays it has been largely replaced by IR64 because of its better grain quality. More recently, IR64 is being gradually replaced with TXD306 based again on a further improvement in grain quality. Therefore, it is possible that farmers will tend to reject NERICA 14 despite its high yielding capacity since this cultivar was evaluated as being of poorer quality than Mapembe. In contrast, NERICA 1 may well be accepted by farmers due to its good grain quality even though its yield capacity is slightly lower than that of NERICA 14.

**Conclusion**

Yields of the NERICA cultivars are strongly associated
with rainfall so that their high-yielding properties were exhibited only during the long-rains season of Masika but not during the short-rains season of Vuli. Thus, in Tanzania, it is important that techniques be investigated for water harvesting or for water conservation in conjunction with the introduction of a rice double-cropping system. The yield variations were explained mostly by spikelet number per panicle and % filled spikelets. This suggests that yields were determined mainly during the latter part of the growth period. The grain qualities of some of these cultivars, especially of NERICA 1, were evaluated as high. Therefore, the NERICA cultivars, especially NERICA 1, should be promoted as being suitable for replacing existing cultivars for rainfed rice production in Tanzania.

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