Lodging Resistance In Rice Cultivars Under Rates of Nitrogen Fertilizer; Does The Main Culm Represent The General Pattern of Lodging In Primary Tiller?

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LODGING RESISTANCE IN RICE CULTIVARS UNDER RATES OF NITROGEN FERTILIZER; DOES THE MAIN CULM REPRESENT THE GENERAL PATTERN OF LODGING IN PRIMARY TILLER?

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Abstract

Purpose Lodging resistance (LR) in rice cultivars is usually established using the main culm (MC) as a good representative of tillers on the plant. However, it remains unclear whether LR of MC represents LR of the primary tiller (PT) to guide in the selection of tillers during LR assessment in rice cultivars under rates of nitrogen fertilizer.

Methods Four lodging resistant cultivars namely: NERICAs 1, 4, 6 and Moroberekan were established under three rates (0, 60, 120 kg ha^{-1}) of nitrogen fertilizer. At 20 days after heading of each of the MC and PT, the culms were harvested for assessment of LR.

Results Increasing application rates of nitrogen fertilizer increased the culm morphological traits (CMTs) such as culm wall thickness, internode and lumen diameters, bending moment and breaking strength of MC and PT with little effect on lodging index (LI). The CMTs were however, higher in the MC and with lower LI than in the PT. The higher CMTs in MC did not translate to lower LI in all the rice cultivars such as Moroberekan compared with the PT. Correlations of CMTs with LI were higher and significant in the MC than in the PT.

Conclusion Main culm remains reliable for the mechanical assessment of LR in upland rice but does not represent the general pattern of lodging in the PT. There is need for consistency in selection of tiller for mechanical assessment of lodging in rice cultivars under rates of nitrogen fertilizer.

Keywords: Lodging index; main culm; NERICAs; nitrogen fertilizer; primary tiller.

Introduction

Lodging is a major problem militating against achieving high yield in many crops, most especially cereal crops due to the hollow nature of the stem (Berry and Spink 2012). The term lodging, which describes bending to prostrate appearance of the stem, can result in 80% loss in yield if not properly managed (Foulkes et al. 2011; Muhammad et al. 2020). Lodging developed either as a result of the inability of the root to anchor the plants to its substratum (Manzur et al. 2014) or the possession of a weak stem that cannot withstand the weight of panicle (Plaza-Wüthrich et al. 2016). Variation in basal and aerial stem diameter combined with increased fruit weight instigated by increased nitrogen fertilizer rates has also been reported to contribute to lodging (Olagunju et al. 2019). Culm morphological traits such as increased primary panicle weight, culm height, plant height, height at the center of gravity, culm wall thickness, internode diameter, internode weight, and internode length and lumen volume are some of the traits associated with lodging that have been used to assess lodging resistance in cereals(Zhang et al. 2016b; Olagunju et al. 2020). Assessment of lodging using these traits has been limited to the main culm as good representative of the tillers on rice plant. However, investigation on the reliability of primary tiller in expressing similar resistance to lodging as the main culm, which could guide in the selection of tillers for lodging resistance assessment, has not received considerable attention.

Tillers are formed in cereals from non-elongated internode at the base of the stem in acropetal succession (Yoshida 1981; Mohapatra et al. 2011). The main culm appears first before other tillers and is usually with higher vigour than the tillers. Most of a time, the main culm usually bears the heaviest panicle weight but the panicle on the primary tiller can also compete well with the main culm in some cultivars. There have been reports on the variation in panicle weight of main culm and the tillers and differences in their contribution to total grain yield (Duy et al. 2004; Wang et al. 2017; Huang et al. 2020). However, little report exists on differences in culm morphological traits of main culm and primary tiller and their contribution to lodging in upland rice. It has been observed that the number of vascular bundles decrease from the primary to secondary and tertiary tillers of rice cultivars and can limit the amount of assimilates that can be transported to late emerging tillers (Mohapatra et al. 2011). A slight variation in vigour and panicle weight of tillers can result in differing responses in lodging resistant traits. Among the culm morphological traits influencing lodging resistance in upland rice, panicle weight plays a pivotal role in demanding for increased strength of the culm walls to remain positioned in the vertical form. This has the potential to influence the culm morphological traits between main culm and the primary tiller, differently.

One of the management practices influencing panicle weight in cereals is application of nitrogen fertilizer which can increase grain yield of rice through increase in number of spikelets (Yi et al. 2019). Nitrogen also exerts significant effect on tillering in upland rice and are capable of modifying the growth form of tillers due to its regulatory role on tiller bud growth (Wang et al. 2016; Wang et al. 2017). Upland rice responds well to nitrogen fertilizer application through increase in vegetative organs which culminate in the production of higher panicle weight. Increased rates of nitrogen fertilizer can predispose upland rice to lodging attributed to reduced structural carbohydrates in the stem combined with assimilate loading from the stem into the grains especially when nitrogen is applied at very high rates (Wang et al. 2015; Zhang et al. 2016b). Past studies on the effect of nitrogen fertilizers on lodging traits had reported increased culm wall thickness, culm diameter with reduced internode length and breaking strength at high rates of the fertilizer (Zhang et al. 2016b). The ability of a cultivar to balance the heavy weight of the panicle with sturdiness of the basal part for improved lodging resistance is a way to achieve high yield in lodging prone areas under nitrogen fertilizer application. However, balancing the panicle weight with sturdy basal stem can vary between the main culm and the primary tiller.

The New Rice for Africa (NERICA) is among the common cultivated rice bred purposely for high yield and resistance to harsh environmental condition of the tropics (Dingkuhn et al. 1998; Balasubramanian et al. 2007; Ndjiondjop et al. 2018). The cultivars, which were obtained from the cross between *Oryza sativa* and *Oryza glaberrima*, are known to have between moderate to tall height with high yield (Africa Rice Center 2008). Until recently, the mechanical basis of lodging resistance in first generation NERICA cultivars was not elucidated. Past studies on first generation NERICAs, that is, NERICAs 1 to 8, had established good resistance of these rice cultivars to lodging based on visual scoring (Africa Rice Center 2008). Recent study however, conducted on the rice cultivars established significant differences in lodging resistance based on culm morphological traits under silicon application (Olagunju et al. 2020). NERICAs 1, 4 and 6 were among the few cultivars selected for having higher resistance to lodging among the cultivars in addition to Moroberekan, a well-known cultivar that has been widely cultivated for its massive root system and sturdy stem. Adequate knowledge of the mechanical basis of lodging has been suggested to establish lodging resistance in rice cultivars as this can aid in achieving complete success in reducing lodging during plant breeding programs (Crook and Ennos 1994; Oladokun and Ennos 2006). The mechanical basis of lodging is subject to influence by nitrogen fertilizer application which is yet to be established in these selected cultivars.

Studies that investigated the effect of nitrogen fertilizers on yield of rice cultivars are many (Zhang et al. 2014b; Khan et al. 2017; Zhang et al. 2017) but scanty literatures exist on the similarities or otherwise of the mechanical basis of lodging of main culm and primary tiller in differentiating lodging resistance among rice cultivars under rates of nitrogen fertilizer. Furthermore, it is important to establish the effect of nitrogen fertilizers on culm morphological traits contributing to lodging in the selected NERICA cultivars. We therefore hypothesize that culm morphological traits contributing to lodging exhibit similar lodging resistance among rice tillers and that response of these lodging traits to nitrogen fertilizer application are the same in the main culm and primary tiller. Specifically we ask the following questions (i) do culm morphological traits of main culm and primary tiller confer similarities in lodging resistance among rice cultivars? (ii) do the main culm and primary tiller respond similarly to increase rates of nitrogen fertilizer in NERICA cultivars? (iii) in which of these culms do the culm morphological traits better express lodging resistance among the rice cultivars under rates of nitrogen fertilizer?.

Materials and methods

Experimental site

The experiment was conducted in an open field within the Teaching and Research Farm of College of Agricultural Sciences, Olabisi Onabanjo University. The area was characterized with erratic rainfall pattern with average annual rainfall of 1200 mm. The temperature range of the area was between 22 - 23^0C in the morning to 32-33^0C in the afternoon and relative humidity that was as high as 80% and as low as 55%. The soil texture was loamy sand based on analyses conducted before and after the experiment. The pH of the soil was strongly acidic. Exchangeable bases (Ca, Mg, Na and K), Effective Cation Exchange Capacity (ECEC), base saturation, total nitrogen, organic carbon and available P were also measured before and after the experiment (Table 1). Nutrient analyses of the soil before the experiment revealed moderate level of soil fertility which became lowered after the experiment.

Soil sample collection, preparation and analyses

The soil used in the experiment was scooped to a depth of 0 - 15 cm deep from the Teaching and Research Farm. The soil collected was homogenized to obtain uniform soil samples across pots. Sub-sample of the soil was air-dried and later sieved with 2 mm sieve before taken to the laboratory for analyses. Similar procedure was carried out on soil samples collected on treatment basis after the experiment. In the laboratory, pH of the soil was determined in 1:2 soil water ratio with glass electrode meter (McLean 1982) (Table 1). Hydrometer method was used in determining particle size distribution of the soil samples (Gee and Bauder 1986). Calcium (Ca), Magnessiun (Mg), Potassium (K), and Sodium (Na) were extracted using ammonium acetate method (Thomas 1982). Following extraction of exchangeable bases, Ca and Mg were determined with Buck Scientific 210 VGP model, Atomic Absorption Spectrophotometer (AAS), while K and Na were read on flame photometer. Titration method was used in determining the exchangeable acidity (Anderson and Ingram 1993). The summation of exchangeable bases and exchangeable acidity was used in estimating the ECEC (Anderson and Ingram 1993). The fraction of the exchangeable bases and ECEC expressed in percentage was used in calculating the base saturation. Total nitrogen was determined by Kjeldahl method (Bremner 1996). Organic carbon was determined by the wet oxidation method as described by Walkley-Black (Nelson and Sommer 1996) while Bray-1 method was used in determining the available phosphorus (Bray and Kurtz 1945)

Experimental design

The experiment was a factorial combination of four upland rice cultivars namely NERICAs 1, 4, 6 and Moroberekan; and three rates of nitrogen fertilizer: 0, 60, and 120 kg ha^{-1}, with three replications in Complete Randomized Design. Uniform number of seeds of each rice cultivar was first nursed in a pot containing 5 kg of loamy sand soil for 21 days. At 14 days after sowing (DAS), the seedlings were supplied with 3 g of NPK 20:10:10 in preparation for transplanting. At 21 DAS, seedlings were transplanted into respective pots containing 10 kg soil which had already been homogenized through the use of shovel before potting to ensure uniformity in nutrient distribution within the soil. Seedlings were transplanted at one seedling per pot after which the soils were watered to full field capacity. Pots receiving the 60 and 120 kg ha^{-1} of nitrogen fertilizer treatment were all supplied with N:P:K 20:10:10 at 60 kg ha^{-1}N: 30 kg ha^{-1}P and 30 kg ha^{-1} K equivalent of 1.35 g of the fertilizer per pot. The remaining nitrogen dose (60 kg ha^{-1}N) for pots receiving 120 kg ha^{-1} was supplied using urea at an equivalent rate of 0.58 g per pot at maximum tillering stage. At seedling stage, watering of pots was at every other day which increased to every day at maximum tillering stage. Between maximum tillering and maturity when panicles were initiated and fully formed, watering of pots was both in the morning and evening.

Sampling and measurement for lodging traits

At 20 days after heading of each of the main culm and primary tiller, both stems were cut from the soil mark with the leaf and leaf sheaths intact. The second tiller was harvested at 7 days after harvesting the main culm in all cultivars while harvesting of the primary tiller was delayed correspondingly by two weeks in the late maturing Moroberekan. The culms were later taken to the laboratory where the lodging resistance traits were assessed. The leaves and the leaf sheaths were first carefully removed to expose the inner skeleton of the culm while at the same time preventing the breakage of the culm during leaf sheaths removal. The height of the plant was determined by measurement from the base of the culm to panicle tip. Culm height was measured from culm base to the neck of the panicle (Yoshida 1981). The culm skeleton was thereafter placed on a pivot/fulcrum until it reached an equilibrium to determine the height at center of gravity (HCG) (van Delden et al. 2010). The culm was later cut into different segments at the nodes and at the panicle neck. Panicle weight was determined by placing the panicle on a sensitive weighing machine (Model BY-B). Panicle length was also measured with a ruler from the panicle neck to the tip of the panicle. Counting from the base of the culm, the second internode was identified and further morphological analysis was conducted on it. Internode length, the distance between the two terminal ends of the internode, was measured using meter ruler on a centimeter scale. Due to the oval nature of the culm, the internode diameter readings consisting of the minor diameter (the smaller diameter, a_1) and the major diameter (bigger diameter, b_1) were obtained by using leaf thickness gauge (Model YH-1, Top Instrument, China). Internode weight was determined by placing the second internode on the sensitive weighing machine. To determine the stem breaking force (SBF), the internode segment was placed on two supports, separated at 4 cm, of a plant culm strength tester (Model TYD-1,Top Instrument, China), where a force was applied at the middle point of the internode until it breaks (Zhang et al. 2014a). The maximum force applied which gave the stem breaking force (SBF) was then recorded. The culm wall thickness was determined by cutting out a thin section of the culm walls along the length of the internode and placing it under the leaf thickness gauge. Lumen diameter, diameter of the hollow space within the culm, which was also of two types viz inner minor (a_2) and inner major diameter (b_2) of the lumen, was determined using the formula;

$$\text{Lumen diameter (mm)} = \text{internode diameter (mm)} - 2 * \text{ culm wall thickness(mm)}$$

respectively for the minor and major diameter. Lumen volume was determined using the formula;

$$Lumen\ volume\ (mm^3) = \pi\ a_2 b_2 \mathrm{h}$$

where a_2, b_2, and h are minor and major diameters of the lumen and length of the internode, respectively. The cross-section modulus was computed as

$$Cross\ section\ modulus\ (mm^3) = \left\{\frac{(a_1^3 * b_1 - a_2^3 * b_2)}{a_1}\right\} * \frac{\pi}{32} \qquad \text{(Zhang et al. 2014a).}$$

Stem length (SL) and fresh weight (FW) of the stem from breaking point to the tip of the panicle were determined with measuring ruler and by weighing on the weighing machine, respectively. Bending moment (BM) was computed as

$$Bending\ moment\ (g\ cm) = \text{Stem length from breaking point to panicle tip (SL, cm)} * \text{Fresh weight from breaking point to panicle tip (FW, g)}$$

Breaking strength was determined using the formula

$$Breaking\ strength\ (g\ cm) = \frac{\text{Stem breaking force (N)} * \text{distance between the two fulcra, L (cm)}}{4}$$

(Zhang et al. 2016a).

Bending stress was obtained as

$$Bending\ stress\ (g\ mm^{-2}) = \frac{\text{Breaking strenght (g cm)}}{\text{Cross section modulus } (mm^3))}$$

The weight per unit length ($W\ L^{-1}$) was computed as

$$Weight\ per\ unit\ length\ (g\ cm^{-1}) = \frac{\text{weight of internode (g)}}{\text{Length of internode (cm)}}$$

Lodging index (LI) was thereafter computed as

$$Lodging\ index = \frac{\text{Bending moment (g cm)}}{\text{Breaking strength (g cm)}}$$

This was achieved after converting the unit of breaking strength (N cm) to ‘g cm’ using a unit conversion of 1g = 0.00981N, so as to have a uniform unit.

Data analysis

Data collected on culm morphological traits were subjected to Analysis of Variance. Significant treatment means were separated in descending order using Fischer’s protected Least Significance Difference (LSD). Pearson moment correlation analyses was conducted between the culm morphological traits and lodging index for each of the main culm and primary tiller and between all the lodging traits when pooled for both culms. Principal component analyses

(PCA) bi-plot showing the relationships between the culm morphological traits and the interaction of tiller types by cultivars was plotted on one hand, while PCA bi-plot was also plotted to show the relationship between the culm morphological traits and the interaction of nitrogen rates by cultivars, on the other hand. The statistical package used for the analyses was Genstat 15th, edition (Payne et al. 2009)

Results

The result of analyses conducted on the soil before and after the experiment is presented in Table 1. The concentrations of exchangeable bases; Ca, Mg, Na and K, in the soil before the experiment were moderate (4.39, 1.01, 0.36, and 0.39 cmol kg^{-1}, respectively), except for low concentration of Ca observed. The exchangeable bases became low in the soil after the experiment. The base saturation (98.09%), organic carbon (21.8 g kg^{-1}) and available phosphorus (26.29 mg kg^{-1}) in the soil were higher before the experiment and remained high after the experiment except for available phosphorus that was reduced to moderate level (13.32 – 14.99 mg kg^{-1}). The total N of the soil was within the critical limit of 0.15 -0.25 g kg^{-1} before the experiment and after the experiment when higher rate (120 kg ha^{-1}) of N:P:K 20:10:10 fertilizer was applied to the soil. At lower rates of the fertilizer, total N of the soil became low (0.14 g kg^{-1}).

Significant reduction in all the culm morphological traits (22) related to lodging was observed in the primary tiller when compared with the main culm (Tables 2 and 3). The exception to this general observation was the non-significant differences observed in panicle weight, height at the center of gravity, culm height, internode length, bending stress and weight per unit length (6 out of 22). Increased application rates of nitrogen within the range of zero to 120 kg ha^{-1} caused an increase in all the culm morphological traits with little effect on lodging index. The exception was a non-significant differences observed on weight of primary panicle, height at the center of gravity, culm height, inner major diameter (b_2), internode weight, lumen volume, bending stress and weight per unit length (9 out of 22). Significant differences were also observed among the cultivars with Moroberekan and NERICA 6 having the highest in many of the culm morphological traits.

Significant interaction of tiller types by cultivars was observed on weight of primary panicle, height at the center of gravity, culm and plant height, outer major and minor diameter (b_1 and a_1, respectively), inner major diameter (b_2), cross-section modulus, lumen volume, stem length and lodging index (Fig. 1a-j). Among the tiller types and cultivar interaction, NERICAs 1 and 4 exhibited similar lodging traits in both the main culm and the primary tiller unlike NERICA 6 and Moroberekan which exhibited higher lodging traits in main culm than in the primary tiller and are both taller cultivars. However, the lodging index is lower in the main culm than in the primary tiller of NERICAs 1 and 6 but were similar for NERICA 4 and Moroberekan. Nitrogen by cultivar interaction was significant for internode length, inner major diameter (b_2) culm wall thickness, stem breaking force, lumen volume and lodging index (Figs 2a-f). Among the nitrogen fertilizer rates and cultivars interaction, NERICA 4 maintained similar response to increase rates of nitrogen fertilizer in the affected culm morphological traits while NERICA 6 responded well to increase rates of the fertilizer among the cultivars. Significant increase in culm wall thickness and stem breaking force was observed in NERICA 6 with increase rates of nitrogen fertilizer (Fig 2c and d) while a reduction in internode length and lumen volume was observed in the same cultivar under this condition (Fig 2a and e). Lodging index varied significantly among the rates of nitrogen fertilizer in NERICA 6 and Moroberekan but was the same in NERICAs 1 and 4 (Fig 2f). Highest LI (0.24) was observed at 60 N kg ha^{-1} in NERICA 6 while the lowest (0.13) was observed in Moroberekan at 120 N kg ha^{-1}. In both NERICA 6 and Moroberekan, the lowest lodging index was observed at 120 N kg ha^{-1}. The two 2- way interactions were significant for different traits except for inner major diameter (b_2), lumen volume and lodging index. No significant interaction of tiller types by nitrogen was observed in all the traits.

The correlation between the lodging traits and lodging index of the main culm and primary tiller is presented in Table 4. Higher correlation coefficients were observed in the main culm than in the primary tiller. The correlation coefficients of internode weight, culm wall thickness, stem breaking force and lumen volume with lodging index were not significant in both the main culm and the primary tiller. All significant correlations of culm morphological traits with lodging index in the primary tiller were also significant in the main culm but not *vice-versa* except for breaking strength (-0.25^{ns} in main culm and -0.55*** in primary tiller). Bending stress recorded the highest significant inverse correlation (-0.79**) with lodging index in the main culm while the height at the center of gravity had the highest significant correlation (0.59**) with lodging index in the primary tiller. Pooled correlation of culm morphological traits across the two culms showed a high correlation values in the range of 0.25 to 0.75 (at 'n' = 72), dominating the relationships (Fig. 3). The correlations of culm length and fresh weight from breaking points to panicle tip, bending moments and breaking strength with other lodging traits dominated these range.

Principal components bi-plot showing the relationships of the lodging traits with the interaction of tiller types by cultivars is shown in Fig. 4 and with nitrogen by cultivars interactions in Fig. 5. In both PCA bi-plots, the first 18 lodging traits with highest loading score (data not shown) among the 22 lodging traits assessed in the first axis were later included in the bi-plots. In fig. 4, the first and second principal component axes of tiller types-by-cultivars interaction bi-plot captured 73.39 and 14.06% variations in lodging traits, respectively. In all, a total of 87.45% variation in the selected lodging traits was captured by the two axes. The two polygons (black and red polygons) within the bi-plot represent the main culm and the primary tiller, respectively. The main culm of all the rice cultivars tends toward the increasing end of the variable axes (the labeled end) while the primary tiller of the rice cultivars tends toward the decreasing end except for the primary tiller of Moroberekan which extended into the polygon representing the main culm. The bending stress of all the lodging traits extended to the opposite end of other variables and was closely related with the main culm of NERICA 4.

For the bi-plot of interaction of nitrogen fertilizer rates and cultivars and the relationship with lodging traits (Fig. 5), the first and second principal components axes of the bi-plot captured 75.01 and 14.54% variation in the lodging traits, respectively. In all, a total of 89.55% variations in lodging traits of the rice cultivars were captured by both axes. The three polygons (black, green, and red) within the bi-plot represent the rates of fertilizer applied. The vertex representing Moroberekan at each rate of the fertilizer extended into the polygon representing the rate of fertilizer next to the rate. Moroberekan under 60 and 120 N kg ha^{-1} as well as NERICA 6 at 120 N kg ha^{-1} showed the highest increase in the lodging traits among the interactions while all the cultivars under no fertilizer application except Moroberekan had the lowest lodging traits. Similar to fig 4, the bending stress was directly opposite other variables and but was closely related with NERICA 1 under no fertilizer application

Discussion

The main culm and the primary tiller of different rice cultivars exhibited differences in culm morphological traits with the primary tiller having reduced culm morphological traits. This cascaded in differences in expression of lodging index between the main culm and primary tiller of the rice cultivars with the main culm having higher lodging resistance (reduced lodging index) than the primary tiller. Poor vascularization of late emerging tillers which decreases the amount of assimilate that is transported to develop both the vegetative and the reproductive part of the tiller could have played a role in the reduced culm morphological traits observed in the primary tiller. Mohapatra et al. (2011) observed a reduction in vascular bundles in subsequent tillers produced by rice which limited the amount of assimilate that can be transported to the primary tiller. Lafarge et al. (2002) also observed that assimilate availability in the main culm at the time of tiller emergence is the main determinant of fertility of the primary tiller. This could as well have affected the culm morphological traits of this tiller. The pattern of resource sharing in which the main culm take as many as possible from the resource pools while leaving the remaining resource for other emerging tillers to share can in addition explain the reduced culm morphological traits observed in the primary tiller.

The non-significant interaction of nitrogen rates with tiller types observed in the study was an indication of the similarities in pattern of response of culm morphological traits of main culm and primary tiller to nitrogen fertilizer rates. This could otherwise imply that the nitrogen fertilizer rates elicited similar morphological response between the main culm and the primary tiller of the rice cultivars. Significant decrease in panicle size, weight of panicle, and reduced vascular bundles had been observed consistently between main culm and primary tiller of rice with and without nitrogen fertilizer (Wang et al. 2016; Wang et al. 2017). These panicle traits are capable of influencing the culm morphological traits towards supporting the panicle weight and could have contributed to the reduced culm morphological traits of the primary tiller observed at all rates of nitrogen fertilizer. The non-significant difference in LI index observed across rates of nitrogen fertilizer applied especially for NERICAs 1 and 4 could be linked to moderate application rates of the fertilizer as well as lodging resistance ability of the rice cultivars. Moderate application of nitrogen fertilizer has little influence on lodging but may increase the susceptibility of rice to lodging when applied at higher rates (Wang et al. 2015). However, the reduced concentration of exchangeable bases as well as other elements within the soil after the experiment across rates of fertilizer applied, (except total nitrogen at 120 kg ha^{-1}) indicated the possibility of these nutrients being taken up by the plants and the need for higher rate of the fertilizer to sustain the total nitrogen concentration of the soil towards increase in lodging traits of the two tillers.

While a non- significant interaction was observed between tiller types and nitrogen fertilizer rates, significant interaction of tiller types and cultivars was observed in this study. This is a clear indication that responses of lodging traits that contribute to lodging resistance of the two culms vary among the cultivars. For example, NERICAs 1 and 4 were both observed to exhibit similar lodging traits in the two culms, while NERICA 6 and Moroberekan exhibited higher lodging traits in the main culm than in the primary tiller. However, the higher lodging traits in these two cultivars only translated to reduced lodging index (increased lodging resistance) in the main culm of NERICA 6 and not in Moroberekan. Meanwhile, NERICA 1 which exhibited similar lodging trait in both the main culm and the primary tiller had reduced lodging index in the main culm than in the primary tiller. The inconsistencies in lodging resistance exhibited by the two culms in some of the cultivars revealed the need to be consistent while selecting tillers to be used in assessing lodging resistance in rice cultivars. The ability of NERICA 4 and Moroberekan to maintain similar LI in both the culm could be attributed to the increased vigour and strength as exhibited by the tillers on the rice cultivars especially the Moroberekan cultivar. In a study conducted by Olagunju et al. (2020) on culm morphological traits of first generation NERICAs, which also included Moroberekan and a locally grown Ofada, Moroberekan was identified as an exceptional cultivar with highest culm morphological traits and vigor and with a sturdy stem. NERICA 4 was also among the cultivars with higher lodging resistant selected in the study. The increased vigour exhibited by Moroberekan even under no fertilizer re-affirms the potential of the cultivars to exhibit traits of improved lodging resistance in the absence of the fertilizer in the main culm and the primary tiller.

Despite the higher lodging traits exhibited by Moroberekan and NERICA 6, the two cultivars were unable to maintain lower lodging index across the culms due to their tall heights. NERICAs 1 and 4 were however observed to have the lowest lodging index across the two culms among the cultivars in the current study. The lowest LI exhibited was attributed to the reduced heights possessed by the rice cultivars. NERICA 1 had earlier been used in the study of structural development and stability of rice (Oladokun and Ennos 2006) and has been observed as a candidate cultivar for comparing the lodging resistance among first generation NERICA cultivars (Olagunju et al. 2020). The similarity in LI of NERICAs 1 and 4 observed implied that NERICA 4 could be a potential cultivar to be identified with NERICA 1 for selecting the most lodging resistant cultivars.

Among the lodging traits, bending stress was observed to contribute the highest significant and inverse correlation to lodging index especially in the main culm. Bending stress may have a very strong link with NERICAs 1 and 4 than with other cultivars as it was revealed in its close relationship with the two cultivars in the PCA bi-plots. Past study conducted on the relationship of culm morphological traits contributing to lodging resistance also revealed similar link of bending stress with NERICA 4. Bending stress has been regarded as a more reliable trait for assessing the mechanical strength in first generation NERICAs (Olagunju et al. 2020). Its close association with NERICAs 1 and 4 indicated higher mechanical strength of the culm which resulted in its increased lodging resistance. The consistency in contribution of stem length and fresh weight from breaking point to panicle top, as well as bending moment, panicle weight, height at the center of gravity, culm and plant height to lodging index across the main culm and primary tiller are indications that these traits are indispensable in lodging resistance evaluation in upland rice.

Conclusion

Culm morphological traits vary widely between the main culm and primary tiller of rice cultivars and do not confer similarity in resistance to lodging in all rice cultivars. The higher culm morphological traits in main culm which resulted in reduced lodging index across cultivars as compared with higher lodging index of the primary tiller emphasized the importance of consistency in tiller selection and the reliability of the main culm for the assessment of lodging resistance differences among rice cultivars. The higher correlation observed between the culm morphological traits of main culm and LI and differences in response of the cultivars between the two culms, in addition, emphasized the need for this consistency. Nitrogen fertilizer can improve the lodging traits of rice cultivars in both the main culm and primary tiller. However, it has little effect on lodging index of some rice cultivars when applied at moderate rates. Cultivars with reduced height and LI such as NERICAs 1 and 4 can be good varietal checks for identifying lodging resistant cultivars under rates of nitrogen fertilizer.

Authors' contribution

The research concept and manuscript was developed by SOO; Material preparation and data collection were performed by PAA, TAA and OJI; Data analysis was performed by SOO; OAO and ALN reviewed the draft manuscript. Nobody who qualified for authorship of this manuscript has been excluded. All authors read and approved the final manuscript.

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Conflict of interest/competing interests

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Figures

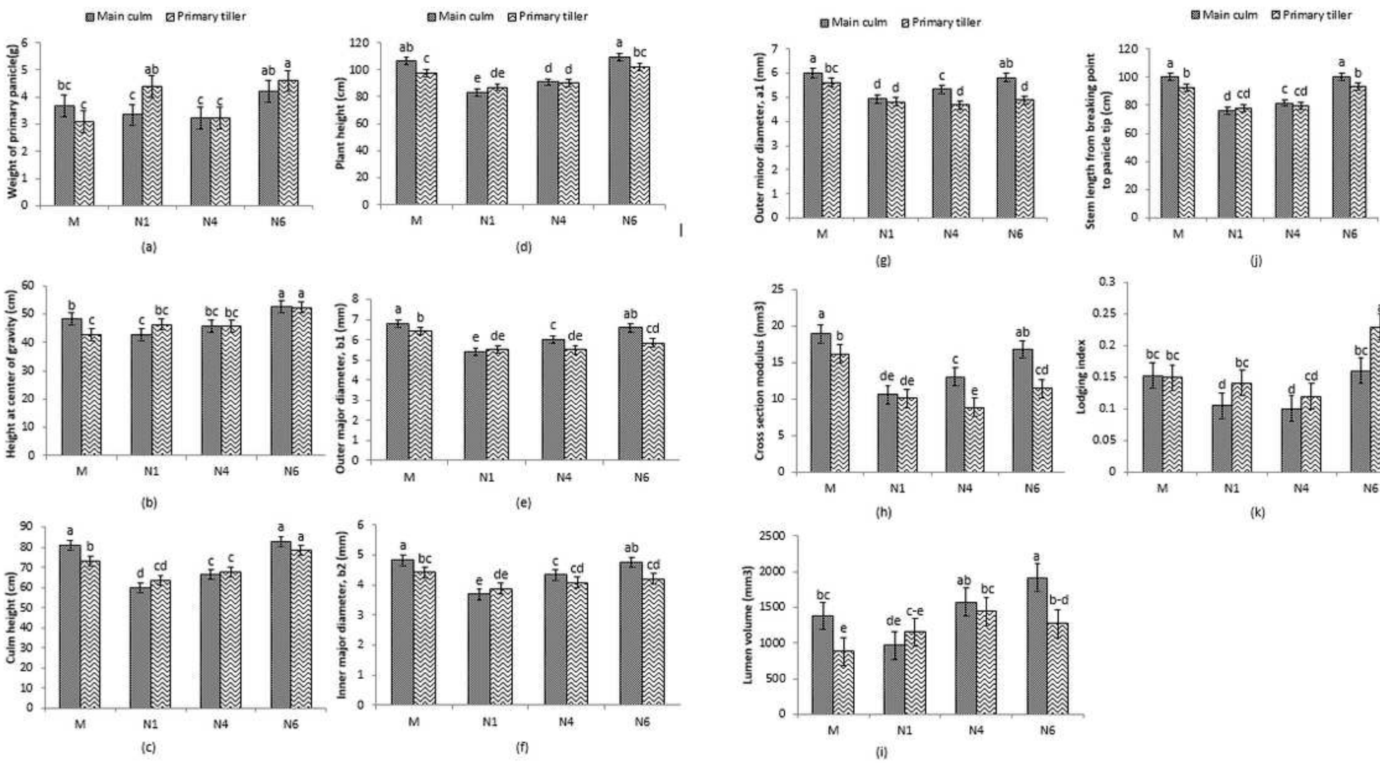

Figure 1

Interaction of tiller types and cultivars on (a) weight of primary panicle, (b) height at center of gravity, (c) culm height (d) plant height (e) outer major diameter, b1 (f) inner major diameter, (g) outer minor diameter, (h) cross section modulus, (i) lumen volume, (j) stem length from breaking point to panicle tip, (k) lodging index, of the main culm and primary tiller of rice cultivars. M= Moroberekan; N1, N4, and N6 = NERICA 1, 4 and 6, respectively

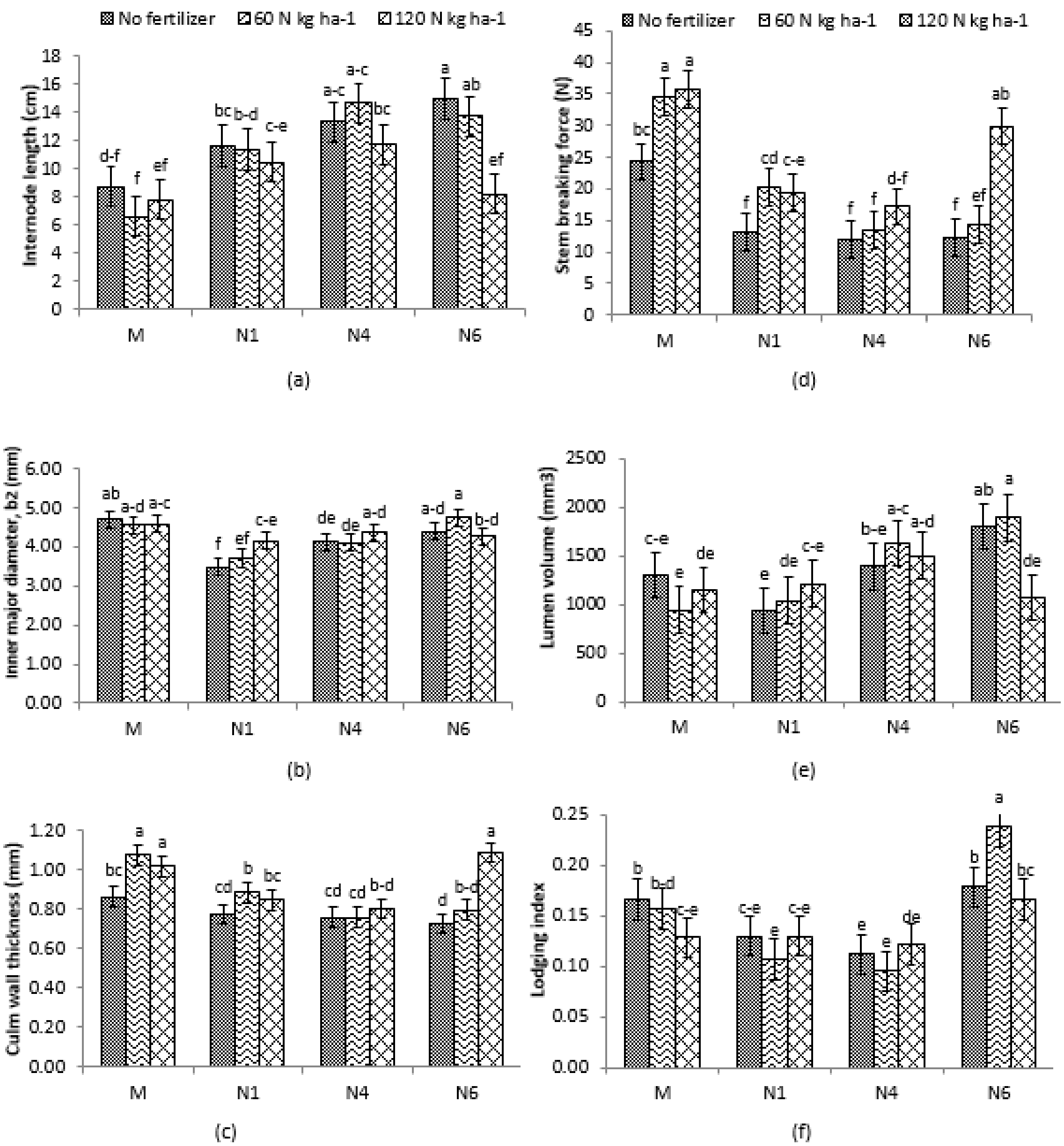

Figure 2

Interaction of nitrogen fertilizer rates and cultivar on (a) internode length, (b) inner major diameter, (c) culm wall thickness, (d) stem breaking force, (e) lumen volume, and (f) lodging index, across the main culm and primary tiller of rice cultivars

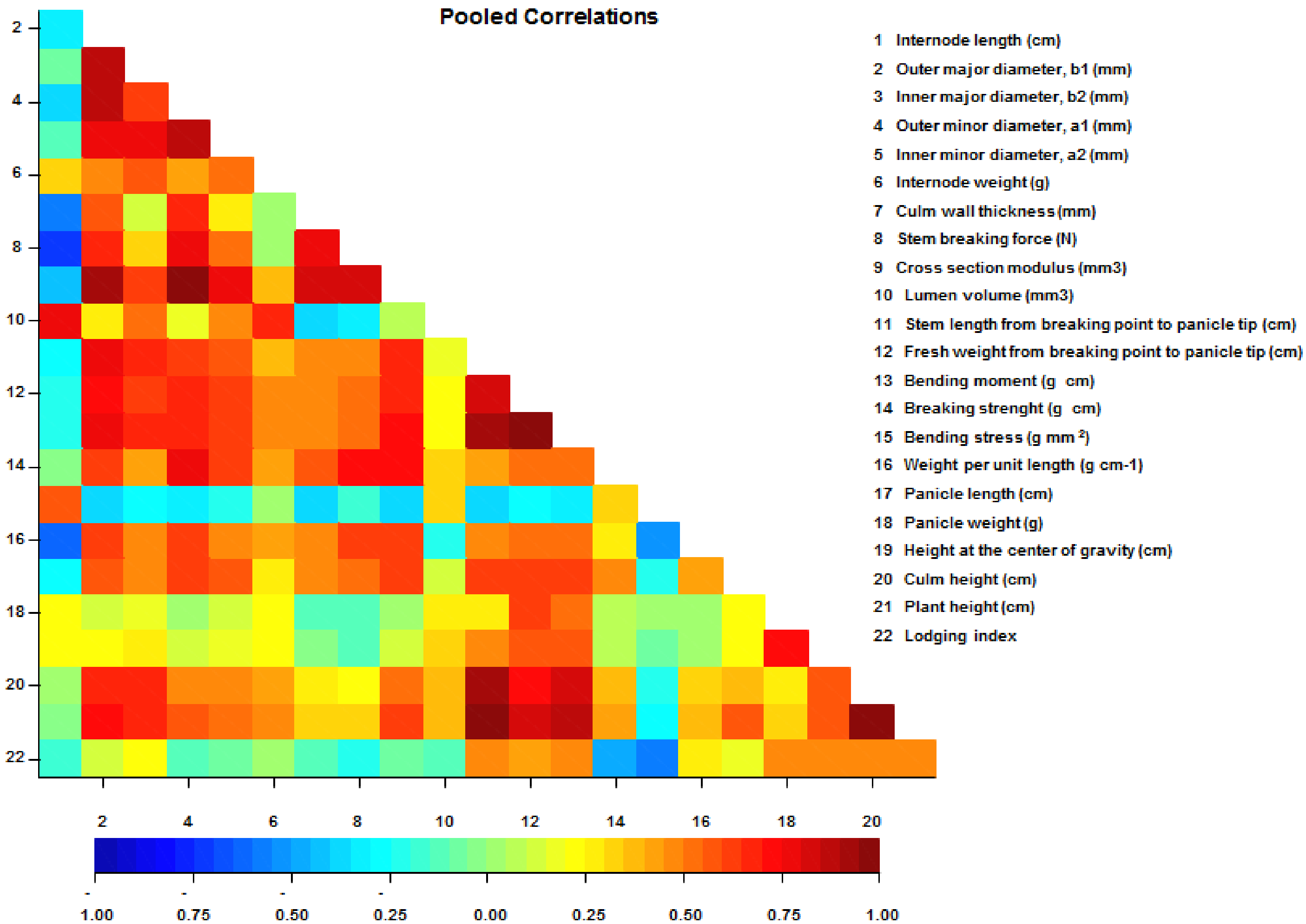

Figure 3

Pooled correlations of culm morphological traits of main culm and primary tiller of rice cultivars under nitrogen fertilizer rates

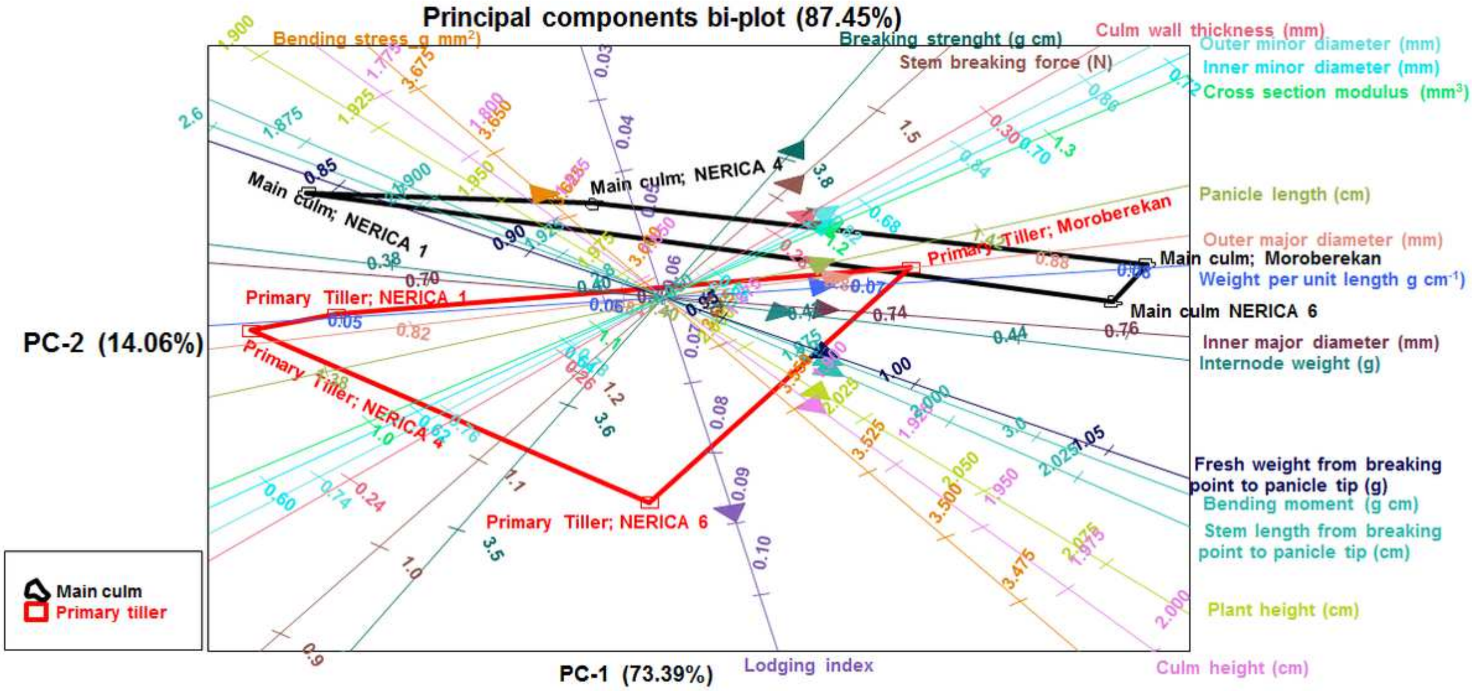

Figure 4

Principal components bi-plot showing the relationships of lodging traits with tiller types and cultivars interaction. The black and red polygons within the bi-plot represent the main culm and primary tiller of the rice cultivars, respectively.

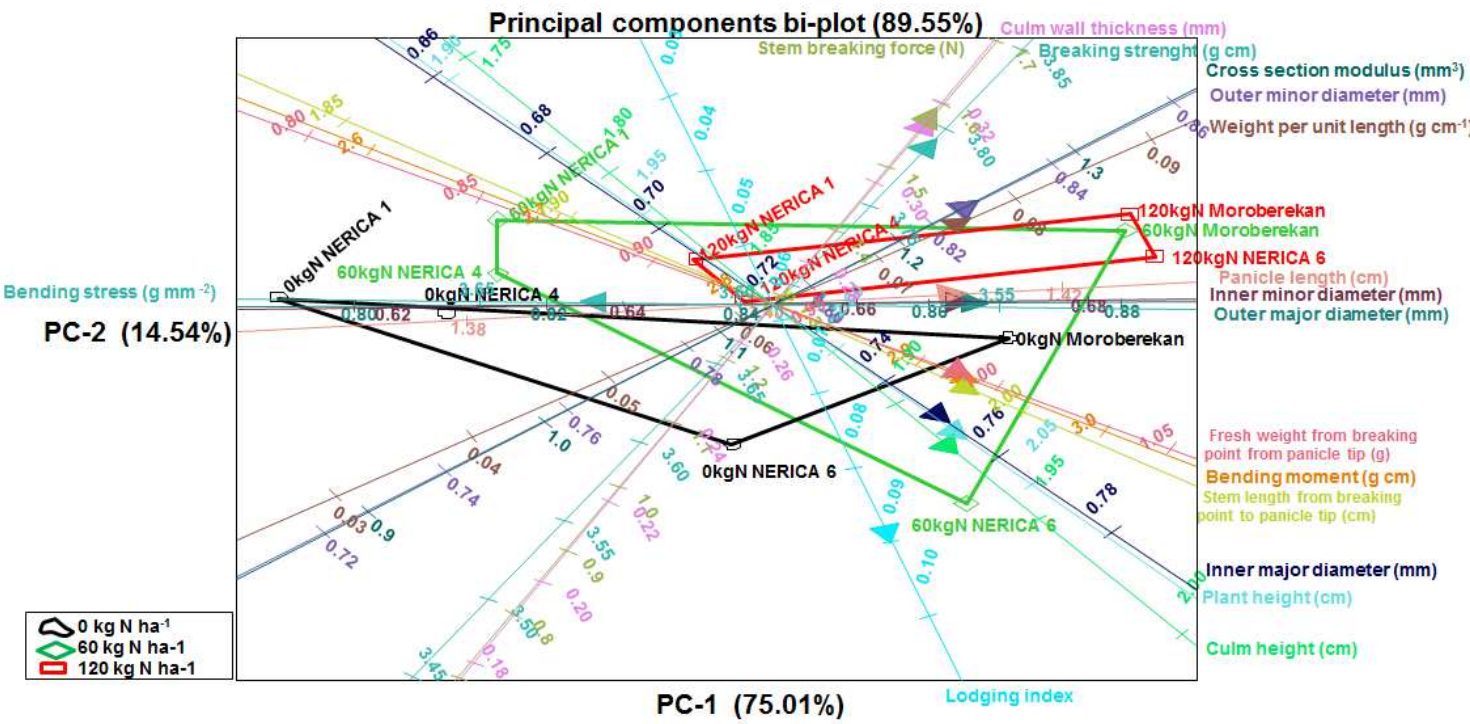

Figure 5

Principal components bi-plot showing the relationships of lodging traits with nitrogen fertilizer rate and cultivar interaction. The black, green and red polygons within the bi-plot represent 0, 60, and 120 N kg ha-

1 applied on the rice cultivars