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Full Length Research Paper

Genotypic variation in coleoptile or mesocotyl lengths of upland rice (*Oryza sativa* L.) and seedling emergence in deep sowing

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Rain-fed upland rice (*Oryza sativa* L.) is one of the important crops in Sub-Saharan Africa (SSA) accounting for over 40% of the area under rice cultivation. In SSA, upland rice is primarily established by dry direct seeding (DS), which saves time and labour, although DS is associated with poor seedling emergence and establishment. It is thought that coleoptile and mesocotyl elongation in rice seedlings enhance emergence in deep sowing. A screen house study was conducted from May to December 2011 at Tokyo University of Agriculture in Japan to determine the effect of coleoptile and or mesocotyl elongation on seedling emergence in deep sowing. Six upland rice genotypes which vary in coleoptile + mesocotyl lengths, and another ten genotypes varying only in mesocotyl lengths were selected and evaluated for seedling emergence at 2, 4, 6 and 8 cm sowing depths. The experiment was laid out in a split-plot design based on randomised complete blocks. Seedling emergence was significantly reduced by sowing depth. Across the genotypes, seedling emergence was not associated with coleoptile + mesocotyl length. And although coleoptile and mesocotyl lengths both increased with sowing depth, seedling emergence in deep sowing was affected largely by mesocotyl elongation rather than coleoptile elongation. We found that only those genotypes that significantly elongated their mesocotyls like Nutsurikui and Plu-go were able to emerge from deep sowing. Our results therefore suggest that seedling emergence in dry direct seeded upland rice can be improved by planting genotypes with long mesocotyls.

Key words: Coleoptile, dry direct seeding, mesocotyl, upland rice.

INTRODUCTION

Rain-fed upland rice (*Oryza sativa* L.) is one of the important crops in Sub-Saharan Africa (SSA) where it accounts for over 40% of the land under rice cultivation (WARDA, 2002). It has increasingly become popular amongst first time rice growers in non traditional rice producing regions of SSA like Uganda because; (1) the yields are stable even in adverse environments (Bouman, 2001), (2) initial cost of establishment is lower because the cost of paddy field development has been deducted (3) it is easy to convert to non rice upland crops and vice versa, and most importantly, (4) it is easy to plant through direct seeding by simply broadcasting, drilling or dibbling seeds in prepared dry to moist soil. Direct seeding also saves time and labour (Pandey and Velasco, 1999) allowing for efficient utilization of family labour (the most predominant form of agricultural labour in SSA) by spreading it out over time and space thereby reducing labour bottlenecks (Singh et al., 1994). However, direct seeding has disadvantages too, that is, because direct seeded upland rice germinates and emerges simultaneously with weeds, it tends to succumb to weed pressure especially where the weeds grow quickly and there is inadequate weed control. In shallow planting,

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direct seeded rice is prone to lodging due to poor anchorage in soil (De Datta, 1986; Moody, 1982). Direct seeding is also commonly associated with poor seedling emergence and establishment, which may result from pre-emergence death of seedlings due to unfavourable seedbed conditions (high soil temperature, moisture deficiency and high soil strength) or the inability of seedlings to emerge from deep sowing; hence rice seedlings with the ability to rapidly and uniformly emerge from deep sowing and in suboptimal conditions are desirable. Whereas pre-emergence death of seedlings directly affects yield by reducing plant population, delayed or non uniform emergence may be a yield reducing factor in late-emerging plants due to competition with the larger early-emergers (Gravois and Helms, 1994). Hence the rate of seedling emergence is critical for subsequent plant survival, fitness in competitive situations (Nielsen, 1991) and optimizing yield. Even so, deep sowing sometimes enhances seedling emergence and establishment because of the higher soil-water content in the seed zone which quickens germination. Emergence ability or seedling vigour is a function of seed quality and genotype (Sun et al., 2007). For instance, seed produced during a year with favourable growing conditions will produce more vigorous seedlings than seed produced during stressful growing seasons. Similarly, seedlings from seed stored for a long time under unfavourable storage conditions will have lower vigour (Kapoor et al., 2011). Moreover, seedling vigour has also been shown to vary among genotypes. It is genetically controlled and modified by the environment (Perry, 1972) and as a trait can be incorporated into high yielding varieties (Seshu and Krishnasamy, 1987). Rice seedlings with the genetic potential for long coleoptiles or mesocotyls may be able to emerge through the soil better and faster than those with short coleoptiles or mesocotyls (Turner et al., 1982). According to the findings of Turner et al. (1982), planting depth influenced rice mesocotyl and coleoptile length and their relative contributions to emergence. Since coleoptile and mesocotyl elongation are primarily determined by genotype and only influenced by sowing depth, the objective of this study was to determine how inherent differences in genotypic coleoptile and or mesocotyl elongation of upland rice affect seedling emergence from varying sowing depth in aerobic soil conditions. High seedling emergence rates for dry direct seeded upland rice can possibly be realized on farmers' fields by selection of genotypes with long coleoptiles or mesocotyls.

MATERIALS AND METHODS

Experiment 1

Following from a study that was conducted to determine inherent genotypic differences in mesocotyl and coleoptile elongation in 63 upland rice genotypes, we selected 6 genotypes varying in mesocotyl + coleoptile length (Table 1) and evaluated them in the screen house for emergence in 2, 4, 6 and 8 cm sowing depth. The 63 upland rice genotypes of diverse origins were obtained from the National Institute of Agro-biological Sciences (NIAS) gene bank and the Tropical crop science laboratory of Tokyo University. Thirty four (34) of the genotypes were from Africa, 25 from Japan, 3 from Taiwan and 1 from Myanmar.

The experiment was laid out as a split plot design based on the randomized complete block design (RCBD) with two replications. Sowing depths of 2, 4, 6 and 8 cm constituted the main plots and the six genotypes were assigned to the sub-plots. Sieved silt clay loam soil was added to concrete plots to a depth of 15 cm and carefully levelled to ensure uniformity. Planting spots were marked at a spacing of 20 by 20 cm and seed holes made by driving a cylindrical rod (5 cm in diameter) into the soft ground up to the corresponding sowing depth. Three seeds were sown into each of the seed holes, covered with the same soil and pressed gently to ensure adequate contact between the seeds and soil. The plots were then watered at regular intervals to ensure germination and subsequent seedling growth. Counts of emerged seedlings were recorded daily beginning from the fourth day after sowing and continued for 8 days when emergence was considered complete. Data of the emergence counts was used to compute a single summary value (speed of emergence) for easy comparisons between genotypes of emergence ability. To eliminate the effects of variability in the rates of seedling emergence from time to time, overall speed of emergence (SOE) was computed as the average of instantaneous SOE's determined for specific dates when emergence counts were taken, using the formula:

$$SOE = \left(\frac{S_1}{t_1} + \frac{S_2}{t_2} + \cdots + \frac{S_n}{t_n}\right) \Big/ T$$

Where S_1, S_2 and S_n are the total number of emerged seedlings by time t_1, t_2 and t_n corresponding to the days after sowing when emergence counts were taken. T represents the total number of times that counts were made. Data from the experiment was subjected to Analysis of Variance (ANOVA) and a series of linear contrasts to compare emergence and speed of emergence in relation to earlier determined genotypic coleoptile and mesocotyl lengths. Relationships between different attributes were determined by Pearson's correlation coefficient. The statistical software used was GENSTAT Seventh Edition DE 3 (2008).

Experiment 2

In a separate experiment to determine the effect of inherent genotypic differences in mesocotyl lengths on seedling emergence, 10 genotypes varying in mesocotyl lengths (Table 2) but with relatively similar coleoptile lengths were selected and evaluated for emergence in 2, 4, 6 and 8 cm sowing depth.

The experiment was set up as a split plot design based on RCBD with 2 replications in plastic boxes of dimensions 68 × 42 × 14 cm^3. Sowing depths of 2, 4, 6 and 8 cm constituted the main plots and the 10 genotypes were designated as sub plots. Seeds were sown into a mixture of sand and *akadama* soil (1:1 ratio). *Akadama* is inert inorganic volcanic clay with good water retention abilities used as a potting medium in Japan. The mixture of *Akadama* soil and sand were used to ease excavation of seedlings and allow for observations of coleoptile and mesocotyl elongation to be made. The soil - sand mixture was added to the plastic boxes and uniformly spread to provide a 4 cm layer on to which the rice seeds were sown and covered up to the required sowing depth with the same soil-sand mixture. For each main plot, a total of 10 seeds per genotype were used with 5 seeds per replication. Water was added to the boxes at regular intervals (when the top soil appeared dry) to maintain adequate soil moisture for germination. 14 days after sowing, the seedlings were carefully excavated and washed, and

Table 1. Selected upland rice genotypes with different mesocotyl and coleoptile lengths determined in seedlings grown in the dark under submergence at 30°C and 95% humidity for 10 days.

Genotype	Origin	Mean ± standard deviation		
		Mesocotyl length (cm)	Coleoptile length (cm)	Mesocotyl + Coleoptile length (cm)
Sankanka	JPN	0.38 ± 0.09	3.52 ± 1.71	3.89 ± 1.83
Yar-2	MMR	0.67 ± 0.07	3.79 ± 0.44	4.47 ± 0.48
NERICA-11	CIV	0.26 ± 0.08	4.33 ± 0.60	4.59 ± 0.62
NERICA-4	CIV	0.35 ± 0.08	4.29 ± 0.37	4.63 ± 0.39
Shichimenchou Mochi	JPN	0.44 ± 0.10	5.23 ± 0.40	5.67 ± 0.42
Gaisen Mochi	JPN	0.53 ± 0.40	5.39 ± 0.62	5.92 ± 0.65

Table 2. Selected upland rice genotypes with different mesocotyl lengths but with relatively similar coleoptile lengths.

Genotype	Origin	Mesocotyl length (cm)	Coleoptile length (cm)	Mes + Col (cm)
ACC1697 Malagasy	ZMB	0.30	3.1	3.4
Bawku Market	GHA	0.70	3.7	4.4
Zebila Market	GHA	0.85	3.8	4.7
Ex Dar Es Salaam	TZA	0.90	2.7	3.6
Bogutti	SLE	1.15	4.0	5.1
IS 280	CIV	1.35	4.3	5.6
Tarupatsumochi	TWN	1.80	3.9	5.7
Bengbete	SLE	1.93	3.0	5.0
Plu Go	LBR	2.50	4.0	6.5
Nutsurikui	TWN	4.40	3.2	7.6

coleoptile and mesocotyl lengths determined. The two experiments are related, in that experiment 1 was conducted to determine the effect of coleoptile + mesocotyl length on seedling emergence and based on the findings; it became necessary to conduct a second experiment (experiment 2) to find out the role of mesocotyl elongation in seedling emergence.

RESULTS

Experiment 1

Seedling emergence

Seeding emergence decreased significantly with sowing depth. We found significant differences in seedling emergence among the rice genotypes tested, as well as significant interactive effects of genotype and sowing depth on seedling emergence (Figure 1). Generally good seedling emergence occurred in 2, 4 and 6 cm sowing depths, but became largely reduced at 8 cm depth. We observed 89.2, 93.5 and 84.2% emergence for 2, 4 and 6 cm depths sowings, respectively, against 33% emergence for the 8 cm sowing. Although seedling emergence was generally poor at 8 cm depth, obvious differences could be seen among genotypes. The early and quick emergers were clearly distinct from the late and slow emergers. Whereas the quick emergers, Sankanka, NERICA-4 and NERICA-11 attained more than 50% emergence, the slower emergers, Yar-2, Schichimenchou Mochi and Gaisen Mochi could only show about 10% emergence.

Speed of emergence

Speed of emergence (SOE), a measure of the rate at which seedlings grow out of soil or a growth medium in which they are planted is represented by the number of seedlings emerged per unit time. Sowing depth significantly lowered SOE for all genotypes, as indicated by the strong negative correlation (r = -9.4) between SOE and sowing depth. Individual genotypes responded differently to sowing depth. Some genotypes showed more rapid declines in SOE with sowing depth rather than others (Figure 2).

The rate of decline in SOE with sowing depth indicated by coefficient of correlation (r) was lower for the good emergers and higher for the poor emergers. One outstanding genotype - Sankanka appeared to be little affected by sowing depth (r = -0.32). Sankanka emerged significantly faster and achieved the best final stand even at 8 cm depth. We found a good relationship between

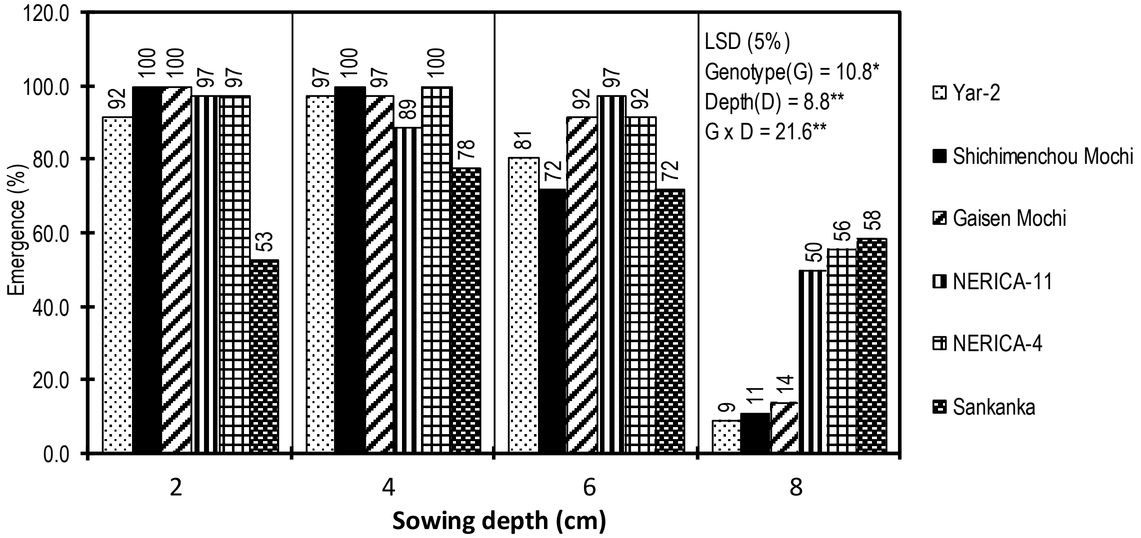

Figure 1. Emergence percentage of six upland rice genotypes from different sowing depths 12 days after sowing. Inset are Fisher's Least Significant Difference (LSD) values; * Significant at 5% level. ** Significant at 1% level. % emergence was rounded off to the nearest whole number

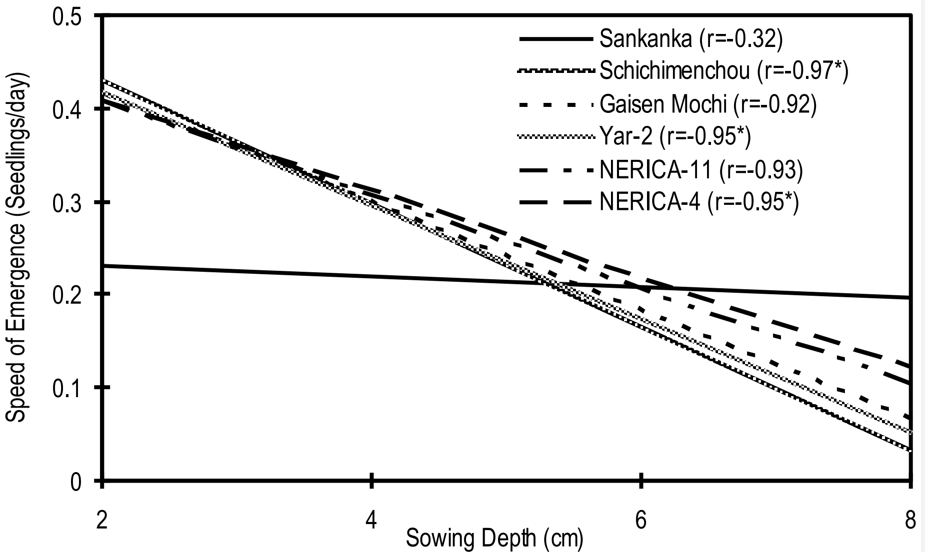

Figure 2. A comparison of the correlation between speed of emergence and sowing depth for selected upland rice genotypes that vary in coleoptile + mesocotyl length.

SOE and final emergence percentage (12 days after sowing). Genotypes with significantly higher mean emergence percentages (Figure 1) also showed higher SOE, especially at greater sowing depths (Table 3). Similar findings recurred in the time course analysis of seedling emergence of the different genotypes from varying sowing depths (Figure 3). Whereas maximum and final seedling emergence counts were realized just within 6 to 7 days after sowing in the shallow 2 and 4 cm for most of genotypes, it took 8 to 10 days for the deeper 6 and 8 cm depth sowings. Sankanka, NERICA-4 and NERICA-11 emerged earlier from 8 cm depth than Gaisen Mochi, Shichimenchou mochi and Yar-2. Our study found a negative relationship between coleoptile + mesocotyl elongation determined under submergence (Table 1) with emergence or SOE. Increase in coleoptile + mesocotyl elongation did not correspond to increased emergence or SOE. This may have perhaps been due to the difference in conditions or media in which potential coleoptile and mesocotyl elongation were determined versus conditions in which seedling emergence was evaluated. The correlation coefficient (r) between

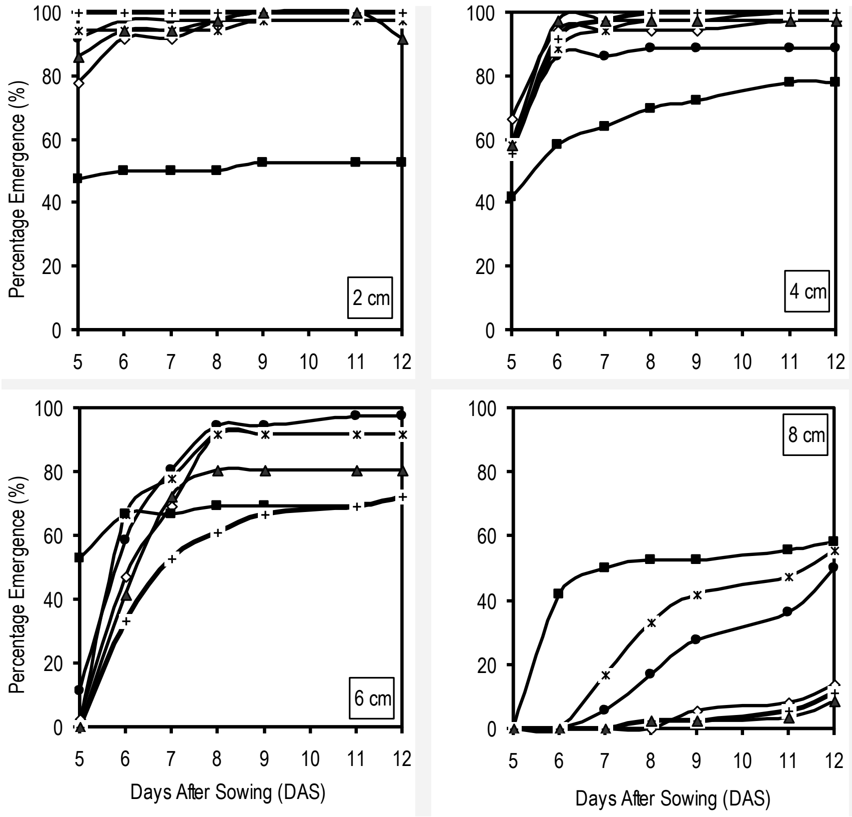

Figure 3. Time course of genotypic seedling emergence from varying sowing depth. Inset text boxes show sowing depths. Genotypes represented by different line markers; (■) – Sankanka, (▲) – Yar-2, (◇) – Gaisen mochi, (+) - Shichimenchou mochi, (✳) – NERICA-4 and (●) – NERICA-11.

Table 3. Speed of emergence (SOE) of selected upland rice genotypes from different sowing depth.

Genotype	Sowing depth (cm)			
	2	4	6	8
Yar-2	0.37	0.35	0.22	0.01
Shichimenchou Mochi	0.39	0.35	0.17	0.01
Gaisen Mochi	0.36	0.35	0.24	0.01
NERICA-11	0.38	0.32	0.27	0.06
NERICA-4	0.38	0.34	0.26	0.09
Sankanka	0.20	0.25	0.26	0.16

LSD (5%): Genotype = 0.027, sowing depth = 0.022, variety X sowing depth = 0.054. CV = 10.8%.

coleoptile or mesocotyl elongation and SOE was -0.66 and -0.58 respectively.

Experiment 2

Effect of selection for increased mesocotyl length on seedling emergence

We found a strong and significant positive relationship ($r = 0.69$, $p<0.05$) between earlier determined genotypic mesocotyl length and seedling emergence. Nutsurikui and Plu-go which had longer mesocotyls emerged significantly better than those with shorter mesocotyls. The relationship between pre-determined mesocotyl elongation and seedling emergence seemed stronger and more significant with sowing depth (Table 5). We also observed that seedling emergence in deep sowing was positively correlated with coleoptile + mesocotyl length. But there was a weak correlation between coleoptile length and seedling emergence in deep sowing.

Sowing depth, mesocotyl or coleoptile elongation and seedling emergence

Seedling emergence combined for all genotypes rapidly decreased with sowing depth (Figure 4) in spite of the high variability among individual genotypes, especially at greater depths (Table 4). Seedling emergence was generally good for the 2 and 4 cm depth sowings. At 6 cm sowing depths however, some genotypes could barely emerge while others like Nutsurikui, Plu go, IS-280, and Zebilla attained significantly high seedling emergence

Table 4. Mesocotyl and coleoptile elongation, and seedling emergence from varying sowing depth of 10 upland rice genotypes selected for the study based on varying pre-determined mesocotyl lengths.

Genotype	Sowing depth (cm)	Mean ± Standard Deviation		Seedling emergence rate
		Coleoptile length (cm)	Mesocotyl length (cm)	
ACC-1697 Malagasy	2	1.85 ± 0.16	0.02 ± 0.03	4.5
Bawku Market		1.69 ± 0.27	0.09 ± 0.07	5.0
Benbete		1.99 ± 0.21	0.41 ± 0.13	3.5
Bogutti		2.44 ± 0.21	0.18 ± 0.05	4.0
Ex Dar es Salam		2.23 ± 0.16	0.30 ± 0.12	4.0
IS-280		2.20 ± 0.27	0.43 ± 0.12	4.0
Nutsurikui		1.61 ± 0.35	1.29 ± 0.22	5.0
Plu go		2.00 ± 0.27	0.59 ± 0.29	4.5
Tarupatsumochi		2.29 ± 0.34	0.21 ± 0.16	2.0
Zebila		2.22 ± 0.11	0.21 ± 0.14	5.0
ACC-1697 Malagasy	4	2.17 ± 0.27	0.06 ± 0.02	2.0
Bawku Market		2.74 ± 0.17	0.34 ± 0.08	4.5
Benbete		2.21 ± 0.26	0.54 ± 0.23	2.5
Bogutti		2.86 ± 0.29	0.33 ± 0.13	4.5
Ex Dar es Salam		2.55 ± 0.06	0.38 ± 0.15	1.0
IS-280		2.82 ± 0.34	0.96 ± 0.34	4.5
Nutsurikui		1.57 ± 0.17	2.59 ± 0.25	5.0
Plu go		2.52 ± 0.21	0.91 ± 0.20	4.0
Tarupatsumochi		1.74 ± 0.41	0.45 ± 0.24	0.5
Zebila		2.81 ± 0.51	0.36 ± 0.13	3.0
ACC-1697 Malagasy	6	2.51 ± 0.29	0.03 ± 0.07	0.0
Bawku Market		3.35 ± 0.59	0.32 ± 0.09	2.0
Benbete		3.02 ± 0.25	0.51 ± 0.29	1.0
Bogutti		3.28 ± 0.28	0.33 ± 0.09	0.5
Ex Dar es Salam		2.65 ± 0.42	0.35 ± 0.13	0.5
IS-280		3.69 ± 0.37	0.93 ± 0.17	2.5
Nutsurikui		2.66 ± 0.49	3.16 ± 0.31	5.0
Plu go		2.87 ± 0.24	1.03 ± 0.27	2.5
Tarupatsumochi		3.40 ± 0.48	0.72 ± 0.23	2.0
Zebila		3.19 ± 0.34	0.24 ± 0.01	2.5
ACC-1697 Malagasy	8	2.41 ± 0.34	0.03 ± 0.05	0.0
Bawku Market		2.92 ± 0.59	0.34 ± 0.12	0.0
Benbete		2.53 ± 0.46	1.05 ± 0.40	0.0
Bogutti		2.99 ± 0.67	0.65 ± 0.12	0.0
Ex Dar es Salam		2.81 ± 0.46	0.51 ± 0.20	0.0
IS-280		3.76 ± 0.66	0.66 ± 0.15	0.0
Nutsurikui		3.77 ± 0.40	3.35 ± 0.68	4.5
Plu go		4.00 ± 0.36	1.77 ± 0.28	0.0
Tarupatsumochi		3.94 ± 0.51	0.74 ± 0.19	0.0
Zebila		3.48 ± 0.48	0.46 ± 0.21	0.0
LSD (5%)	Genotype (G)	0.35**	0.21**	1.07**
	Depth (D)	0.22**	0.14**	0.68**
	G X D	0.71*	0.43**	2.15
CV		13.0	30.4	44.3

Values of coleoptile and mesocotyl length are means ± standard deviation for 10 seedlings. * Significant at 5% level. ** Significant at 1% level.

Table 5. Relationship between pre-determined inherent genotypic mesocotyl, coleoptile and mesocotyl + coleoptile elongation and seedling emergence from varying sowing depths.

Sowing depth (cm)	Pearson coefficient of correlation (r)		
	Mesocotyl length (cm)	Coleoptile length(cm)	Mesocotyl + Coleoptile (cm)
2	0.04	-0.09	0
4	0.36	0.43	0.51
6	0.79**	0.25	0.85**
8	0.83**	-0.24	0.67*
Combined depth	0.69*	0.15	0.70*

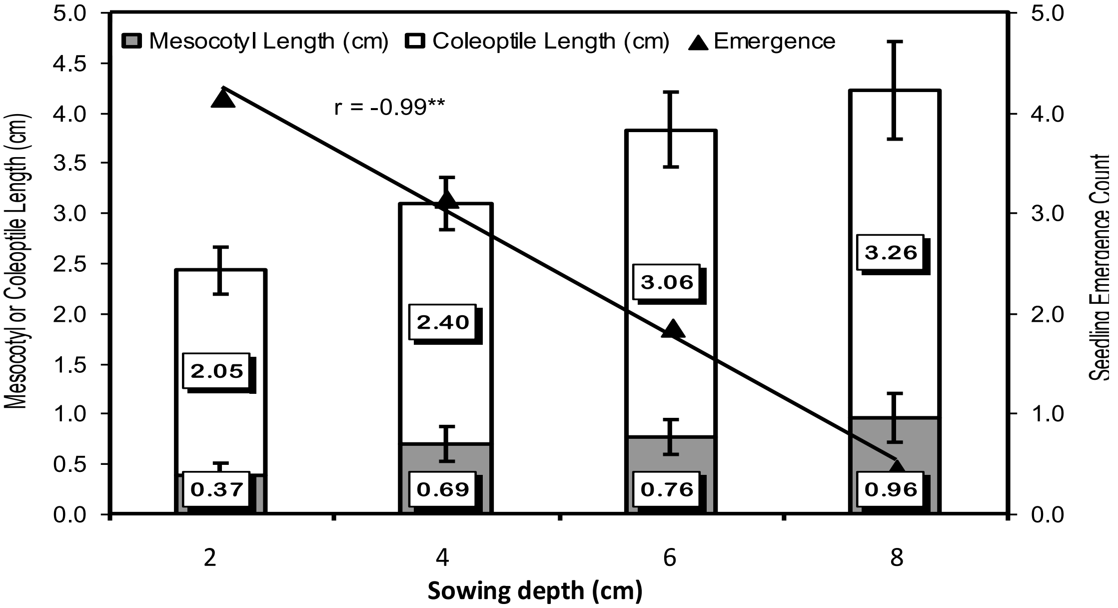

Figure 4. Relationship of mesocotyl elongation, coleoptile elongation and seedling emergence with sowing depth. Mesocotyl and coleoptile data are means, bars are standard deviations. Correlation coefficient(r) for mesocotyl or coleoptile elongation and sowing depth is 0.97 (P<0.01) and 0.98 (P<0.01) respectively. The scale on the Y-axis represents seedling emergence counts (▲).

rates (≥50%).

Only Nutsurikui successfully emerged from 8 cm sowing depth, achieving 90% seedling emergence after 12 days. Nutsurikui consistently attained the highest seedling emergence rates at all sowing depths (Table 4). Although increasing sowing depth had undesirable effects on seedling emergence, it appeared to enhance mesocotyl elongation. Our study found a strong significant relationship ($r = 0.97$, $p<0.01$) between mesocotyl elongation and sowing depth (Figure 4). Similarly, there was a highly positive correlation ($r = 0.98$, $p<0.01$) between coleoptile elongation and sowing depth despite the initial relative similarity in coleoptile lengths of the genotypes selected for the study. Accordingly, both mesocotyl and coleoptile lengths seem to vary and increase with sowing depth.

Our study further analysed the general relationship between mesocotyl and coleoptile elongation, as well as the interactive relationship between mesocotyl and coleoptile for different sowing depths and found a weak general relationship ($r = 0.2$) but varied relationships for different depths. There were dissimilar patterns of mesocotyl and coleoptile elongation for 2, 4 and 6 cm sowing depths (Figure 5). In the deeper 8 cm sowing depth however, increase in mesocotyl elongation seemed to correspond with increase in coleoptile elongation. The interactive association between mesocotyl elongation and coleoptile elongation appeared to gradually change with increasing sowing depth from a dissimilar negative association towards a strong complementary relationship.

DISCUSSION

The results of our study suggest that although seedling emergence of dry direct seeded upland rice from deep sowing is a function of both coleoptile and mesocotyl elongation, it appears to be largely the effect of mesocotyl

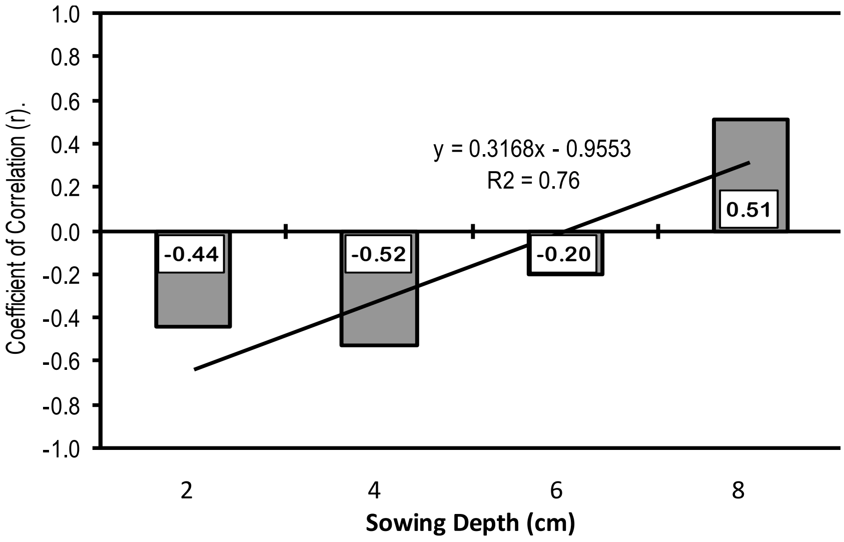

Figure 5. Interactive relationship between coleoptile and mesocotyl elongation at different sowing depths. Inset are coefficient of correlation (r) values determined between coleoptile and mesocotyl elongation in seedlings sown at different depths.

elongation. We found a strong relationship between mesocotyl elongation and seedling emergence in deep sowing (Table 5). Only those genotypes which were able to significantly elongate their mesocotyls like Nutsurikui and Plu-go (Figure 6) emerged in deep sowing.

Our findings replicate those of Luo et al. (2007) who found a significant positive interactive effect of mesocotyl elongation and sowing depth on seedling emergence. They showed that mesocotyl elongation increasingly influenced seedling establishment when sowing depth was increased, but only extremely long coleoptiles affected seedling establishment. Similarly, Chung (2010) observed a significant positive relationship between mesocotyl elongation in weedy rice (close relative of cultivated rice) and seedling emergence but found no correlation between coleoptile length and emergence.

We also found in our study that coleoptile and mesocotyl length increase with sowing depth (Figure 4). Chung (2010) and Luo et al. (2007) reported a similar result. We noted however that the relationship between coleoptile elongation and mesocotyl elongation tended to vary with sowing depth, gradually shifting from a dissimilar negative association towards a more complementary relationship as sowing depth increased (Figure 5). And our observations seem to suggest that the role played by coleoptile or mesocotyl elongation in seedling emergence varies according to sowing depth. The variation in seedling emergence roles of coleoptile and mesocotyl elongation could perhaps be related to their relative positions on a rice seedling, that is, mesocotyl at the base and joined to the coleoptile at the top. And as such, elongation of the mesocotyl serves to elevate the coleoptile to a point within a few millimetres of the soil surface where upon the coleoptile extends outwards to make contact with the atmosphere and allow the primary leaves to emerge (Mgonja et al., 1994). Thus, inability of the mesocotyl to elongate in deep seed placement would result in failed seedling emergence if the coleoptile is not capable of reaching the soil surface. According to Dov Koller (2011), the coleoptile lacks meristematic activity, and therefore its growth is entirely dependent on elongation of existing cells which places an upper limit on its final length. The mesocotyl on the other hand contains an intercalary meristem, albeit of limited life span, that enables it to continue growing long after the coleoptile has exhausted its own growth potential. Growth in length of the mesocotyl varies with sowing depth, and the mesocotyl is very short in seedlings which germinate near the soil surface (Saha, 1956).Thus, the dissimilar negative association between coleoptile and mesocotyl elongation that we observed at 2, 4 and 6 cm sowing depths may have been due to the negligible mesocotyl elongation near the soil surface, which could not match up with coleoptile elongation. But an increase in sowing depth to 8 cm enhanced mesocotyl elongation, making it consistent with coleoptile elongation (Figure 5). Heckman et al. (2002), Newman and Moser (1988) found that coleoptiles of warm-season forage grasses were not affected by sowing depth, yet the sub-coleoptile internode (mesocotyl) increased with sowing depth. M'Ragwa et al. (2001) showed that selection for coleoptile length in finger millet (*Pennisetum glaucum* (L.) did not increase seedling emergence. Luo et al. (2007) on the other hand showed that a change in mesocotyl length from short to long greatly improved seedling establishment although there was no obvious correlation between coleoptile and mesocotyl elongation. Wu et al. (2005) hinted that the longer length of mesocotyl and a higher proportion

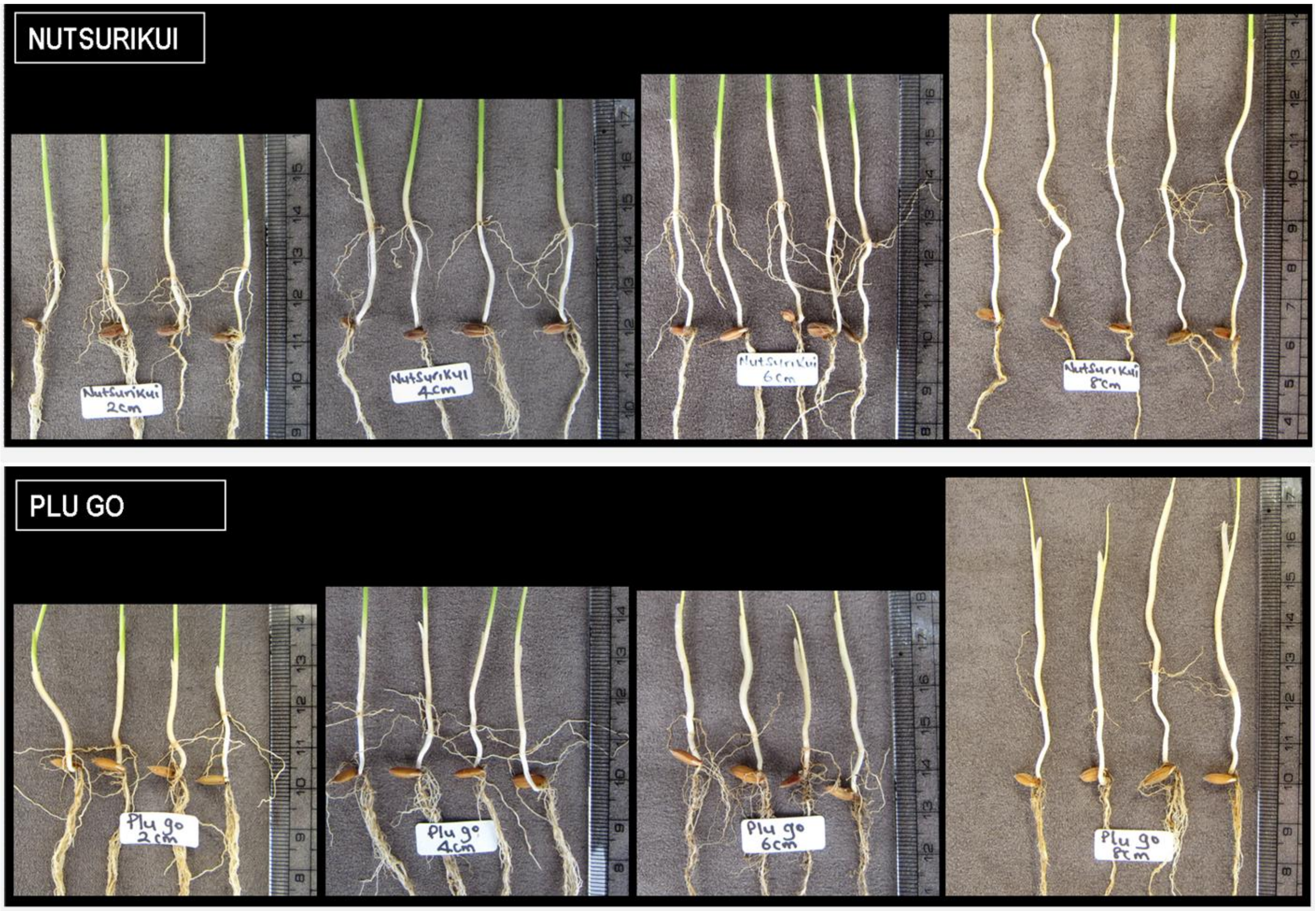

Figure 6. Seedlings of selected upland rice genotypes showing coleoptile and mesocotyl elongation in different sowing depths. From left to right, the pictures show seedlings sown at 2, 4, 6 and 8 cm, respectively.

mesocotyl elongation in upland rice might be an adaptation to boost seedling emergence from deep sowing. Hence our findings suggest that good seedling emergence in dry direct seeded upland rice from deep sowing is largely the effect of mesocotyl elongation, and the findings correlate well with results of many similar studies, that is, Newman and Moser (1988), Luo et al. (2007) and Wu et al. (2005). A similar effect of mesocotyl (sub-coleoptile) elongation was observed by Heckman et al. (2002) on emergence of buffalo grass seedlings.

In Experiment 1, we found that selection for long coleoptile or mesocotyl length based on seedling emergence under submergence had little effect on seedling emergence in dry direct seeding. Although the selected genotypes differed considerably in their seedling emergence (Figure 1) and SOE (Figure 2), the differences were not associated with the genotypic variation in coleoptile + mesocotyl elongation earlier determined under submergence. In experiment 2 however, we saw that the genotypes with long mesocotyl lengths selected based on their growth in soil-sand culture exhibited higher seedling emergence rates in dry direct seeding (Table 5). Experiment 1 results therefore suggest that in selection of genotypes for dry direct seeding, evaluation for mesocotyl or coleoptile elongation would be better in drained soil-sand but not under submergence. Submerged conditions promote coleoptile elongation but inhibit development of the mesocotyl (Yamauchi and Biswas, 1997). Greater emphasis on selecting for long mesocotyl can improve seedling emergence in dry direct seeded upland rice systems.

Conclusion

This paper has shown that it is possible to improve seedling emergence in dry direct seeded upland rice by planting genotypes with long mesocotyls. This study set out to determine whether inherent differences in coleoptile and mesocotyl lengths of rice genotypes have a bearing on their ability to emerge in deep sowing. One of the more significant findings to emerge from this study was that although coleoptile and mesocotyl length both increased with sowing depth, coleoptile + mesocotyl length was not associated with seedling emergence in deep sowing. Emergence in deep sowing was largely the effect of mesocotyl elongation as seen in the genotypes Nutsurikui and Plu-go. Evidence from this study suggests that the problem of poor seedling emergence that occurs on farmer's fields due to their inability to regulate sowing depth can possibly be resolved by identifying or developing and recommending rice genotypes with inherently longer mesocotyls. It would however be interesting to evaluate seedling emergence in deep sowing under field conditions for genotypes with varying mesocotyl lengths.

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