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RESPONSE OF BREAD WHEAT GENOTYPES TO DROUGHT SIMULATION UNDER A MOBILE RAIN SHELTER IN KENYA

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ABSTRACT

Selection of drought tolerant wheat genotypes for Arid and Semi-arid lands (ASALS) of Kenya, which consist of 83% of total land area, can provide alternative agricultural land for expansion. To reduce cost of dryland research, simulated drought under a rain shelter offers a good alternative for screening because marginal areas are vast and widespread. Four moisture regimes which simulated terminal, early, mid- and late- season droughts were created under the mobile rain shelter at Njoro in 1998/99, by applying drip irrigation (i) up to seedling stage (70 mm) (ii) through tillering (82 mm) (iii) up to anthesis (94 mm) and (iv) grain filling (106 mm), respectively, to determine drought responses of five wheat varieties (Duma, R748, R830, R831 and R833) and identify drought tolerant genotypes. Control watering regime had 118 mm applied at all stages. Yield and yield components in each season and the two seasons combined showed significant difference ($P<0.05$ and 0.01, respectively). Early drought during seedling stage and tillering caused significant reduction in plant heights, tiller number and number of reproductive tillers. However, drought from anthesis and grain filling to maturity caused significant ($P<0.05$) reduction in ear length (16.9%), spikelets/head (14.3%), 1000-kernel weights (22.4%) and an increase in the number of sterile florets/head (28.3%), compared to control. Seedling and reproductive stage (anthesis and grain filling) droughts caused the highest grain yield reduction (25 and 67%, respectively), indicating that they were the most critical stages in moisture requirement compared to control. Genotype R748 out-performed Duma (check) in all moisture regimes, and was recommended for field testing and participatory evaluation. From this study, it is possible to select drought tolerant cultivars using mobile rain shelters by drought simulations in Kenya.

Key Words: Duma, irrigation, dryland, moisture stress

RÉSUMÉ

La sélection des génotypes tolérant a la sécheresse pour les terres arides et semi-arides (ASALS) du Kenya, lesquelles consistent a 83% de la surface de terre, peut pourvenir de terre pour l'expansion agricole. Pour réduire le coût de la recherche dans les régions arides, la sécheresse simulée a l'abris de la pluie offre une bonne alternative pour la sélection parce que les aires marginales sont vastes et éparpillées. Pour les régimes humides qui sont simulés a l'état terminal, matinal, en pleine et en retard des saisons séches étaient crées sous un abri mobile a Njoro entre 1998/1999, par application de l'irrigation par goutte 1) jusqu'a l' étape de semis (70 mm) ii) a travers le labourage (82 mm), iii) jusqu'a l'étape d'anthere (94 mm) et iv) graine nourrissante (106 mm), respectivement pour déterminer les réponses a la sécheresse aux cinq variétés de blé (Duma, R748, R830, R831 et R833) et identifier les génotypes tolérant la sécheresse. Le contrôle du régime en eau avait 118 mm appliqués a toutes les étapes. Les composants de la production et du rendement dans chaque saison et les deux saisons combinées ont montré une différence significative ($P<0{,}005$ et 0,01 respectivement). La sécheresse matinale durant l'étape de semis et de labeur a causé une réduction significative en hauteurs de plante en nombre de laboureurs et nombre de laboureurs reproductifs. Cependant, la sécheresse à partir de maturité d'anthere et graine nourrissante a causé une réduction significative ($P<0{,}05$) en longueur d'épi (16,9%), de pointes/ tête (14,3%), poids de 1000 grains (22,4%) et croissance dans le nombre de fleurons steriles / tête (28,3%) comparée au contrôle. L'étape de semis et reproductive (anthere et graine nourrissante) de sécheresse a causé la réduction la plus élevée en rendement de graines (25 a 67%, respectivement)., indiquant qu'elles étaient les étapes les plus critique en humidité requise comparée au contrôle. Le génotype R748 donne une mauvaise performance en tous les régimes humides, et était recommendé pour les test sur terrain et l'évaluation participative. De cette étude, il est possible de sélectionner les variétés tolérantes a la sécheresse en utilisant les abris mobiles pour simuler la sécheresse au Kenya.

Mots Clés: Duma, irrigation, terre sèche, stress d'humidité

INTRODUCTION

Worldwide, wheat *(Triticum aestivum)* is the second most important cereal crop after rice, (Ekboir, 2000) maize *(Zea mays)* and barley (Poehlman, 1985) in decreasing order (FAO, 1999). In Kenya, wheat is the second most important cereal crop after maize, and contributes significantly to food security.

About 60% of the wheat area in the developing world (75 million ha) is affected by abiotic stresses, with approximately 45 million ha subjected to moisture stress (Pfeiffer *et al.*, 2000). Temperature extreme and nutrient stresses affect a similar area. Eastern Africa has recently experienced periodic food shortages partly attributable to intermittent but severe droughts (FAO, 1997).

In Kenya, semi-arid lands represent 83% of total land area (56.9 million ha), which experience frequent crop failure due to drought stress. Approximately 300,000 hectares of these areas are arable land (Kinyua *et al.*, 2000) and are not fully utilised because annual rainfall is low (200-400mm), unreliable (40-50 days) and highly erratic (Keating *et al.,* 1992). It is often varying in intensity and timing and occurs at any stage of growth (Mugo and Njoroge, 1997). Lack of widely adapted drought wheat varieties and unfavourable weather patterns pose a major problem to wheat production in these areas.

Land under wheat in the high potential areas has gradually declined because of land sub-division and settlement due to increasing population, mixed farming and competition with other farming enterprises. Therefore, future production increases will only come from boosting yields or from expanding wheat production into less favourable areas (KARI, 1994). Consequently, there is need to develop improved plant materials that have drought tolerance and allow efficient utilisation of limited rain water.

Various studies of wheat in Mediterranean and temperate regions (Austin *et al.*, 1980; Simane *et al.,* 1993; Ravichandran and Mungse, 1995; Blum, 1998) have indicated that the reproductive stage is more sensitive to drought than the seedling and tillering stages, hence, causing the highest yield reduction. However, some investigations (El Hafid *et al.*, 1998) indicate that seedling stage is the most sensitive stage to moisture stress in durum wheat in Mediterranean environment. In the tropical environment, little information is available for bread wheat. Drought stress from heading to maturity gives greater reduction in grain yield than from emergence to tillering (Imityaz *et al.*, 1990). However, post anthesis grain yield loss is associated with kernel abortion or reduction in kernel growth leading to fewer grains per head and low kernel weights (Hossain *et al.*, 1990). Drought stress at seedling and flowering stages of maize is estimated to cause annual yield losses of about 17% in the tropics (Edmeades *et al.,* 1997). Severe water stress from seedling stage to maturity reportedly reduced all grain yield components, particularly the number of fertile ears per unit area by 60%, grain number per head by 48%, dry matter and harvest index (Giunta *et al.*, 1993).

With only two varieties, Duma and Ngamia, that had been recommended and released for commercial production in the marginal rainfall areas of Kenya (Kinyua *et al.,* 1998), there is need to develop more drought tolerant wheat varieties for the ASALS. This study was, therefore, undertaken to determine drought responses of five wheat genotypes under simulated drought conditions and the most critical stage(s) that require moisture in wheat under tropical dry conditions.

MATERIALS AND METHOD

The experiment was conducted under a mobile rain shelter for two seasons, 1998 and 1999, at the National Plant Breeding Research Centre, Njoro in Kenya (at 2160 m a.s.l, 0^0 20^0S, 35^0 56'E). The area receives bimodal rainfall with an annual average of 931mm and between 400-550mm in the cropping season. Mean maximum temperatures range from 21 to 26^0 C. Soils are well-drained *Mollic Andosols* with pH 5.6-6, deficiencies in Cu and phosphorus (Jaetzold and Schimdt, 1983).

A mobile rain shelter similar to that earlier described by Upchurch *et al.* (1983) and Jefferies (1993) was used to exclude rain and induce drought stress. In this experiment, the crop was covered only when raining. A drip irrigation set (Watermatics, 1999) was used and each plot was irrigated separately by controlling gates and nozzles of the irrigation system. The main pipe was laid 15 m length and spaced at 40 cm. The delivery pipes were laid between the rows and spaced 30 cm. Pressure regulators within the irrigation system ensured that the total amount of water supplied by each nozzle remained constant in the whole experimental plot.

The experimental design was randomised complete block design (RCBD) in a split-plot arrangement, with 3 replicates. Main plots were assigned to five moisture regimes, which included four stress environments and one non-stress environment. Sub-plots had five wheat genotypes, R748, R830, R831, R833 and a check variety, Duma. Stress treatments were created by having different dates of irrigation termination (from seedling establishment to grain filling) to simulate the amount and nature of rainfall patterns that commonly occur in marginal areas of Kenya during the cropping seasons (Jaetzold and Schimdt, 1983; Mugo and Njoroge, 1997). Irrigation was terminated at different growth stages as follows:

(1). Terminal drought (at seedling establishment): 46 mm of water was applied during the first week and additional 12 mm at the 2nd and 4th week after planting, thus total water supply was 70 mm. (2). Early drought (at tillering): water was supplied as above but 12 mm were applied in the 6th week. Total moisture applied was 82 mm. (3). Mid-drought (at anthesis): water was supplied as above but additional 12 mm was applied in the 8th week. The total moisture applied as then 94 mm of water. (4). Late drought (at grain filling): Irrigation was applied as above but additional 12 mm were applied in the 10th week, hence, raising the amount of water to 106 mm. (5). Control (no stress): Water was applied as above but additional 12 mm were applied at 12th week, thus total water supply was 118 mm.

At planting, all treatments had water applied to field capacity as determined by gravimetric method. This was done to enable the seeds to germinate uniformly. The first 46 mm of water supplied was in two halves (23 mm) each applied on the 3rd and 6th day after emergence. Water treatments were not randomized in order to keep the incremental change in water application between adjacent treatments as small as possible, as suggested earlier by Fernandez (1991) and Steyn *et al*. (1995). This reduced the chances of water movement, especially if wet (control) and dry plots were bordering each other. Plot size was 4 rows, 1 m long and 20 cm between the rows.

The following parameters were taken from the inner 2 rows: number of tillers plant^{-1} (on ten randomly selected plants before booting), plant height at maturity, percent reproductive tillers at maturity, ear length on primary tillers, days to 50% heading and maturity, number of spikelets head^{-1}, number of seeds head^{-1} and sterile florets head^{-1}, 1000-kernel weight and total grain yield per hectare.

Data obtained were subjected to analysis of variance. A combined analysis over water treatments and seasons was also performed using SAS (SAS, 1996), and means were separated using Fisher's least significant difference ($P \leq 0.01$ and 0.05), respectively. The Eberhart and Russel (1966) model for stability analysis was used to estimate regression coefficients (b_i) of yield for individual cultivars across the moisture regime. It was tested for significance from unity using t-test, while significance of the deviations from regression (S^2d_i) were tested by F-test.

RESULTS

Combined analysis of variance for the two seasons indicated significant difference due to water treatment, season (except for tillers/plant and grain yield) and season x water treatments interactions (except for reproductive tillers and kernel weight) for all traits measured (Table 1). There were significant genotype, genotype x water interactions (except for kernel weight and plant height) for all traits measured. Similarly, except for plant height, tillers/plant, seeds per head and days to maturity, significant genotype x water treatment x season interactions occurred for all traits (Table 1).

The control treatment where water was applied at all stages of growth, had the highest grain yield among all genotypes in both seasons, while the most stressed conditions (70 mm) had the lowest grain yield, which was lower than overall grand mean (834.4 kg ha^{-1}) (Table 2). Generally, yield decreased with increasing moisture stress, as expected. There was, however, no significant grain yield reduction between early- and mid- season drought stress. Genotype R748 yielded the highest grain in both seasons across the watering regimes. This was followed by check variety, Duma and R833. Genotypes R831 and R830 had consistently low yields across all the watering regimes.

Seeds per head, kernel weight, spikelets per head and ear length decreased significantly with increasing moisture stress (Table 3).

Similarly, seeds per head did not significantly differ between terminal and early season drought stress. Floret sterility increased proportionally with increasing moisture stress, with no significant difference between the control water treatment and late drought stress from grain filling to maturity (Table 3). Genotype R748 attained the highest seed weight, followed by Duma. R831 ranked third, while R833 and R830 had the lowest kernel weight. Similarly, R748 and Duma produced the lowest number of sterile florets per head and the second highest seed number per head (Table 3). Genotype R833 had the highest number spikelets per head and seeds per head, but lowest kernel weight, thus lower yield as compared to R748 and Duma. Genotype R831 had the longest ears and second highest number of spikelets per head, but the highest number of sterile florets per head (Table 3).

The control water treatment produced the highest number of tillers per plant and reproductive tillers, while the most stressed conditions produced the lowest (Table 2). There was, however, no significant difference in tiller number between the control and water stress, from grain filling to maturity. Similarly, drought stress from seedling to maturity reduced plant height significantly resulting in shortest plants. R831 produced the highest number of tillers per plant. R833 had both the lowest tiller number (Table 2) and highest tiller fertility (Table 3).

Under severe water stress, in both seasons, combined plant height decreased significantly ($P \leq 0.05$) relative to the well-watered treatment (Table 2). Genotype R748 was the tallest, followed by R831 and R830, while R833 produced the shortest plants (Table 3). Duma and R833 cultivars had the shortest interval from sowing to anthesis and physiological maturity across the water stress regimes. However, under severe water stress, time to 50% heading was considerably reduced, thus significantly reducing time to reach physiological maturity. R748 took the longest time to mature followed by R830.

There was however, no difference between terminal and early drought stress on kernel weight and also between mid- and late- drought stress (Table 4).

The presence of genotype x water interaction ($P \leq 0.05$) for grain yield, indicates that cultivars responded differently to the specific water stress treatments. The water stress environments were ordered according to the mean grain yields in that environment. Mean yields were 490.1 kg ha^{-1} for 70 mm, 625 kg ha^{-1} for 82 mm, 754.8 kg ha^{-1} for 94 mm, 1014.7 kg ha^{-1} for 106 mm and 1321.9 kg ha^{-1} for control. Duma had regression coefficient estimate that did not significantly deviate from 1.0 and had non-significant deviation mean square (Table 4). R830 had non-significant deviation means square and smallest mean yield difference between control and moisture stress at all other stages (not shown), indicating smaller response in grain yield with increasingly favourable environment. R830 also had lowest average grain yields in all water regimes. Duma and R830 indicated high stability in response to increasing water availability. Genotypes R748, R833 and R831 had regression estimates significantly ($P<0.05$) different from one and highly significant ($P<0.05$) deviation mean squares, suggesting lack of stability. They had good response to favourable environments, but R748, had high mean grain yields across all water regimes and demonstrated increased capacity to respond to both favourable and non-favourable environments. R833 and R831 had low mean yields under severe stress indicating good responses to favourable environments but poor responses to unfavourable ones.

DISCUSSION

This study shows that severe water stress (from seedling stage and tillering to maturity) reduces grain yield on average by 62.2 and 52.7%, respectively, compared to control. When drought stress was imposed from anthesis to grain filling, yield reduction was 44.3% over the control. These values show that the reproductive stage was the most critical for moisture requirement, followed by the seedling stage. Similar results were reported by Imtiyaz *et al*. (1990), Simane *et al*. (1993) and Blum (1998). Duma, R833 and R748 suffered highest yield loss under mid- to late- season drought, exhibiting low drought tolerance at flowering to grain filling stages. Hence, introgression with germplasm carrying this tolerance would be appropriate. Since R748 performed better than Duma, which has been released for commercial production, this shows that there is room to increase yield potential and drought tolerance of cultivars for marginal rainfall areas. R830 and R831 suffered high yield reduction under early season mainly because of their low early-season growth, thus inability to utilise initially available moisture at seedling stage. R830 however had the lowest overall yield reduction, suggesting that it was the most drought resistant cultivar, although not the highest yielding. It also had the lowest drought susceptibility index (DSI) of 0.95, indicating high drought tolerance. It appears to be a good source of drought tolerance for improving drought resistance of high yielding, but susceptible genotypes through introgression. Its inherent low yield potential could also be improved through breeding.

Generally, yield and yield components decreased with increasing moisture stress in both seasons (Table 2). The highest yield loss during reproductive stages was associated with reduced number of seeds head^{-1} (20.3%), increased number of sterile florets head^{-1} (28.3%), reduced number of reproductive tillers (13%), reduced length of ears and number of spikelets head^{-1} (16.9% and 14.3%, respectively), and reduced kernel weights (22.4%) for all genotypes (Table 2).

Kernel weight was affected more by moisture stress from grain filling to maturity, which confirmed the expected that moisture stress affects the grain filling period. Moisture stress from grain filling to maturity, reduced kernel weights by 14.7% for all genotypes. This could have been caused by shortened grain filling periods and reduced stem reserve accumulation and remobilisation for grain filling. This observation is in agreement with the results of Blum (1998). Duma and R833 had the lowest kernel weight reduction (11.7 and 13.1%, respectively), while R830, R831 and R748 had the highest reduction. Higher reduction of kernel weight was because these genotypes are late maturing and could have been affected by prolonged drought stress. The situation could have been the reverse for Duma and R833, which were early maturing.

Highest reduction in seed number occurred in R830 and R833 (28.5 and 25.3%, respectively) under mid- season drought from anthesis to maturity. This was probably because moisture stress hastened the development of spikekelet primordia, flowering and pollination, which consequently resulted in poor or incomplete pollination, fertilisation and seed set. There was also increased kernel abortions and increased number of sterile florets per head (28.3%) under these conditions. Machando *et al*. (1993) and Simane *et al*. (1993) reported similar findings.

Highest reduction in ear length and spikelets per head occurred in R831and R830 under mid-late season drought. This is consistent with work by Ooesterhius and Cartwright (1983), who observed that soil moisture during reproductive stage reduced spike vegetative development, resulting in reduced spike size and spikelets per head. A combination of low kernel weights, floret and kernel abortion leading to low seeds per head were responsible for the low grain yields in R833, R830 and R831.

Tiller abortion made genotype R831 and R830 produce the highest number of tillers plant^{-1}, with the lowest number of reproductive tillers. R833 and R748 produced the lowest tiller number, but highest reproductive tillers (Table 3). This could have contributed to low yield in genotype R831 and R830. This is consistent with work by Kirby and Jones (1970) who noted that abortive tillers contributed to low yield because they compete with main culm for resources without significantly contributing to yield. Hence, selection for few tillers plant^{-1} and higher tiller survival is ideal for improving drought stress in wheat.

Drought stress accelerated all phenological growth stages, reduced the normal growth and development periods, resulted in reduced dry matter production and final yield. Duma and R833 were early maturing cultivars and, therefore, they exhibited drought escape as a drought tolerance mechanism. Drought escape is highly heritable but it is associated with lower yields (Wortmann, 1998) as shown by this results. It is apparent that R748 maintained superior performance under all moisture conditions despite its being late maturing. This suggests that its tolerance mechanism could be associated with increased desiccation tolerance and/or improved turgor or osmotic adjustment as elsewhere (White and Izquierdo, 1991). Hence, late maturing cultivars can be grown in marginal areas although they may suffer high yield reductions during grain filling. This study indicates that not all-late maturing wheat cultivars will succumb to drought stress.

Duma and R830 showed non-significant deviation mean square and smallest mean yield difference between control and moisture stress at all other stages (not shown). Duma also had non-regression coefficient estimate, features that indicate high stability according to Eberthart and Russel (1966). They were well buffered under stress and could adjust response to changing environments. Hence, the final yield could have minimal variation, thus reducing risk of total crop failure. These would be cultivars of choice in a region that receives low rainfall. However, drought, especially in East Africa is erratic and favourable seasons are often interspersed with unfavourable ones (Stewart *et al.,* 1984; Keating *et al.,* 1992; Njoroge *et al.,* 1997). Genotype R748, with greater average grain yields and more responsive to favourable environments, would maximise grain yield in these regions.

CONCLUSION

Early drought from seedling and tillering stages are critical in bread wheat, causing the highest yield reduction and affects all yield components drastically. Seedling and reproductive stages are more sensitive to moisture requirement in wheat, hence there is need to develop varieties that are tolerant to drought at these stages. R748 was the highest yielding cultivar across all watering regimes, although it is late maturing and susceptible to drought at flowering and grain filling stages. Improvement of tolerance at flowering is desirable as it is expected to increase grain yield stability. Duma is still a good variety for marginal rainfall areas, and incorporation of flowering drought tolerance might widen its zone of adaptation. Due to differences in varietal responses and instability across water treatments, recommendation of genotypes should be based on performance of genotypes at specific rainfall regimes but not based on overall mean yield. The use of mobile rain shelter for selection of drought tolerant wheat cultivars is recommended as it enhances screening efficiency.

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TABLE 1. Combined sum of squares from ANOVA for yield and yield components measured on 5 wheat genotypes for two seasons, 1998 and 1999 at varying water regimes under rain shelter at Njoro, Kenya

Source	DF	Plant height (cm)	Tillers plant^{-1}	%reproductive tillers	Ear length	Spikelets head^{-1}	Seeds head^{-1}	Sterile flowers head^{-1}	Days to 50% heading	Days to 50% maturity	1000-kernel weight (g)	Grain yield (kg ha^{-1})
Replication	2	285.4	1.19	1000.3	0.77	0.79	67.5	9.8	6.2	36.6	48.6	1628.8
Water treatment	4	1639.1**	13.9*	5217.7**	26.2	36.0**	385.4**	46.9**	280.4**	328.3**	570.6**	3414.3**
Season	1	1550.6**	0.01	286.7*	6.9**	2.9**	23.4*	72.2**	68.0**	568.4**	1101.7**	70.8
Water x season	4	505.0**	0.36**	28.9	0.55*	0.69*	32.8**	0.62*	1.76*	9.41**	10.84	405.7*
Genotype	4	625.8**	2.62**	2759.7**	16.6**	23.8**	199.7**	75.14**	427.5**	564.6**	313.28**	696.5**
Genotype x sea	4	180.4*	0.32**	79.4*	0.67**	0.58**	5.8**	2.74**	38.1**	1.6*	38.67**	49.0*
Genotype x water	16	10.3	0.09*	206.0**	0.14*	0.27*	2.51*	0.97**	4.46*	5.1*	8.90	44.12*
Genotype x water x sea	16	7.1	0.046	27.7*	0.108*	0.225*	1.82	0.64*	1.63*	2.61	9.92*	31.94*
Pooled error	80	16.1	0.048	32.43	0.075	0.259	2.49	0.424	1.24	1.8	13.13	34.14
MSE		4.01	0.22	5.69	0.27	0.57	1.57	0.65	1.11	1.33	3.62	5.84
CV%		10.68	11.35	6.98	4.58	5.20	6.90	9.44	1.94	1.43	12.69	21.64

*, ** Significant at the 5 and 1% levels of probability, respectively; Sea = season; Geno = genotype; Water = water treatment

TABLE 2. Mean separation for yield and yield components measured at different watering levels during season I (1998) and season II (1999) and combined over the two seasons (1998/99) under rain shelter at Njoro, Kenya

Water regime (mm)	Plant height (cm)	Days to 50% heading	Days to 50% maturity	Tillers plant^{-1}	Percent reprod. tillers	Ear length (cm)	Spikelets head^{-1}	Seeds head^{-1}	Sterile florets head^{-1}	1000-kernel weight (g)	Grain yield (kg ha^{-1})
Season I (1998)											
118	49.8a	60.9a	100.5a	2.5a	96.3a	7.5a	11.3a	30.1a	4.3c	38.9a	1525.9a
106	42.0a	58.2b	96.5b	2.4a	92.9b	6.7b	10.5b	25.0b	5.7b	32.4b	1029.7ab
94	31.2a	56.9c	94.3c	2.1b	81.6c	6.2c	9.3c	22.8c	6.1b	30.2b	694.7b
82	27.9bc	54.4d	92.1d	1.6c	69.1d	5.6c	8.9cd	20.2d	6.7a	27.5bc	587.2b
70	21.0c	52.8	91.1d	1.2d	63.1e	4.8d	8.3d	18.7d	7.9a	27.3c	431.9b
Mean	34.4	56.7	91.1	1.9	80.2	6.2	9.7	23.4	6.2	31.3	850.9
$LSD_{0.05}$	6.7	3.4	11.3	0.9	11.2	0.58	1.05	5.8	3.5	6.9	543.5
Season II (1999)											
118	45.1a	61.7a	94.7a	2.7a	96.3a	6.8a	11.1a	25.8a	6.7d	31.8a	1117.9a
106	42.8b	60.1b	92.5b	2.5ab	92.4a	6.3b	10.6b	24.6b	6.7c	27.8b	970.5b
94	41.3c	57.7c	90.9c	2.3b	85.1b	5.9c	9.9c	21.8c	7.4c	24.7c	784.2c
82	38.3d	55.9d	89.5d	1.5c	73.7c	5.1d	9.4d	20.8d	8.6b	23.4d	676.3d
70	36.6e	54.5e	87.3e	0.8d	67.2d	5.0e	8.6e	19.4e	9.1a	21.4d	561.3e

Mean	40.8	58.0	91.0	1.9	82.9	5.8	9.9	22.5	7.6	25.8	822.2
$LSD_{0.05}$	9.7	3.7	3.1	1.16	2.4	0.54	0.98	3.4	3.3	2.7	326.4
Both seasons combined (1998/99)											
118	47.3a	61.3a	97.7a	2.6a	96.3a	7.1a	11.2a	28.0a	5.3d	35.3a	1321.9a
106	42.4a	59.2b	94.5b	2.4a	91.7a	6.7b	10.6b	24.7b	6.2d	30.1b	1037.5b
94	36.3b	57.3c	92.6c	1.8b	83.3b	5.9c	9.6c	22.3c	6.8c	27.4b	733.1c
82	33.1bc	55.2d	90.8d	1.5c	71.4c	5.3d	9.2d	20.5d	7.8b	25.4c	625.0c
70	28.8c	53.7e	89.2e	1.0d	65.2d	4.9e	8.5e	18.9d	8.4a	24.5c	500.0d
Grand mean	37.6	57.3	93.0	1.9	81.6	6.0	9.8	22.9	7.0	28.6	834.4
$LSD_{0.05}$	7.8	1.4	2.1	0.11	2.9	0.5	0.26	0.31	3.1	3.2	357.1

Values followed by the same letter along the columns are not significantly different at 5% level of lsd; repro = reproductive

TABLE 3. Mean separation for yield and yield components of five wheat genotypes tested during season I (1998) and season II (1999) and combined over the two seasons (1998/99) under rain shelter at Njoro, Kenya

Water regime (cm)	Plant height (cm)	Days to 50% heading	Days to 50% maturity	Tillers plant^{-1}	% reprod. tillers	Ear length (cm)	Spikelets head^{-1}	Seeds head^{-1}	Sterile florets head^{-1}	1000-kernel weight (g)	Grain yield (kg ha^{-1})
Season I (1998)											
R748	45.0a	58.6b	100.3a	1.9c	87.9a	6.7b	9.5d	24.5b	4.8d	35.6a	1134.4a
Duma	30.5c	52.9e	89.0d	2.0c	86.6a	6.4c	9.6c	23.5b	5.4c	32.5b	913.3b
R833	26.5c	55.0d	90.5d	1.6d	89.5a	5.1e	11.0a	27.5a	5.5c	28.5c	832.5b
R831	36.0b	56.9c	95.1c	2.2a	64.6c	7.1a	10.2b	22.1c	8.4a	32.8b	723.0cd
R830	33.9b	60.0a	98.2b	2.1b	72.1d	5.4d	8.3e	19.3d	6.7b	23.6c	674.7d
Mean	34.4	56.7	94.6	1.9	80.1	6.1	6.7	23.4	6.2	30.6	855.6
$LSD_{0.05}$	4.7	1.9	4.4	0.87	3.5	0.71	2.1	1.9	2.9	2.9	329.3
Season II (1999)											
R748	43.6a	61.1b	95.8a	1.7c	88.3a	6.1b	9.4c	22.9b	6.0d	30.6a	990.0a
Duma	39.8c	51.6d	86.3d	1.9d	86.9a	6.0b	10.0b	22.6b	6.9c	28.4a	883.8b
R833	37.5d	54.2c	86.9d	1.5e	90.3a	4.9d	10.9a	25.9a	6.1d	22.9c	814.4c
R831	41.2b	60.7b	91.7c	2.5a	72.7b	6.5a	10.5a	20.8c	10.1a	23.7b	691.6d
R830	42.0b	62.4a	94.3b	2.2b	75.8b	5.4c	9.0c	19.9d	8.9b	23.6c	729.7d
Mean	40.1	57.2	89.8	2.1	81.4	5.7	10.1	22.3	8.0	24.7	822.2
$LSD_{0.05}$	2.1	2.3	3.5	0.31	3.9	0.38	1.45	1.64	1.8	3.9	268.5
Both seasons combined (1998/99)											
R748	44.3a	59.9b	98.0a	1.8d	88.5ab	6.5b	9.2d	23.7b	5.4e	33.3a	1072.2a
Duma	35.1c	52.2e	88.4d	1.9c	86.8b	6.2c	9.8c	23.2b	6.2c	30.3b	868.4b
R833	32.0d	54.6d	88.7d	1.6e	89.9a	5.1e	10.9a	26.5a	5.8d	25.7d	821.7b
R831	38.6b	58.8c	93.4c	2.3a	68.7d	6.9a	10.4b	21.4c	9.2a	28.3c	721.9c
R830	38.0b	61.2a	96.0b	2.1b	74.0c	5.3d	8.7e	19.6d	7.8b	25.4d	702.2c
Grand mean	37.3	57.0	93.0	1.9	81.6	6.0	9.8	22.9	6.9	28.6	843.2
$LSD_{0.05}$	3.8	1.6	3.1	0.52	2.8	0.14	1.8	1.12	1.21	2.7	265.1

Values followed by the same letter along the columns are not significantly different at 5% level; repro = reproductive

TABLE 4. Mean grain yields, regression coefficient estimates (b_1) and deviation from regression (S^2d_i) of five wheat genotypes tested at different moisture regimes during 1998 and 1999 under the rain shelter at Njoro, Kenya

Genotype	Mean yield	Deviation mean square (S^2d_i)	Regression coefficients (b_1)
Duma	901.6	218.93	1.01
R748	1061.7	378.23**	3.24**
R830	702.2	148.05	1.76*
R831	743.0	350.78**	1.94**

*, ** Significance at the 5 and 1% levels of probability, respectively