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COMPARATIVE RESPONSE OF YIELD COMPONENTS IN HEXAPLOID TRITICALE x BREADWHEAT DERIVATIVES TO CONTRASTING SOIL PHOSPHORUS LEVELS

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ABSTRACT

The response of 23 derivatives of hexaploid triticale x breadwheat crosses at two contrasting levels of soil phosphorus was examined. High phenotypic variability was recorded in the two P environments for all the traits except early growth vigour (normal P level) and spikes/plant (P deficient). Grain yield/plant, followed by number of tillers and spikes/plant, early growth vigour, and leaf area index were most sensitive to phosphorus deficiency, which caused delayed heading and maturity and increased specific leaf weight. The heritability for grain yield was low under both the phosphorus levels, which necessitates the use of indirect selection parameters. The overall character association and path coefficient analysis revealed that selection for higher 1000-grain weight and increased number of spikes/plant in both the environments, whereas that for relatively taller plants under phosphorus deficiency could be useful for improvement in grain yield.

Key words: Character correlations, Phosphorus stress, triticale x breadwheat, *Secale cereale*, *Triticum aestivum*.

Soil acidity hampers wheat productivity in about one billion hectares in the tropics and subtropics [1]. One of the prominent ill-effects of low pH is reduced phosphorus availability to plants due to the conversion of soluble phosphorus into insoluble chelated form. In this context, rye (*Secale cereale* L.), besides being a donor of many valuable genes, possesses genes for greater phosphorus utilization in acidic soils [2, 3]. Such desirable traits of rye can be effectively transferred to breadwheat via hexaploid triticale. A number of promising wheat-like derivatives were selected on low-pH soils in the advanced generations of the hexaploid triticale (x*Triticosecale* Wittmack) x breadwheat (*Triticum aestivum* L. em. Thell) crosses which possess some rye traits, and were used in the present study [4].

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The efficiency of breeding varieties for low-P availability conditions can be augmented if plant traits that confer yield stability under such conditions are identified using appropriate selection criteria. However, the realistic utilization of indirect traits in such a breeding programme depends on their heritability and association with grain yield under specific stress environment. Also, the use of indirect selection is more desirable when the primary character like grain yield has a low heritability [5].

The present study has been undertaken to (i) know the relative sensitivity of different plant traits to phosphorus deficiency, (ii) compare the variability parameters in the two contrasting phosphorus regimes, and (iii) know the parallelism or differences in character associations under phosphorus deficiency compared to the normal level. Such information could improve the efficiency of breeding procedures in low-pH and P-deficient soils.

MATERIALS AND METHODS

Twenty three elite genomically stable hexaploid triticale x breadwheat derivatives along with 2 Al-tolerant breadwheat strains were raised at Palampur, where soils are moderately acidic (pH 5.5–5.8) separately under normal and low phosphorus levels in randomized complete block design, each with three replications, with the plot size 2.0 x 0.8 m and 23 x 5 cm spacing. The normal phosphorus level was created by adding 60 kg/ha P_2O_5 in the form of single superphosphate at sowing, whereas no phosphorus was applied in the phosphorus-deficient treatments. Moreover, the experimental block with phsophorus deficiency was not applied with phosphorus for the last 2 years. Nitrogen (120 kg/ha) and potassium (30 kg/ha K_2O) were applied to both the phosphorus environments in the forms of urea and muriate of potash, respectively. The soil analyses before and after the crop revealed highly significant differences for the soil phosphorus content in the two environments. Data were recorded on 5 competitive plants for grain yield/plant and 15 other quantitative traits (Table 1). The parameters of variability were calculated as suggested earlier [6, 7]. Correlation coefficients between all possible character pairs were computed from the mean values and were partitioned into direct and indirect effects following the path-coefficient analysis [8].

RESULTS AND DISCUSSION

The analysis of variance revealed large genetic variability for all the characters recorded in the two phosphorus levels, except for early growth vigour and number of spikes/plant in the normal and phosphorus-deficient environments, respectively. This indicates that almost all the characters in the two environments are amenable to selection. All the characters under study were significantly affected by phosphorus deficiency (Table 1). However, grain yield with 66.5% reduction was most sensitive, followed by number of tillers

Table 1. Range, mean, per cent decrease under phosphorus stress (–P) and variability means for different plant characters under normal phosphorus (+P) and stress (–P) environments

Character	Phosphorus level	Range	Mean	Decrease under –P (%)	PCV (%)	GCV (%)	h^2 (%)	GA (%)
Grain yield/plant, g	+P	2.5–7.9	5.1	66.5*	30.2	16.7	30.5	24.0
	–P	1.0–2.9	1.7		42.1	25.2	36.0	40.0
Harvest index, %	+ P	30.2–52.3	44.6	8.0*	15.2	12.4	66.0	26.1
	–P	27.2–49.5	42.0		18.3	13.1	48.4	23.1
1000-grain weight, g	+P	30.7–49.1	37.2	8.4*	14.8	13.0	76.7	29.6
	–P	25.6–43.1	34.1		18.2	12.2	45.2	21.3
Grains/spike	+P	25.9–60.6	47.1	17.2*	20.7	17.8	73.5	39.6
	–P	21.3–50.7	39.1		25.8	20.7	64.3	43.2
Spikelets/spike	+P	14.4–19.0	15.8	8.6*	8.0	6.0	57.0	11.5
	–P	11.9–17.1	14.4		12.0	10.0	65.3	20.3
Tillers/plant	+P	2.3–4.3	3.0	56.0*	21.2	11.9	31.6	17.3
	–P	1.0–2.3	1.3		33.3	16.1	20.9	19.2
Spikes/plant	+P	2.3–4.1	2.9	55.2*	21.6	11.0	25.7	14.3
	–P	0.9–2.3	1.3		34.8	13.3	14.7	13.3
Spike length, cm	+P	8.7–11.2	9.8	14.8*	7.7	5.8	56.1	11.3
	–P	6.9–10.2	8.3		11.7	7.7	43.6	13.2
Plant height, cm	+P	65.3–86.5	78.1	18.4*	7.5	6.5	73.9	14.5
	–P	55.4–72.7	63.7		9.7	6.5	44.2	11.2
Peduncle length, cm	+P	10.5–22.0	15.6	19.7*	31.7	30.7	94.0	77.4
	–P	6.3–19.0	12.5		31.5	27.4	75.6	61.9
Days to heading	+P	114.0–166.7	126.6	- 9.3*	10.4	10.1	94.6	25.6
	–P	128.0–165.7	138.4		6.8	6.3	85.0	15.1
Days to maturity	+P	159.3–184.0	166.9	- 3.8*	3.8	3.5	86.4	8.5
	–P	166.7–185.3	173.2		2.9	2.8	91.4	6.9
Leaf area, cm^2	+P	42.6–76.5	53.9	14.3*	19.9	14.9	56.3	29.6
	–P	34.7–70.8	46.2		23.8	19.5	67.0	41.5
Leaf area index	+P	0.8–2.9	1.3	29.4*	34.7	25.9	55.8	50.5
	–P	0.4–1.3	0.9		33.2	18.9	32.3	28.1
Specific leaf weight, g	+P	5.0–6.7	5.8	- 5.3*	10.9	5.2	22.7	6.4
	–P	5.2–7.1	6.1		11.1	4.8	19.0	5.4
Seedling vigour	+P	4.0–7.0	5.2	54.5*	22.8	9.3	16.7	9.8
	–P	1.7–3.3	2.4		25.7	18.5	51.9	34.8

*Significant at $P \leq 0.05$.

and spikes/plant (56.0%), early growth vigour (54.5%), and leaf area index (29.4%). Ruiz-Torres et al. [9] also observed significant reduction in spike density in wheat varieties susceptible to acidic soils under unlimed condition as compared to lime application. However, these authors did not show whether spike density was reduced to lower tillering or nonproductive tillers, or both. Consistent with the present findings, Bouma [10] reported leaf area index rather than leaf weight as a prominent trait responsive to phosphorus fertilization. The phosphorus stress caused 10–20% reduction in grains/spike, spike length, plant height, peduncle length, and leaf area. On the other hand, harvest index, 1000-grain weight and spikelets/spike were marginally influenced by the stress. By contrast, phosphorus deficiency increased specific leaf weight by 5.3% and delayed heading and maturity by 12 and 7 days, respectively. The delay in anthesis and maturity [11, 12] by about 12 days [13] under phosphorus deficiency has been explained by the effect of phosphorus shortage on cytokinin synthesis [11].

The magnitudes of phenotypic and genotypic coefficients of variability (PCV and GCV) for different parameters in the stress environment generally exceeded their counterparts in the normal environment. Higher estimates of PCV as well as GCV were recorded for grain yield/plant, grains/spike, peduncle length, leaf area and leaf area index in the stress environment. The heritability of grain yield was low in both the environments which call for indirect selection on low-P soils. High heritability in conjunction with high genetic advance was observed for grains/spike and leaf area in both the environments, and for 1000-grain weight and leaf area index in the favourable environment only. Moderate heritability as well as genetic advance were recorded for harvest index and spikelets/spike on the phosphorus rich and deficient soils, respectively. Early growth vigour exhibited moderate heritability and genetic advance in the stress environment only. PCV, GCV, heritability and genetic advance were generally higher for grains/spike, peduncle length, leaf area and early growth vigour in the stress environment, suggesting additive gene effects for these traits [7]. Such traits may be more appropriate for selection in the low-P soils. Days to heading and maturity showed high heritability and low genetic advance, indicating that dominance and/or epistatic effects were preponderant in these traits.

In general, the magnitude of genotypic correlation coefficients was greater than their phenotypic counterparts. In both the environments, grain yield showed positive correlations with 1000-grain weight, number of tillers and spikes/plant, and plant height, indicating the associations of these traits with grain yield to be independent of the levels of soil phosphorus under study. This also suggests the suitability of these traits for simultaneous selection for yield in any phosphorus level. Harvest index was positively associated with grains/spike and peduncle length but negatively with the phenological traits in both the environments. This indicates restricted mobilization of the assimilates towards the sink under conditions of late heading and maturity due to more vegetative growth. Spike length was associated with 1000-grain weight. Therefore, selection for longer spikes could favour higher test weight, besides taller plants. Larger number of days to heading and maturity resulted in less number of grains/spike. Delayed heading and maturity and larger leaf area increased spikelets/spike but reduced the peduncle length. A previous study [14] in triticale also revealed plant height to be positively correlated with spike length and grain weight, whereas peduncle length and heading duration were negatively correlated.

However, the positive association of grain yield with grains/spike, peduncle length and negative association with heading duration, as observed in the phosphorus rich environment, was missing in the low-P environment, implying the phosphorus dependence of these correlations. Under phosphorus stress, grain yield showed positive association with spike length as also observed in triticale [15], whereas taller plants produced larger number of spikelets. Longer spikes were associated with larger leaf area, and both these traits were positively associated with number of spikes or tillers/plant. The positive association of early growth vigour with plant height under phosphorus stress might assist the predictability of taller genotypes in the low-P soils.

The direct effects obtained in path analysis revealed that in both the environments, grain yield primarily depended on number of spikes/plant, grains/spike, and 1000-grain weight, whereas spikelets/spike and plant height had substantial effects in the stress environment only (Table 2). The magnitude of all the direct effects except spikes/plant in the phosphorus-deficient environment, was less than unity, which indicates the minimal inflation due to multicolinearity [16]. In spite of positive correlations of tillers/plant and spike length with grain yield, these traits had negative direct effect on yield. However, these traits contributed substantially through spikes/plant. This indicates the shortcoming of making selection on the basis of correlation studies alone.

Under the stress, 1000-grain weight and plant height contributed directly to yield and also had substantial effect via spikes/plant. The number of spikes/plant had a positive correlation with grain yield under phosphorus deficiency due to its very direct effect, though it was slightly offset by grains/spike and tillers/plant. Leaf area had positive effect on grain yield via spikelets/spike and spikes/plant in the stress environment.

Keeping in view the simple correlation coefficients in conjunction with the path analysis, indirect selection for higher 1000-grain weight and increased number of spikes per plant in both the phosphorus environments, whereas that for relatively taller plants under restricted phosphorus supply could be useful for improvement of grain yield.

Table 2. Estimates of direct (in bold) and indirect effects at the phenotypic level under normal phosphorus (+P) and phosphorus stress (–P) environments

Character	Phosphorus level	Harvest index	1000-grain wt.	Grains per spike	Spikelets per spike	Tillers per plant	Spikes per plant	Spike length	Plant height	Peduncle length	Days to heading	Days to maturity	Leaf area	Leaf area index	Specific leaf wt.	Seedling vigour
Harvest index	+P	**0.12***	-0.02	0.09	-0.05	-0.03	-0.02	-0.03	0.03	0.07	-0.09	-0.09	-0.08	-0.06	-0.04	0.01
	–P	**0.09***	0.01	0.06	-0.01	-0.02	-0.01	-0.02	0.01	0.04	-0.04	-0.05	-0.02	0.01	0.01	0.02
1000-grain wt.	+P	-0.06	**0.37***	-0.08	-0.02	0.09	0.07	0.18	0.19	0.07	-0.05	0.01	0.08	-0.05	0.02	0.01
	–P	0.06	**0.37***	-0.05	0.06	0.09	0.10	0.15	0.21	0.04	-0.10	-0.08	0.09	0.01	0.03	0.01
Grains/spike	+P	0.37	-0.11	**0.49***	-0.02	-0.11	-0.07	0.02	0.10	0.22	-0.30	-0.34	-0.24	-0.20	-0.13	0.03
	–P	0.25	-0.05	**0.39***	0.04	-0.13	-0.12	-0.04	0.04	0.14	-0.18	-0.17	-0.02	0.08	0.01	0.12
Spikelets/spike	+P	-0.02	-0.00	-0.00	**0.04***	0.00	0.00	0.02	-0.01	-0.02	0.02	0.02	0.01	0.01	0.00	0.00
	–P	-0.02	0.03	0.01	**0.15***	0.04	0.03	0.11	0.06	-0.05	0.06	0.06	0.11	0.08	0.02	-0.01
Tillers/plant	+P	-0.12	0.11	-0.09	0.05	**0.42***	0.37	0.07	0.06	-0.03	0.08	0.11	0.15	0.12	-0.04	0.05
	–P	0.06	-0.07	0.10	-0.07	**-0.28***	-0.27	-0.11	-0.07	0.06	-0.05	-0.04	-0.12	-0.02	-0.02	-0.08
Spikes/plant	+P	-0.04	0.06	-0.04	0.01	0.28	**0.31***	0.05	0.07	0.01	0.00	0.03	0.09	0.05	-0.07	0.03
	–P	-0.13	0.27	-0.31	0.24	0.98	**1.01***	0.40	0.31	-0.15	0.09	0.07	0.40	0.06	0.08	0.01
Spike length	+P	0.00	-0.00	-0.00	-0.00	-0.00	-0.00	**-0.00***	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	–P	0.05	-0.08	0.02	-0.15	-0.08	-0.08	**-0.20***	-0.14	0.02	-0.03	-0.05	-0.11	-0.07	-0.00	0.29
Plant height	+P	0.01	0.03	0.01	-0.02	0.01	0.01	0.02	**0.05***	0.03	-0.03	-0.02	-0.01	-0.02	-0.01	0.01
	–P	0.01	0.08	0.01	0.05	0.03	0.04	0.09	**0.13***	0.04	-0.02	-0.00	0.04	0.05	0.00	0.06
Peduncle length	+P	0.01	0.00	0.01	-0.01	-0.00	0.00	0.00	0.01	**0.01***	-0.01	-0.00	-0.00	-0.00	-0.00	-0.00
	–P	0.01	0.00	0.00	-0.00	-0.00	-0.00	-0.00	0.00	**0.01***	-0.00	-0.00	-0.00	-0.00	-0.00	0.00
Days to heading	+P	0.01	0.00	0.01	-0.01	-0.00	-0.00	0.00	0.00	0.01	**-0.01***	-0.01	-0.00	-0.01	-0.00	0.00
	–P	0.05	0.03	0.05	-0.04	-0.02	-0.01	-0.01	0.01	0.06	**-0.10***	-0.08	-0.03	-0.02	-0.01	-0.01

(Contd.)

Table 2 (contd.)

Character	Phosphorus level	Harvest index	1000-grain wt.	Grains per spike	Spikelets per spike	Tillers per plant	Spikes per plant	Spike length	Plant height	Peduncle length	Days to heading	Days to maturity	Leaf area	Leaf area index	Specific leaf wt.	Seedling vigour
Days to maturity	+P	0.24	-0.01	0.20	-0.15	-0.08	-0.04	-0.03	0.13	0.20	-0.27	-0.29*	-0.19	-0.19	-0.15	0.04
	-P	-0.03	-0.01	-0.02	0.02	0.01	0.00	0.01	-0.00	-0.02	0.04	0.04*	0.01	0.00	0.00	10.0
Leaf area	+P	-0.01	0.00	-0.01	0.01	0.01	0.00	0.01	-0.00	-0.00	0.01	0.01	0.02*	0.01	0.00	0.00
	-P	-0.02	0.02	-0.00	0.05	0.03	0.03	0.04	0.02	-0.03	0.02	0.02	0.07*	0.04	0.00	-0.00
Leaf area index	+P	-0.08	-0.02	-0.08	0.06	0.03	0.03	0.00	-0.05	-0.08	0.10	0.09	0.09	0.13*	0.01	0.00
	-P	-0.00	-0.00	-0.01	-0.02	-0.00	-0.00	-0.01	-0.01	0.00	-0.00	-0.00	-0.02	-0.04*	0.00	0.00
Specific leaf wt.	+P	-0.08	0.01	-0.07	0.06	-0.02	-0.06	0.01	-0.07	-0.09	0.10	0.12	0.02	0.02	0.26*	0.02
	-P	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.00	0.00	0.00	0.00	-0.00	0.00*	-0.05
Seedling vigour	+P	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.01*
	-P	-0.01	-0.01	0.00	-0.00	-0.01	-0.01	-0.01	-0.02	-0.00	0.01	0.01	-0.01	-0.00	-0.00	-0.04*
Correlation coefficient with grain yield	+P	0.35	0.42**	0.45**	-0.04	0.59**	0.62**	0.31	0.51**	0.40**	-0.44**	-0.36	-0.04	-0.19	-0.15	0.19
	-P	0.37	0.57**	0.25	0.31	0.64**	0.71**	0.39**	0.55**	0.16	-0.30	-0.27	0.38	0.18	0.12	0.33

*Denotes the direct effect. **Significant at $P \leq 0.05$. Residual effects: +P = 0.26, –P = 0.23.

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