Iran Agricultural Research 17:35-50 (1998)

EFFECT OF PLANTING DENSITY ON YIELD AND YIELD COMPONENTS OF TRITICALE IN COMPARISON TO BARLEY

H.R. KABIRIAN, Y. EMAM, M.T. ASSAD, H. GHADIRI AND A.A. KAMGAR-HAGHIGHI[1]

Departments of Crop Production and Plant Breeding, and Irrigation, College of Agriculture, Shiraz University, Shiraz, Iran.

(Received : March 11, 1997)

ABSTRACT

Three cultivars of hexaploid triticale (× *Triticosecale* Wittmack.) and one barley (*Hordeum vulgare* L.) cultivar were examined at three planting densities, 150, 325 and 500 plants m^{-2} at two field sites, with low and high fertility, in a factorial experiment arranged in a randomized complete block design at Agricultural Research Station of Shiraz University, Shiraz, Iran. The results showed that for most of the characters investigated, there were significant differences between 'Valfajr' barley and the triticales, and also among the three triticales. Effects of plant density on number of fertile spikes m^{-2}, number of kernels $spike^{-1}$, mean kernel weight, phytomass and grain yield depended on genotype and soil fertility. Combined analysis showed that increasing plant density from 150 plants m^{-2} to 500 plants m^{-2} increased grain yield in both barley and triticale cultivars. Number of fertile shoots per plant and kernel number $spike^{-1}$ showed a significant decrease as planting density increased. The higher biological yield in barley was mainly associated with higher grain yield. Harvest index was not significantly

1. Former Graduate Student, Associate, Assistant and Associate Professors of Crop Production and Plant Breeding and Associate Professor of Irrigation, respectively.

influenced by density at two sites, however, the barley plants had higher harvest index than triticale cultivars. Further research may shed more light on potential use of triticales in low fertility soils of southern Iran.

تحقیقات کشاورزی ایران

۱۷: ۳۵ - ۵۰(۱۳۷۷)

تاثیر تراکم بوته بر عملکرد و اجزای عملکـرد تریتیکالـه در مقایسه با جو

حمیـد رضـا کبیریـان، یحیـی امـام، محمـد تقـی آســاد، حسـین غدیـری و علی اکبر کامگارحقیقی

به ترتیب دانشجوی سـابق کارشناسـی ارشـد، دانشـیار، اسـتادیار و دانشـیار بخـش زراعت و اصلاح نباتات، و دانشیار بخش آبیاری دانشکده کشاورزی دانشگاه شـیراز، شیراز، ایران.

چکیده

سه رقم تریتیکاله هگزاپلوئـید (*Triticosecale* Wittmack ×) و یک رقـم جو(*Hordeum vulgare* L.) در سه تراکم ۱۵۰، ۳۲۵ و ۵۰۰ بوته در متر مربـع بـه صورت فاکتوریل (۳×۴) در قالب طرح بلوک های کامل تصادفی در چهـار تکـرار در دو مزرعه با سری خاک های متفاوت در باجگاه مقایسه شدند. نتـایج حاصلـه نشـان داد که بین اغلب ویژگی های مورد بررسی، اختلاف معنی داری بین جو 'والفجر' و تریتیکاله و همچنین بین ارقام تریتیکاله وجود دارد. اثر تراکم بوته بر تعداد سنبله در

متر مربع، تعداد دانه در سنبله، وزن دانه، عملکرد بیولوژیکی و عملکـــرد دانــه، بــه ژنوتیپ و حاصلخیزی خاک وابسته بود. نتایج تجزیه مرکـــب نشــان داد کــه افزایــش تراکم از ۱۵۰ تا ۵۰۰ بوته در متر مربع منجر به افزایش عملکرد دانه در جو و ارقـــام تریتیکاله شد. تعداد سنبله های بارور در هر بوته و تعداد دانه در هر سنبله با افزایش تراکم کاهش معنی داری نشان دادند. عملکرد زیاد بیولوژیکی جو با عملکرد زیـــادتر دانه همراه بود. شاخص برداشت در هیچیـک از دو منطقــه تحـت تــاثیر تراکـم قــرار نگرفت، اما مقایسه شاخص های برداشت جو و تریتیکاله نشان داد که بوته های جو شاخص برداشت بیشتری داشتند. پژوهش های بعدی ممکن است امکـــان اســتفاده از تریتیکاله در خاک های کمتر حاصلخیز مناطق جنوبی ایران را روشن تر سازد.

INTRODUCTION

Grain yield of cereals is the result of many plant growth processes which are ultimately expressed in terms of yield components, i.e., productive spikes m^{-2}, kernels $spike^{-1}$, and mean kernel weight. The highest grain yield could be expected when all yield components are optimized for a specific environment. The response of triticale yield and yield components to planting density has been the subject of many investigations (e.g., 5, 9, 10, 12). Larter *et al.* (12) reported that the effect of seeding rate on grain yield differed among the triticale cultivars. Bishnoi (4) also concluded that each genotype had its maximal yield at a specific optimal seeding rate. Jedel and Salmon (10) reported that planting density effects on grain yield of winter cereals varied among seeding dates. They concluded that seeding rates had no effect on grain yield except in 1 out of 3 years when the highest yields were at 258 seeds m^{-2} for the early September and at the 328 seeds m^{-2} for the late September sowing under central Alberta conditions. Furthermore, Yau (21) showed that biological yield of triticale was greater than that of barley at the more favorable site, and less than that at the less fertile and the drier site. However, in Syria, triticale has been reported to have lower yields than the best barley cultivars (3). In some other studies (e.g., 15) triticale produced lower grain yields than barley and oats but similar yields to wheat. However, comparisons of triticale lines with other cereal crops for yield have shown that some triticale lines outyielded rye and wheat (5), or barley, oats, rye and wheat (14).

There is not enough information about the effect of planting density on yield and yield components of triticale in Iran. Also, there is no published data about the adaptation of commercial triticales, compared with barley, to agroclimatic conditions of southern Iran. The objective of the present study was to determine the effect of planting density on yield and yield components of three high yielding triticale cultivars compared with 'Valfajr' barley under low and high fertility soil conditions.

MATERIALS AND METHODS

Field experiments were conducted at two sites namely, Daneshkadeh soil series (fine, mixed, mesic, Calcixerollic Xerochrepts) with very high fertility and Ramjerdy soil series (fine, mixed, mesic, Fluentic Xerochrepts) with very low fertility, Table 1) in the Agricultural Experiment Station of Shiraz University at Badjgah, 1810 m above the mean sea level with a longitude

52° 32′ E and latitude 29° 36′ N, during the 1995-1996 growing seasons. The meteorological data of the experimental site is shown in Fig.1. Three cultivars of hexaploid triticale 'Juanillo 92', 6917 and 'PG s'and the best local barley cultivar, 'Valfajr', were used in this study. The experiment consisted of three planting densities of 150, 325 and 500 plants m^{-2}, conducted as a 4×3 factorial layout arranged in a randomized complete block design with four replicates at each location. Plot size was 2×3.5 m. Graded seeds of each cultivar were hand sown in equidistant form, i.e., square planting. Regulation of spacing and uniformity of sowing depth was achieved by sowing through perforated plywood sheets with the appropriate density of holes, using a hand dibbler to make holes of 5 cm deep. Plots at both sites received N and P fertilizers each at the rate of 60 kg ha^{-1} urea and ammonium phosphate, respectively, prior to planting.

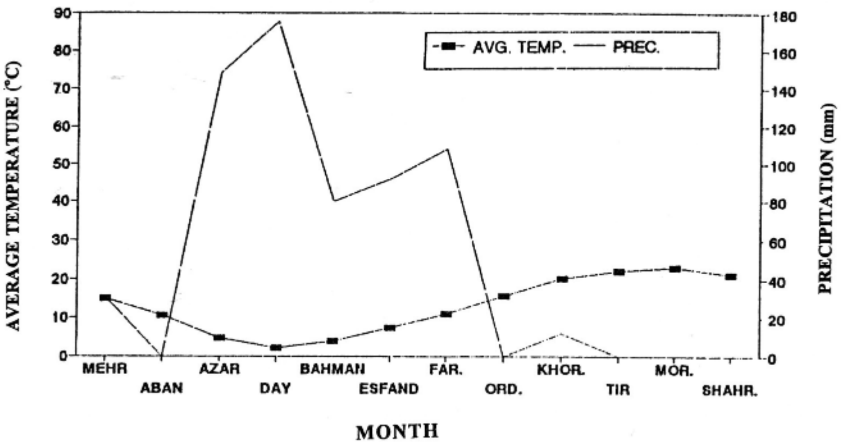

Fig. 1. Monthly average temperature and precipitation at the experimental site for September 21 (Mehr 1)1995 to September 20, (Shahrivar 31) 1996.

Plots were supplemented with additional 60 kg ha^{-1} N as urea just prior to stem elongation [i.e., ZGS 30, see Zadoks *et al.* (22)]. Seeds were sown on 21 October and plots were irrigated properly when required. Plots were regularly hand weeded and no herbicide was used. Dry weights were determined after being oven-dried at 70°C for 48 h. At maturity, the following characters were measured from 1 m^2 final harvest area of each plot:

1) Biological yield (g m^{-2}).

2) Grain yield (g m^{-2}).

3) Harvest index (%).

4) Mean kernel weight (mg).

5) Number of fertile spikes $plant^{-1}$ and m^{-2}.

6) Number of kernels $spike^{-1}$.

Data were analysed using MSTATC (MSTATC Institute, Version 1.42) microcomputer program. Mean comparisons were made using the Duncan's new multiple range test (DNMRT).

RESULTS AND DISCUSSION

According to Table 1, the organic matter, cation exchange capacity (CEC) and electrical conductivity (EC) were higher at Daneshkadeh site. Therefore, the growing conditions between the two sites were particularly affected by the variability in soil fertility. The effect of location on grain yield and yield components is shown in Table 2. There was a highly significant difference

Table 1. Soil physicochemical characteristics of the experimental sites.

Characteristics	Soil series	
	Daneshkadeh	Ramjerdy
Silt (%)	44.4	51.4
Clay (%)	43	29
Sand (%)	12.6	19.6
Gravel (%)	3.84	9.68
Soil texture (%)	Silty clay	Silty clay loam
Potassium (mg K kg^{-1})	670	420
Phosphorus (mg P kg^{-1})	15.13	8.7
Soil pH	7.9	8.1
Organic carbon (O.C. %)	0.92	0.35
Calcium carbonate equivalent (%)	17.0	32.8
Cation exchange capacity (mol kg^{-1})	21.7	13.9
Electrical conductivity (dS m^{-1})	0.560	0.345

Table 2. Location effect on grain yield and yield components of triticale and 'Valfajr' barley.

Characters	Soil series	
	Daneshkadeh	Ramjerdy
Grain yield (ton ha^{-1})	6.1a †	3.5b
Spikes m^{-2}	372.5a	293.5b
Fertile shoots $plant^{-1}$	1.7a	1.2b
Kernels $spike^{-1}$	39.7a	30.4b
Mean kernel weight (mg)	43.1a	38.4b
Biological yield (ton ha^{-1})	13.6a	7.4b
Harvest index (%)	44.2b	46.8a

† In each row means followed by the same letter are not significantly different at 5% level of probability using DNMRT.

between the two sites for most of the parameters measured. For example, the grain yield at Daneshkadeh site was 74% higher than that at Ramjerdy site. This was the result of both higher grain number and the mean kernel weight (Table 2). Comparing the grain yield of barley with triticales averaged over the two sites, it was concluded that the grain yield of 'Valfajr' barley was significantly ($P<0.05$) higher than that of three triticales at all planting densities (Table 3). Increase in plant density up to 500 plants m^{-2} increased the grain yield both in barley and triticales, however, increase in planting density up to 325 plants m^{-2} was not associated with grain yield increase in '6917'(Table 3).

Table 3. Grain yield (g m^{-2}) comparison of 'Valfajr' barley and triticales at different planting densities, averaged over the two experimental sites.

Planting density (plants m^{-2})	Cultivar				
	'Juanillo 92'	'6917'	'PG s'	'Valfajr'	Mean
150	†B 404 b	BC 346 b	C 336 b	A 488c	393 c
325	B 499 a	C 409 b	BC443a	A 597b	487 ab
500	B 564 a	B 483 a	B 475 a	A 685a	552 a
Mean	489 B	413 B	418 B	590A	-

† Means superceeded or followed by the same letter (capital letters in rows and small letters in columns) are not significantly different at 5% level of probability using DNMRT.

The difference in response of triticale cultivars to planting density has also been reported by Larter *et al.* (12). Bishnoi (4) reported a significant effect of row spacing and seeding rates on grain yield of triticale, wheat and barley and concluded that each genotype produced its maximal yield at a specific optimal seeding rate. In the present investigation it was found that 325 and 500 plants m^{-2} were within the range of supposed "optimal" density for both barley and triticales. The only exception was "6917" which did not respond to planting density increase from 150 to 325 plants m^{-2} (Table 3).

The higher grain yield in triticales and 'Valfajr' barley in response to increased population density at both sites was mainly the results of increased grain number with only a slight change in mean kernel weight (Tables 4 and 5). This was consistent with the results reported by other researchers (e.g. 2, 7, 11, 13, 16, 17, 18, 19). Indeed, the triticales had significantly ($P<0.05$) lower fertile shoots per plant (Table 6) as well as lower spikes m^{-2} than 'Valfajr' barley (Table 7). Ellen (7) also reported that the number of shoots m^{-2} in triticale was lower than that of barley. Furthermore, Stapper and Fischer (18) indicated that triticales had lower fertile shoot density as compared to wheats. They also concluded that the number of fertile shoots per plant reduced as the planting density increased. Sethi and Singh (17) studied the interrelationship of quantitative traits with grain yield in triticale and concluded that the number of spikes $plant^{-1}$ was the only effective yield-contributing character.

Mean kernel weight (MKW) of '6917' triticale was less than that of other cultivars at both sites (Tables 4 and 5). Mean kernel weight of barley and triticale cultivars did not show a consistent trend with increased planting density at both sites. Therefore, it appeared that MKW was related to both genotype and environment. Some researchers like Larter *et al.* (12) have found that kernel weight decreased only when seeding rates increased beyond an optimum. Jedel and Salmon (9) reported that seeding rates up to 307 seeds m^{-2} of spring triticale did not affect MKW. Frthermore, Liska and Varga (13) showed that sowing rates up to 500 seeds m^{-2} in triticale had no effect on mean kernel weight. Similar results were obtained in the present experiment. However, Ahmad *et al.* (1) showed that in 40 promising lines of triticale yield per plant revealed positive genetic association with 1000-kernel weight.

Table 4. The effects of plating density on grain yield and its components of 'Valfajr' barley and triticales at Daneshkadeh soil series.

Plants m^{-2}	'Juanillo 92'	'6917'	'PG s'	'Valfajr'
		Grain yield (g m^{-2})		
150	b 532.0 B†	b 458.8 B	b445.8 B	b 665.9 A
325	a 654.9 A	ab 525.3 C	a 575.9 BC	ab 730.5 A
500	a 686.4 B	a 579.0 C	a 610.4 BC	a 801.7 A
		Mean kernel weight (mg)		
150	a 64.38 A	a 37.7 B	a 45.82 A	a 45.34 A
325	ab 46.11 A	a 37.02 C	a 45.5 A	ab 44.15 B
500	b 44.51 A	a 36.83 B	a 44.41 A	b 43.23 A
		Kernels $spike^{-1}$		
150	a41.56B	a49.78A	a40.63B	a43.67B
325	ab36.62B	b43.09A	a38.44AB	a38.95AB
500	b32.66BC	b41.42A	a37.84AB	b31.74C
		Biological yield (g m^{-2})		
150	b 1203 AB	b 1125 B	b 1075 B	b 1365 A
325	a 1469 A	ab 1265 B	a 1353 A	ab 1465 A
500	a 1562 AB	a 1404 B	a 1447 AB	a 1645 A
		Harvest index (%)		
150	a 44.19 B	a 40.71 C	a 41.45 C	a 48.66 A
325	a 44.60 B	a 41.52 C	a 42.54 BC	a 50.10 A
500	a 43.88 B	a 41.29 B	a 42.19 B	a 48.75 A

† Means followed by the same capital letters in each row or superceeded by small letters in each column for each character are not significantly different at 5% level using DNMRT .

Table 5. : The effects of planting density on grain yield and its components of 'Valfajr' barley and triticales at Ramjerdy soil series.

Plants m^{-2}	Cultivar			
	'Juanillo 92'	'6917'	'PG s'	'Valfajr'
		Grain yield (g m^{-2})		
150	b 275.9 A †	b 233.6 A	b 226.2 A	c 310.3 A
325	b 343.3 B	b 292.4 B	ab 309.0 B	b 464.2 A
500	a 441.2 B	a 386.2 BC	a 339.3 C	a 568.1 A
		Mean kernel weight (mg)		
150	a 40.82 A	a 33.70 B	a 41.56 A	a 41.50 A
325	a 40.66 A	a 33.63 B	ab 39.24 A	a 40.35 A
500	a 39.85 A	a 33.62 B	b 36.66 AB	a 39.20 A
		Kernels $spike^{-1}$		
150	a35.36B	a45.96A	a34.96B	a32.35B
325	ab32.08B	b40.24A	ab30.89B	ab29.96B
500	b28.49A	c31.24A	b25.38A	b26.17A
		Biological yield (g m^{-2})		
150	b 613 A	b 557 A	b 504 B	b 598 A
325	b 743 AB	b 600 B	ab 716 AB	a 851 A
500	a 978 AB	a 885 AB	a 795 B	a 1067A
		Harvest index (%)		
150	a 45.06 A	a 41.86 A	a 44.72 A	a 51.82 A
325	a 46.33 AB	a 48.74 AB	a 43.19 B	a 54.77 A
500	a 45.33 AB	a 43.70 AB	a 472.55 B	a 53.26 A

† Mans followed by the same capital letters in each row and superceeded by small letters in each column for each character are not significantly different at 5% level using DNMRT.

Increase in grain yeild of both barley and triticales as a result of increased population density was associated with increased biological yield at both Daneshkadeh (Table 4) and Ramjerdy soil series (Table 5) with no significant change in harvest index. The biological yield of 'Valfajr' barley was significantly higher than '6917' at all planting densities at Daneshkadeh site (Table 4). This was mainly the result of higher fertile shoots $plant^{-1}$ in barley (Table 6) which was discussed before.

Table 6: Effect of planting density on number of fertile shoots $plant^{-1}$ at Daneshkadeh and Ramjerdy soil series (sites).

Site	planting density (plants m^{-2})	Cultivar			
		'Juanillo 92'	'6917'	'PG s'	'Valfajr'
a) Daneshkadeh site	150	†B 2.6 a	B 2.4 a	B 2.4 a	A 3.8 a
planting densiy	325	B 1.4 b	B 0.9 b	B 0.8 b	A 2.4 b
(plants m^{-2})	500	A 0.9 b	A 0.5 b	A 0.5 b	A 1.2 c
b) Ramjerdy site	150	B 1.8 a	BC1.4 a	C 1.2 a	A 3.2 a
planting density	325	B 1.1 b	B 0.7 b	B 0.8 b	A 1.9 b
(plants m^{-2})	500	A 0.5 c	A 0.5 b	A 0.5 b	A 0.9 c
Averaged over two sites and three planting densities		B 1.4	C 1.1	C 1.0	A 2.2

† Means superceeded or followed by the same letter (capital letters in rows and small letters in column) are not significantly different at 5% level of probability using DNMRT.

Table 7. Spike number (spikes m^{-2}) comparison of 'Valfajr' barley and triticales at different planting densities, averaged over the two sites.

Planting density (plants m^{-2})	Cultivar			
	'Juanillo 92'	'6917'	'PG s'	'Valfajr'
150	†B 240.3 c	B 198.2 c	B 199.1 b	A 311.3 c
325	B 341.7 b	C 273.3 b	B 333.4 a	A 417.4 b
500	B 413.3 a	B 381.1 a	B 354.8 a	A 524.8 a

† Means superceeded or followed by the same letter (capital letters in rows and small letters in columns) are not significantly different at 5% level of probability using DNMRT.

Although harvest index was not influenced by density at any of the two sites, the 'Valfajr' barley had higher grain efficiency, based on harvest index (Tables 4 and 5). Indeed, the mean harvest index of the Daneshkadeh site

(44.2%), as a high fertility site, was lower than that of the Ramjerdy site (46.8%), as a low fertility site. The difference may be related to the higher biological yield at the Daneshkadeh site (1364.8 g m^{-2}) than at the Ramjerdy site (742.4 g m^{-2}, Table 2), with perhaps higher competition between vegetative and reproductive parts in favor of the vegetative parts at Daneshkadeh site. All triticales had significantly ($P<0.05$) lower harvest index than 'Valfajr' barley at Daneshkadeh site. Harvest index of 'Juanillo 92' in 150 plants m^{-2} was more than that of 'PG s' and '6917' and in 325 plants m^{-2} was more than that of '6917' at Daneshkadeh site (Table 4). There was no significant difference in harvest index among triticales at the Ramjerdy site (Table 5).

Results of this study also demonstrated that in both sites the number of fertile shoots per plant in triticale cultivars appeared to pose a limitation to increase in grain yield. The yield components of the triticales and 'Valfajr' barley had different responses in each environment. For example, the results indicated that MKW of 'Juanillo 92' and 'Valfajr' barley was significantly reduced with increased planting density under the high fertility conditions (Table 4), while it was not affected at low fertility site (Table 5). Also the present investigation showed that the higher grain yields could be achieved under high fertility conditions. Since some important variations between the yield and major yield components of triticale cultivars were evident in the present investigation, the release of higher grain yielding triticales might be possible, so that the yields of the triticales can reach parity to the barley. Ford *et al.* (8) reported that the triticale breeding lines with *Rht1* dwarfing gene produced higher phytomass than those with *Rht3* gene. There is an increasing interest towards production of triticale under acid soils conditions (20). Thus, further comparisons of the performance of these two cereals under these conditions might be useful. It would be of great interest to examine, in more detail, how the triticales could maintain their significant yield advantage over barley in terms of yield structure.

ACKNOWLEDGEMENT

The authors wish to thank Mr. Akbari of Ministry of Agriculture, Islamic Republic of Iran for supplying the seeds of triticale cultivars.

LITERATURE CITED

1. Ahmad, Z., R.R. Gupta, R. Shyam and A. Singh. 1980. Association and path analysis in triticale. Indian J. Agric. Sci. 50: 198-202.
2. Anderson, W.K. 1986. Some relationships between plant population, yield components and grain yield of wheat in a Mediterranean environment. Aust. J. Agric. Res. 37: 219-233.
3. Anonymous. 1981. Cereal Crops Improvement. ICARDA Annual Report for 1981, Syria, 40-83.
4. Bishnoi, U.R. 1980. Effect of seeding rates and row spacing on forage and grain production of triticale, wheat and rye. Crop Sci. 20: 107-108.
5. Bishnoi, U.R., and J.L. Hughes. 1979. Agronomic performance and protein content of fall-planted triticale, wheat and rye. Agron. J. 71: 359-360.

6. Donald, C.M. 1963. Competition among crop and pasture plants. Adv. Agron. 15: 1-18.

7. Ellen, J. 1993. Growth, yield and composition of four winter cereals. I. Biomass, grain yield and yield formation. Neth. J. Agric. Sci. 41: 153-165.

8. Ford, M.A., R.B. Austin, R.S. Gregory and C.L. Morgan. 1984. A comparison of the grain and biomass yields of winter wheat, rye and triticale. J. Agric. Sci., Camb. 103: 359-403.

9. Jedel, P.E. and D.F. Salmon. 1993. Seeding rate response of Wapiti triticale in short-season growing areas. Can. J. Plant Sci. 73: 65-71.

10. Jedel, P.E. and D.F. Salmon. 1994. Date and rate of seeding of winter cereals in central Alberta. Can. J. Plant Sci. 74: 447-453.

11. Kumar, S. and I.S. Singh. 1993. Correlation and path analysis in triticale. Indian J. Genet. 53: 147-202.

12. Larter, E.N., P.J. Kaltsikes and R.C. McGinnis. 1971. Effect of date and rate of seeding on the performance of triticale in comparison to wheat. Crop Sci. 11: 393-545.

13. Liska, E. and J. Varga. 1993. Effect of sowing date, sowing rate and nitrogen fertilization on the yield formation in triticale. Polnohospodarstvo (Slovac Republic) 39: 210-218.

14. Morey, D.D. 1979. Performance of triticale in comparison with wheat, oats, barley and rye. Agron. J. 71: 98-100.

15. Oplinger, E.S. and V.L. Younges. 1975. Performance of spring sown triticale, oat, barley and wheat. Agron. J. 67: 724-729.

16. Piech, M., S. Stankowski and M. Poznanski. 1990. Increasing the reproduction coefficient of spring triticale by reduction of the sowing rate. Bulletin of Plant Breeding and Acclimatization Institute (Poland) 175: 5-13.

17. Sethi, G.S. and H.B. Singh. 1972. Interrelationship of quantitative traits with grain yield in triticale. Indian J. Agric. Sci. 42: 281-285.

18. Stapper, M. and R.A. Fischer. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. I. Phasic development, canopy growth and spike production. Aust. J. Agric. Res. 41: 997-1019.

19. Stapper, M. and R.A. Fischer. 1990. Genotype, sowing date and plant spacing influence on high-yielding irrigated wheat in southern New South Wales. II. Growth, yield and nitrogen use. Aust. J. Agric. Res. 41: 1021-1041.

20. Sweeny, G., R.S. Jessop and H. Harris. 1992. Yield and yield structure of triticales compared with wheat in northern New South Wales. Aust. J. Exp. Agric. 32: 447-453.

21. Yau, S.K. 1987. Comparison of triticale with barley as a dual purpose crop. Rachis 6: 19-24.

22. Zadoks, J.C., T.F. Chang and C.F. Konzak. 1974. A decimal code for the growth stages of cereals. Weed Res. 14: 415-421.