IDRC-024e

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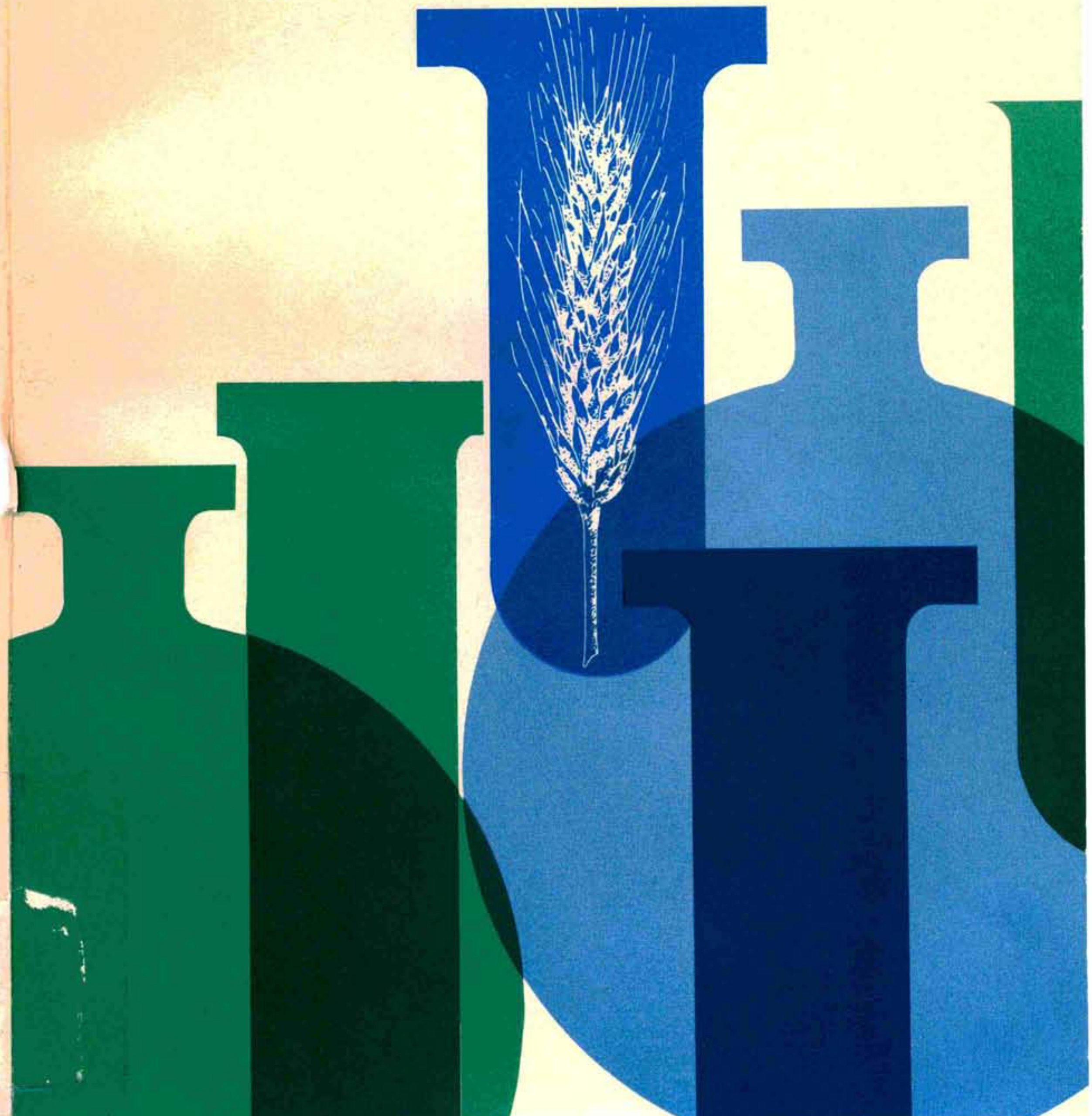

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This symposium was co-sponsored by the Centro Internacional de Mejoramiento de Maiz y Trigo, the University of Manitoba, and the International Development Research Centre.

*The views expressed in this publication are those of the individual author(s) and do not necessarily represent the views of the International Development Research Centre.

ISBN 0-088936-028-6
UDC: 633.1

Head Office: 60 Queen Street, Box 8500, Ottawa, Canada K1G 3H9
Microfiche Edition $1

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Agronomy and Physiology of Triticales

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FISCHER, R. A. 1974. Agronomy and physiology of triticales, p. 201–209. *In* Triticale: proceedings of an international symposium, El Batan, Mexico, 1–3 October 1973. Int. Develop. Res. Centre Monogr. IDRC–024e.

Abstract The agronomic aspects of triticale have not been widely studied, although some unpublished data are available at CIMMYT. The limited work so far suggests that we should expect no important differences between the agronomic management of triticale and bread wheats of the same height. The effects of high soil N on the yield of triticale are discussed, as well as the desirable row spacing, seed depth, and time of planting to obtain maximum yield. Sink size, or the overall capacity of the grains to accept and store photosynthate, is discussed as a possible cause of shrivelling. Eliminating the basic genetic causes of shrivelling should lead to further yield improvement of triticale.

Résumé Les aspects agronomiques du triticale n'ont pas fait l'objet d'études étendues, bien qu'il existe à ce sujet au CIMMYT un certain nombre de données inédites. Les travaux limités effectués jusqu'ici laissent à penser que l'on ne doit pas s'attendre à des différences importantes entre les exigences culturales du triticale et des blés de même taille destinés à la panification. On traite des effets d'une teneur élevée des sols en N sur le rendement du triticale, aussi bien que de l'espacement souhaitable entre les rangs, de la profondeur et de l'époque du semis pour obtenir un rendement maximal. On évoque également la capacité d'accumulation des produits de photosynthèse comme cause possible du plissement des grains. L'élimination des causes génétiques fondamentales de ce plissement devrait amener par la suite une amélioration du rendement.

Agronomy

WHAT there is to say about triticale agronomy is rather inadequate. Firstly, relatively little has been published about this area; secondly, most of the little we have done at CIMMYT, which is unpublished, has involved now-superceded lines of triticale. On the other hand, however, and with one or two exceptions, I do not believe there are reasons to expect important differences between the agronomic management of triticales and that of bread wheats of the same height category. Of course, CIMMYT will continue to intensify agronomic research with the new lines coming forward, but we certainly do not need to wait for all the results to come before encouraging the commercial production of triticales in appropriate situations.

Presently Available Results

Unless otherwise mentioned, these refer to irrigated conditions at latitude 27°N in the winter cycle in northwestern Mexico. The nitrogen response in the older triticales, such as Armadillo, is very close to that of the old tall bread wheats (Fig. 1). Starting with very low soil N, for example in the case of the 1969–70 and 1972–73 experiments, maximum yield under hand harvesting is reached with about 200 kg/ha N given at seeding, after which lodging becomes serious and yields tend to decrease. We have shown by preventing lodging with mesh that lodging at anthesis can reduce yield up to 1.5 t/ha depending on its severity. This is the same for tall bread wheats. The only difference I have observed is that, other things being equal, the triticales will lodge less than the bread wheats and have a greater capacity to right themselves by bending at the stem nodes.

With the shorter triticales now approaching 100–110 cm under our conditions, we have seen that lodging resistance at high N has been improved and there is no doubt that the optimal N application for maximum levels of profit or maximum yield will increase and approach those recommended for the current bread wheat varieties. For this reason as well as another to be mentioned later, yield levels must increase.

When it comes to seeding rate and row spacing, the picture under our conditions is again similar to bread wheats. Trials with

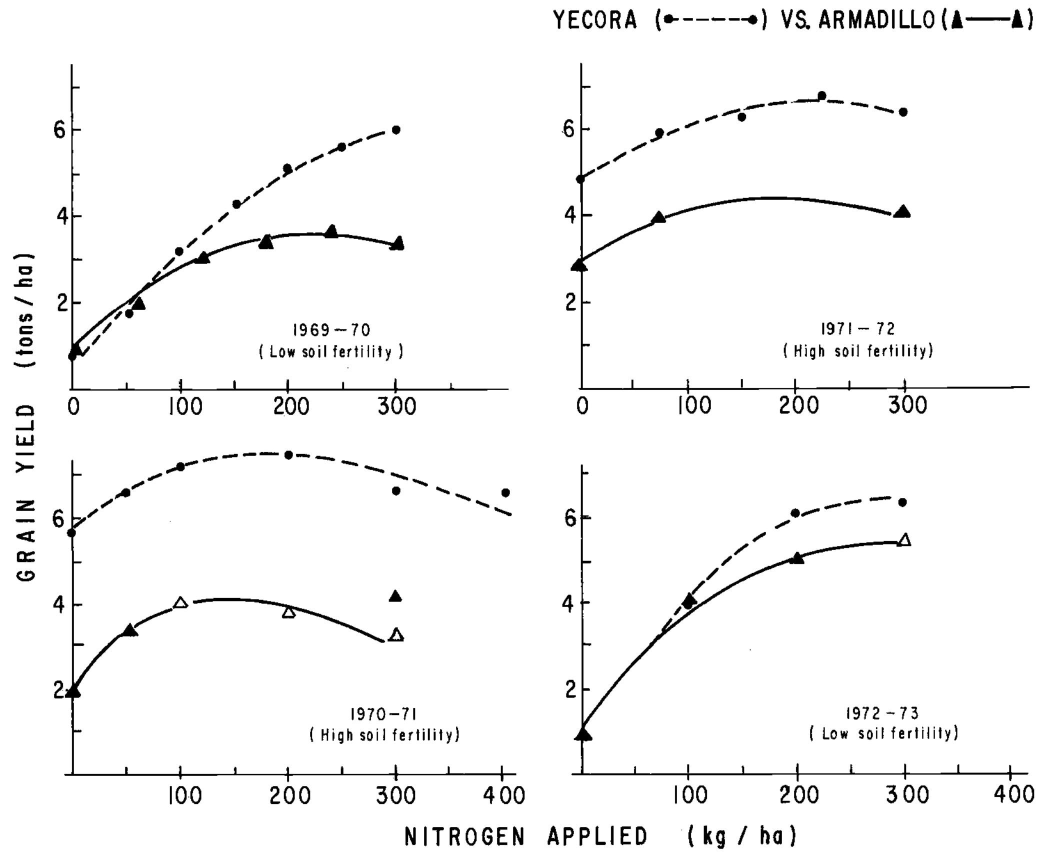

FIG. 1. Nitrogen fertilizer trials, using Yecora and Armadillo triticales.

Armadillo "S" show little response to density over the range 25–150 kg/ha (Table 1). This agrees with Larter and Kaltsikes (1971) who studied the triticale variety Rosner at Winnipeg. A recent study by the triticale section here in CIMMYT and using 10 triticales both old and new showed a 12% reduction in 60-cm row spacing compared with 30-cm row spacing. This is a relatively small reduction and taken along with the few other triticale results and numerous results from bread wheats suggests that a row spacing of up to 45 cm can be tolerated under our conditions without any loss in yield. Rows narrower than 30 cm would probably lead to greater lodging and no increase in yield. Thus unless drastic changes in plant type occur in the future, or weed problems are serious or seed bed preparation poor, I would predict that triticales in the irrigated low latitude environments will produce optimally at densities from 40 to 80 kg/ha and row spacings 20–45 cm.

In the seeding density trials, although increased seeding rate increased ear numbers somewhat, this component even at 150 kg/ha of seed (200 established plants/m^2) still remained noticeably inferior to the bread wheats. This and other studies with bread wheats suggest that increased seeding density will not rectify the supposed problem of low ear numbers observed in triticales.

TABLE 1. Effects of seeding density on grain yield of triticale (Arm "S" 105X-308-OY). Trial A VIII, CIANO, 1970–71; mean of planting systems.

Density *kg/ha*	Grain yield (12% moisture), *t/ha*
25	4.31
50	3.88
100	4.11
150	3.83
Diff. for significance 5%	0.48

Seeding Depth

In many dry-land situations it is important that seedlings can emerge from plantings at considerable depth, for example 10–12 cm. Triticale seedlings appear to be generally low in vigour and in one small trial in northwest Mexico last season the line Cinnamon "S" emerged satisfactorily only when sown no deeper than 9 cm, whereas two bread wheats and another triticale emerged well from 12 cm.

Optimal seeding date is rather a regional specific recommendation. In one trial last winter season in northwest Mexico, Cinnamon "S" was seeded along with three top bread wheat varieties and one top durum at five different dates from 26 October to 18 January. Best yields were obtained for all with December sowings but curiously the triticale showed greatest yields relative to the others with the late October and mid-November sowing (Fig. 2). The early sowings encountered warm conditions early, followed by cool cloudy conditions from jointing through maturity. The triticale showed its superiority especially in grains per ear. This contrasts with results from summer sowings in Canada (Larter and Kaltsikes 1971) where the triticale Rosner became relatively less well adapted with later seedings in the range mid-April to late May, an effect assumed to be related to the increased temperatures during the tillering period with later sowings.

The above Mexican results plus the relatively good performance of triticales observed in certain situations such as northwestern Mexico last season (a cloudy cool season compared with the normal), the summer plantings in central Mexico (always cool cloudy situations), and finally highland conditions in low latitudes (for example Ethiopia) provide sufficient evidence to advance the hypothesis that CIMMYT spring triticales are relatively better adapted to cool cloudy conditions than the Mexican spring wheats from which they have been derived.

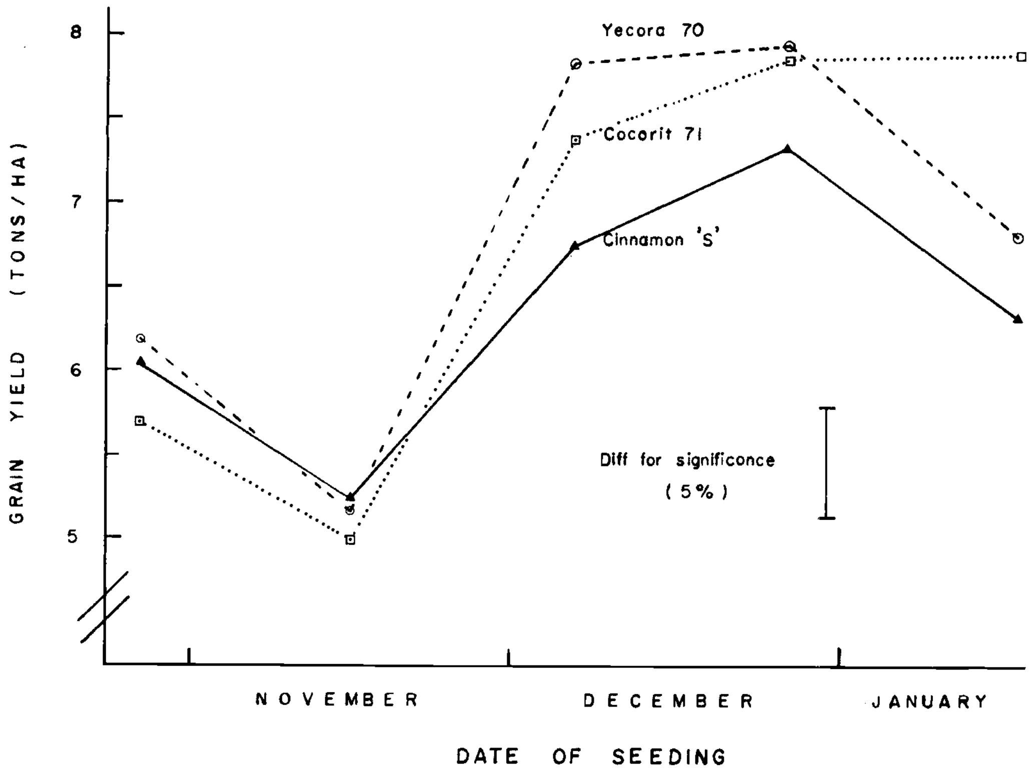

FIG. 2. Date of seeding trial, D II Y72-73.

Drought and Cold Resistance

Another hypothesis relevant to the adaptation and management of triticales is that being descendents of rye they are relatively resistant to drought, and also to cold. I have been unable to find any published evidence relating to this. Kaltsikes (1971) did show that the triticale Rosner was of intermediate yield stability compared to bread wheats and durums across 10 localities in Manitoba. At the outset I would caution that one can usefully recognize around the world three or four quite distinct types of drought faced by cereals, not to mention differences in severity within any type and modifying effects of soil texture and depth. Thus we have only studied the response of certain triticales to what I call simulated Mediterranean drought, involving terminal post-anthesis water stress. On the heavy soils in northwestern Mexico with moderate stresses so far we have found no evidence for greater drought resistance in triticales compared to bread wheats (Fig. 3). On checking some of the old literature on rye one gets the impression that the only mechanism for drought resistance in rye may be earliness, and that in fact rye is quite susceptible to drought and heat in the flowering and post-flowering periods.

Regarding cold resistance one must also recognize different situations when cold damages cereals, specifically winter-kill, for which winter rye has superior resistance, frost damage to elongating stem tissue, frost damage causing sterility of the spike and frosting of the ripening grains. There seems to be some evidence that spring triticales show unusually good winter-hardiness for spring cereals. Superior resistance to frost damage has not been reported to my limited knowledge and I am not sure that it is possessed by rye anyhow.

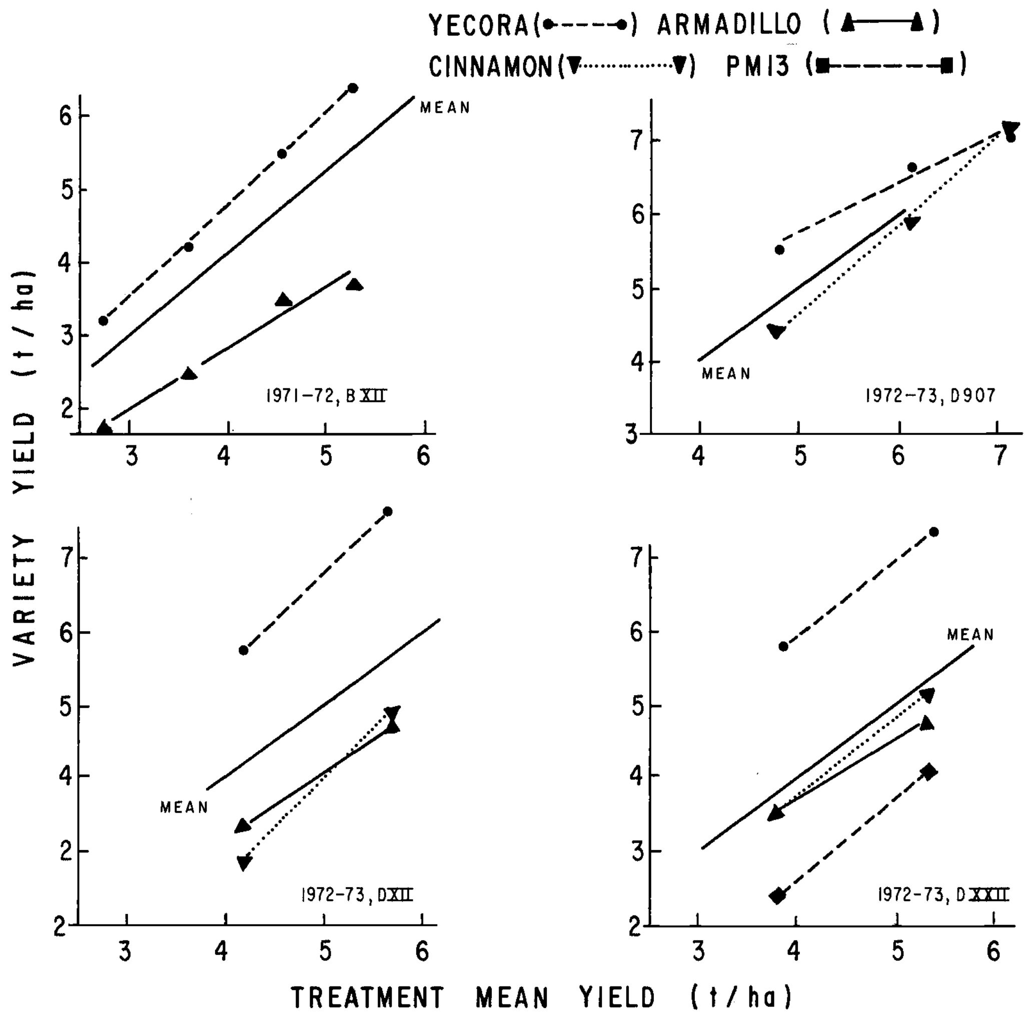

FIG. 3. Triticale water stress trials.

Agricultural Chemicals

Some care must be taken to see that triticales are tolerant of the agricultural chemicals being applied to them. Referring to herbicides, we have found triticales generally to be highly tolerant of dinitro and carbyne, more tolerant of 2,4-D than bread wheats, and reasonably tolerant of Tribunil, depending in the last instance to some extent on the environmental conditions. However, with a moderate dose of the common insecticide DDD-Toxaphene, applied 3 weeks after seedling emergence, in a set of 28 triticales only 5 showed no damage, while 18 showed moderate to severe damage, sufficient to reduce final yield; the same application to many durum and bread wheat lines caused no damage whatsoever. It is not known at the moment which was the toxic ingredient of this insecticide but serious toxicity has been observed in three successive seasons.

Physiology

Except for work on the nature of grain shrivelling, studies of the physiology of triticales are very few. As a corollary to our studies of the crop physiology of bread wheats certain key triticales have been included in most trials. These trials have been conducted under high-fertility irrigated conditions of the winter cycle in northwestern Mexico. Because of lodging of the taller older triticales and the frequent appearance of new improved strains, the results of these comparative studies are of rather limited value. Nevertheless, some points are worth mentioning.

Although the triticales studied tended to have slightly smaller leaf area indices, biomass production has always been close to that of bread wheats. The yield disadvantage of older triticales therefore clearly rested in their reduced harvest indices or ratio of grain to total dry weight. Improvement in the yield potential of triticales has involved a steady improvement in harvest index (Table 2). Extensive studies with bread wheats suggest that this improvement is partly related to the reduction in plant height and is expressed even in the absence of lodging (which, although it occurred in the trials shown in Table 2, was too late to affect yield). Specifically, in the Mexican bread wheats over the past 15 years or so, stature has been reduced from about 120 cm to 75 cm, and in the absence of lodging, harvest index rose from about 0.33 to 0.45 and grain yield rose correspondingly. Triticales appear to be only part way along this course, for they have yet to reach yield potentials and harvest indices of the best triple dwarf bread wheats. Table 3 shows a comparison of the highest yielding

TABLE 2. Improvement in yield and its components in spring triticales at CIMMYT. Trials D XXXI and D XI, Y72-73.

Parameter	Triticale Armadillo "S" (120 cm)	Triticale Cinnamon "S" (130 cm)	Triticale Mayall-Arm "S" (100 cm)	Bread wheat Yecora 70 (75 cm)	LSD 5%
Grain dry wt, g/m^2	481	512	562	585	43
Total dry wt, g/m^2	1440	1449	1415	1285	123
Harvest index	0.33	0.35	0.40	0.46	0.03
Spike/m^2	286	224	319	417	31
Spikelets/spike	21.2	25.0	23.3	18.2	2.4
Grains/spikelet	1.71	2.10	2.07	1.68	0.40
Wt/grain, *mg*	46.3	43.6	36.8	46.0	2.0
Grain no., *1000/m*^{2}	10.4	11.7	15.4	12.7	1.2
Lodging score, 0–100	47	66	30	0	–
Date 50% ear emergence	22 Feb.	28 Feb.	24 Feb.	25 Feb.	–

TABLE 3. Key yield parameters for a very high-yielding crop of triticale and two high-yielding semi-dwarf wheats. Trial D II, seeded 7 December 1972, Y72-73.

Parameter	Bread wheat Yecora 70	Bread wheat Cajeme 71	Triticale Cinnamon "S"	LSD 5%
Grain dry wt, g/m^2	698	724	605	58
Total dry wt, g/m^2	1550	1745	1580	130
Harvest index	0.45	0.42	0.38	0.02
Spikes/m^2	456	437	318	51
Spikelets/spike	18.6	20.1	21.4	1.3
Grains/spikelet	1.84	1.85	2.00	0.17
Dry wt/grain, *mg*	44.9	44.5	44.6	2.2
Grains no., *1000/m*^{2}	15.6	16.3	13.6	1.5
Lodging score, 0-100	0	11	83	–
Date of 50% ear emergence	4 Mar.	12 Mar.	28 Feb.	–

triticale crop I have studied with two triple dwarf bread wheat varieties.

Tennenhouse and Lacroix (1972) reported further evidence that an inverse relationship between height and yield potential operates in triticale just as in bread wheats. These authors studied the effect of two doses of CCC (2-chloroethyl trimethyl ammonium chloride) on Rosner triticale in the field at Winnipeg in the absence of lodging; control height was 95 cm; + 3 kg/ha CCC reduced height to 81 cm and increased yield over control by 4%; + 6 kg/ha CCC reduced height further to 75.5 cm and increased yield over control by 12%.

In summary, I see no reason why triticale will not soon reach the height, harvest index, and yield levels of the best short bread wheats. Spikelet fertility obstacles may, or in fact, have arisen, but this is an entirely independent problem of reproductive physiology, the solution of which is unrelated, I believe, to the problems of partitioning the limited amount of biomass of the crop. The intriguing question, of course, for both bread wheats and triticales is where do we go having once achieved harvest indices of 0.45 (grain/straw ratio of 1.2).

It is interesting to also observe briefly the numerical components of yield reported in Tables 2 and 3. In Table 3 the triticale is clearly inferior only in spike number; spike size and spikelet fertility tend to be better than for the bread wheats, although grain number per unit area still remains somewhat inferior. Table 2 also shows the deficiency in spike number of the triticales; however, for the highest yielding triticale the superiority in spike size and spikelet fertility is sufficient to give a very respectable grain number per square meter.

It is rather dangerous to predict areas of yield improvement from such observations of yield components, even if the observations were more extensive. With less caution, however, Sethi and Singh (1972), after studying a diverse set of 31 triticales, pointed to spikes per plant as the most fruitful area for yield increase because of its strong correlation with grain yield per plant. The study was conducted under spaced plant conditions and, I think, the results predictable and the conclusion quite misleading.

Low spike number per unit area has always been observed with triticales. Tillering in wheats generally increases with lateness; spring triticales in solid stand tiller consistently less than most bread wheats of the same maturity. However, the bread wheat Siete Cerros, amongst others, shows a similarly low tillering capacity. In bread wheats, in general, lower tillering is associated with higher tiller survival; again, triticales fall below the relationship, having tiller survival percentages of around 35% when bread wheats would be averaging 50%.

Spikelet number is related to the length of the period sowing to terminal spikelet formation and hence maturity class, and to the rate of primordia production at the shoot apex. Triticales from our observations here and the published results of Rawson (1971) appear to spend more time for a given maturity class in the pre-terminal spikelet stages and also have a greater rate of primordia production. Thus their ears have greater numbers of spikelets for given maturity classes compared to bread wheats. This character is not solely the result of less inter-shoot competition due to lower tillering although this may be a necessary condition in solid stand. Ear size may in fact be one of the most important unique features of triticales, since it represents a potential avenue for increasing sink size. Suffice to mention that up to 40 or more developed spikelets per spike have been measured in certain spring triticales, a number never observed to my knowledge in spring wheats.

A third feature is the problem of the fertility of triticale spikes. This problem, however, may have been overcome in the spring triticales such as Armadillo, Beaver, and Cinnamon, at least for certain environmental conditions. In terms of grains per spikelet, these triticales compare very favourably with some 40 or 50 wheat and durum genotypes we have studied over the last 3 years. Of course this may not be a very satisfactory basis of comparison and it would be better to have data on grains per perfect floret. I myself prefer to think in terms of grains per unit of dry matter built into the ear structure at anthesis; on this basis also the newer triticales are as good as the other wheats.

Finally we come to the post-anthesis period and the grain size and shrivelling question. By grain size I mean dry weight per grain. The photosynthetic system at the beginning of this period for the triticales that we have studied is different in that the flag leaf lamina tends to be smaller and the area of other green leaf lamina greater than in other wheats. The canopy appears more open, with a greater area of green leaf sheaths and exposed stem tissue. In northwestern Mexico last season, leaf lamina removal treatments were applied at anthesis to random shoots of Cinnamon "S" and of three wheat varieties (Hira, Yecora 70, and Cocorit 71). Flag lamina removal reduced yield per spike 15% in the triticale and an average of 18% in the other wheats; with the removal of all lamina, the reductions were 41 and 27%, respectively. Reductions in grain number and grain size were involved, with clear evidence that lamina removal lead to greater reductions in grain number in the triticale compared to the other wheats.

In an experiment involving extreme crop thinning at anthesis three seasons ago, we showed grain size in two triticales to increase 18% in response to thinning, which we feel simply permits more light interception and therefore more photosynthesis in the remaining shoots. The response to such thinning in some 30 wheat varieties ranged from +3% to +40%. This and the above-mentioned lamina removal studies suggest that grain size in triticales is responsive in both directions to manipulation of post-anthesis photosynthate supply, just as occurs in most other wheats we have studied. If this is the case, it indicates that the capacity of the photosynthate translocation system is probably not a limiting factor. Also, since triticale grains remained typically shrivelled under the above conditions and since this shrivelled grain does not resemble grain of bread wheats produced under conditions of photosynthate shortage (e.g., heavy shading), it is probably safe to conclude that triticale grain shrivelling is a problem internal to the grain and not a supply problem.

From extensive experience with certain key bread wheats, I must emphasize, however, that the above results obtained with change in photosynthate supply do not mean that photosynthate is the only or even the major post-anthesis factor limiting grain yield in triticales. Sink size or the overall capacity of the grains to accept and store photosynthate must be considered. In particular it is interesting to speculate whether grain shrivelling and the metabolic disorders within the grain that it reflects represent a limitation in storage capacity. Evidence against this is that triticale grain size and grain growth rates are quite respectable when compared to bread wheats, and that differences in grain size between lines does not appear to be associated with differences in the degree of grain shrivelling (Klassen et al. 1971).

Evidence to support the above speculation that shrivelling represents a sink or storage limitation could be the following observation. Over the seven replicated triticale advanced yield trials, conducted last cycle in northwestern Mexico and involving 146 separate entries, grain yield variation was highly significantly associated with variation in test weight, which can be accepted as a good indicator of the degree of grain shrivelling. The linear correlation coefficient was low ($r = 0.28$), indicating that many other factors, including experimental error, were involved. Nevertheless the slope of the relationship was estimated with reasonable precision, and indicated an increase in grain yield of 90 ± 50 kg/ha for each 1 kg/hl increase in test weight. These results are especially useful because the experimental sample was large and reasonably diverse, with yields ranging from 4100 to 8300 kg/ha and test weights from 62.5 to 75.1 kg/hl. I would conclude from the above discussion that shrivelling causes reduced grain yields because it represents a limitation in the grain's sink or storage capacity, and that eliminating the basic genetic causes of shrivelling should lead to further yield improvements.

Conclusions

In conclusion, I would speculate that we will soon have for irrigated conditions new triticales that are shorter (90–100 cm), still relatively low in ear number, but very superior in ear size, acceptable in spikelet fertility, and somewhat improved in grain size. In contrast, new bread wheats may well be shorter still (70 cm), with small erect leaves and many more smaller ears and smaller grains. Both crops will approach yield potentials of about 8–9 tons/ha under optimal conditions, and will require, if soil fertility is to be maintained, from 200 to 300 kg/ha of N. The triticales may yield slightly more protein per hectare than the bread wheats.

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