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Karnal bunt (*Tilletia indica*) resistance screening of *Aegilops* species and their practical utilization for *Triticum aestivum* improvement

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Eighty-six accessions of 21 *Aegilops* species, were screened under greenhouse conditions for resistance to Karnal bunt (*Tilletia indica*) using the boot inoculation technique. Infection ranged from 0 to 60% over a severity scale of 0 (zero infection) to 5 (completely bunted grain). All accessions of *Aegilops biuncialis, Ae. columnaris, Ae. crassa, Ae. juvenalis, Ae. ovata,* and *Ae. speltoides* and one or more accessions of *Ae. bicornis, Ae. cylindrica, Ae. kotschyi, Ae. longissima, Ae. sharonensis, Ae. squarrosa, Ae. triaristata, Ae. triuncialis, Ae. umbellulata, Ae. uniaristata, Ae. variabilis, Ae. vavilovii,* and *Ae. ventricosa* were resistant. The greenhouse screening technique and methods to utilize the resistant germplasm for *Triticum aestivum* improvement are discussed.

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Quatre-vingt-six accessions appartenant à 21 espèces d'*Aegilops* ont été soumises à une sélection en serre pour évaluer leur résistance à la carie de Karnal (*Tilletia indica*) en utilisant la technique d'inoculation de la botte. L'infection a oscillé entre 0 et 60% se basant sur une échelle de sévérité de 0 (aucune infection) à 5 (le grain complètement atteint de carie). On a observé la résistance chez toutes les accessions d'*Aegilops biuncialis*, d'*Ae. columnaris*, d'*Ae. crassa*, d'*Ae. juvenalis*, d'*Ae. ovata*, et d'*Ae. speltoides* et chez une ou plusieurs accessions d'*Ae. bicornis, Ae. cylindrica, Ae. kotschyi, Ae. longissima, Ae. sharonensis, Ae. squarrosa, Ae. triaristata, Ae. triuncialis, Ae. umbellulata, Ae. uniaristata, Ae. variabilis, Ae. vavilovii*, and *Ae. ventricosa*. On y discute de la technique de sélection en serre et des méthodes d'utilisation du germoplasme résistant pour l'amélioraton du *Triticum aestivum*.

Karnal bunt is caused by *Tilletia indica* Mitra, [synonym *Neovossia indica* (Mitra) Mundkur], a floral-infecting organism that infects seed of bread wheat (*Triticum aestivum* L.) (21), durum wheat (*Triticum turgidum* L.) and triticale (*X. Triticosecale* Wittmack) (1). It was first reported on wheat in India at Karnal, state of Haryana, during the 1930's (21), when it appears to have been localized in its distribution. Since then, it has spread to northern India, northern Pakistan (29), and southern Nepal. It is also present in Iraq (6) and Mexico (9) and has been found on wheat seed intercepted from Afghanistan (19) and Lebanon (31).

The teliospores of *T. indica* may be deposited in or on the soil at the time of harvesting and threshing, or they may contaminate the surface of the seed (4,5). Each teliospore germinates with a germ-tube that bears a large number of primary sporidia at its tip (27). These sporidia, or secondary sporidia that bud off them, are carried to the wheat spike either by air currents or by splashing water (13,28).

Infection occurs between heading and anthesis when the fungal hyphae enter the developing kernel through the ovary wall (30). Only a few florets on any one spike are bunted, and not all spikes on a plant are infected (4,20). Infection starts at the embryo end of the grain and spreads along the grain suture (30). The endosperm lying alongside the suture remains uninfected, with the dark brown teliospores forming under the pericarp and testa, above the aleurone layer of the endosperm (21). Although teliospores partially surround the embryo, there is no infection in the embryo tissue (30). In severely infected florets, the glumes are spread apart exposing the bunted grains, but this is not a common symptom (12). Although some individual grains in a diseased spike are completely infected, most of the affected grains are only partially infected (13). Freshly collected infected grains emit a foul smell (somewhat like rotten fish) due to the production of trimethylamine by the fungus (16,22).

There are two principle inoculation techniques: 1) The boot inoculation technique — injection of a suspension of secondary sporidia into the boot of the wheat plant at awn emergence using a hypodermic syringe (3,5,33,34). 2) The spray inoculation technique — a suspension of secondary sporidia is sprayed onto the wheat spike at various stages between heading and anthesis (33).

The boot inoculation technique is the most reliable, giving up to 100% infection on susceptible varieties, but it is a severe method that screens for physiological resistance only. This technique requires less humidity than the spray inoculation technique (5) and has therefore been an efficient field screening method in India and Mexico.

The spray inoculation technique more closely mimics field infection and screens for morphological, and to a lesser extent, physiological resistance. It does, however, require high humidity to ensure infection (34) and is therefore unsuitable as a field screening method in dry areas. In the greenhouse, where conditions can be controlled, it provides a rapid, efficient means of screening.

One method of controlling the disease is through the development of lines possessing genetic resistance to Karnal bunt. At present no cultivar of the *aestivum* group of wheats has been reported to be resistant to Karnal bunt (13). All commercial wheats cultivated in India since the first report of Karnal bunt in 1931 have been susceptible to the disease, although they differ in the degree of susceptibility (11).

In India a large number of lines have been screened under both natural infection and artificial inoculation to identify sources of resistance or immunity. Aujla et al. (3) screened 286 genotypes with the boot inoculation technique and found 10 lines with only 1-5% infection. Gautam et al. (11) tested 96 lines with the boot inoculation technique and found 32 lines with zero infection, 10 with less than 1%, 38 with 1-5%, and the remaining 16 lines with over 5% infection.

Studies of aneuploids, ditelosomics, and compensating nulli-tetrasomic groups involving the D genome of cv. Chinese Spring, as well as addition- and substitution lines of the D genome in *T. turgidum* cv. Langdon reveal that all the homologous groups of wheat appear to be involved in the genetic control of Karnal bunt resistance (2). A recent review by Gill et al. (13) showed that the group 6 chromosomes appeared to be involved in the reaction to Karnal bunt. Genes for resistance may be located on 6A and 6B, while 6D has a dominant gene for susceptibility. Chromosome 2D and the short arm of chromosome 4D also appeared to have a gene for resistance to Karnal bunt. Dominant genes for susceptibility were reportedly present in chromosomes 1D and 3D. Because of the apparent large influence of the D genome on the reaction to Karnal bunt, Gill et al. (13) suggested that resistance to Karnal bunt should be sought in *Ae. squarrosa*. This diploid species possesses the D genome, and resistance, if found, could be transferred via synthesizing AABBDD combinations of hexaploid wheat.

Later Gill et al. (14) compared Karnal bunt incidence among various aneuploids of *T. turgidum* and *T. aestivum* and found that the aneuploid in which one of the chromosomes 1A or 1D is missing shows a higher level of susceptibility. This indicates that chromosomes 1A and 1D may have a complementary gene system for Karnal bunt resistance. In addition the long arm of chromosome 4D appeared to possess a dominant gene controlling susceptibility to Karnal bunt.

From our experience with boot inoculations in the greenhouse, *T. aestivum, T. turgidum*, and *X Triticosecale* all show the same degree of susceptibility (E.J. Warham, unpublished data). Since some *Aegilops* species showed no infection after boot inoculation, they may be possible sources of physiological resistance. We therefore screened a larger number of accessions of *Aegilops* species, using the boot inoculation technique. The screening technique, results, and methods for utilizing the resistant germplasm for *T. aestivum* improvement are described in this paper.

Materials and methods

Eighty-six accessions of 21 *Aegilops* species were obtained from P.B.I. Cambridge, England, and the University of Missouri, USA (Table 1). These were planted in pots containing a sterilized soil mix 2:1:1 (soil:sand:peat) under greenhouse conditions with 14 to 16 h natural light, 22°C day and 12°C night temperatures and approximately 45 to 60% relative

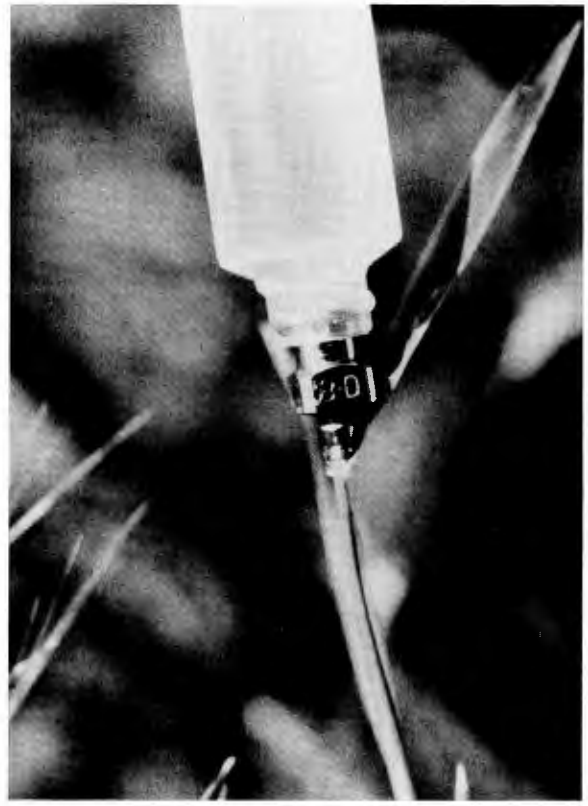

Figure 1. The Karnal bunt boot inoculation technique – injection of a water suspension of secondary sporidia into the *Aegilops* spike at the boot stage.

Table 1. Percentage Karnal bunt in *Aegilops* spp. after boot inoculations with *Tilletia indica*

Aegilops spp.	Genome	No.	Origin	% of grains in severity classes 0-5						Total no. grains	No. infected grains	% of grains infected
				0	1	2	3	4	5			
Ae. umbellulata Zhuk.	U	1A	PBI	100	0	0	0	0	0	80	0	0
		2B	PBI	98	1	0	0	0	1	226	4	2
		211	Kim (TU03)	100	0	0	0	0	0	32	0	0
Ae. ovata L.	UM^O	3A	PBI	100	0	0	0	0	0	104	0	0
		4E	PBI	100	0	0	0	0	0	480	0	0
		160	Kim (T001)	100	0	0	0	0	0	220	0	0
Ae. triaristata Willd.	UM^t	5F	PBI	100	0	0	0	0	0	228	0	0
		6G	PBI	100	0	0	0	0	0	335	0	0
	UM^tM^t	7A	PBI	100	0	0	0	0	0	12	0	0
		8B	PBI	94	0	0	0	0	6	31	2	6
		162	Kim (TN03)	100	0	0	0	0	0	30	0	0
		169	Kim (TN01)	40	0	3	8	1	48	133	80	60
Ae. columnaris Zhuk.	UM^c	9A	PBI	100	0	0	0	0	0	58	0	0
Ae. biuncialis Vis.	UM^b	10A	PBI	100	0	0	0	0	0	9	0	0
		11B	PBI	100	0	0	0	0	0	40	0	0
Ae. variabilis Eig.	US^v	12A	PBI	98	2	0	0	0	0	95	2	2
		13E	PBI	100	0	0	0	0	0	29	0	0
Ae. kotschyi Boiss.	US^v	129	Kim (TK01)	99	0	0	0	0	1	204	1	1
Ae. triuncialis L.	UC	14A	PBI	95	3	0	0	0	2	399	20	5
		15X	PBI	99	0	0	0	0	1	663	9	1
		207	Kim (TW02)	100	0	0	0	0	0	41	0	0
Ae. caudata L.	C	16A	PBI	77	1	1	0	0	21	910	211	23
Ae. cylindrica Host	CD	17A	PBI	99	0	0	0	0	1	651	8	1
		18G	PBI	99	0	0	0	0	1	692	1	1
Ae. comosa Sibth. et Sm.	M	19A	PBI	38	12	0	0	0	50	8	5	62
Ae. uniaristata Vis.	M^u	21A	PBI	94	1	1	1	0	3	535	31	7
		22B	PBI	98	0	1	0	0	1	315	6	2
Ae. speltoides Tausch	S	25A	PBI	100	0	0	0	0	0	67	0	0
		26D	PBI	100	0	0	0	0	0	34	0	0
Ae. longissima Schweinf. et Muschl.	S^l	27A	PBI	90	0	0	2	0	8	153	16	10
		27	Kim (TL12)	85	0	2	0	1	12	66	10	15
		29	Kim (TL07)	75	0	2	1	0	22	533	131	25
		117	Kim (TL23)	99	0	0	0	0	1	112	1	1
		118	Kim (TL14)	89	0	0	0	0	11	279	32	11
		119	Kim (TL13)	100	0	0	0	0	0	65	0	0
		120	Kim (TL22)	96	0	1	0	0	3	103	4	4
		121	Kim (TL16)	95	0	0	0	0	5	741	35	5
		122	Kim (TL08)	97	0	0	0	0	3	328	14	3
		132	Kim (TL10)	97	0	0	0	0	3	138	4	3
Ae. sharonensis Eig.	S^l	29A	PBI	80	2	4	0	3	11	179	36	20
		30B	PBI	68	1	1	1	0	29	1199	387	32
		30	Kim (TL08)	68	1	1	0	0	30	281	89	32
		31	Kim (TL03)	88	0	1	1	0	10	394	47	12
		36	Kim (TL01)	99	0	0	0	0	1	112	1	1
		37	Kim (TL05)	93	0	0	2	1	4	218	15	7
		123	Kim (TL04)	91	0	0	1	0	8	177	12	9
		125	Kim (TL06)	77	0	0	0	0	23	271	62	23
Ae. bicornis (Forsk.) Jaub et Sp.	S^b	31A	PBI	100	0	0	0	0	0	38	0	0
		32C	PBI	100	0	0	0	0	0	313	0	0
		71	Kim (TB05)	99	0	0	0	0	1	194	2	1
		72	Kim (TB06)	100	0	0	0	0	0	94	0	0
		73	Kim (TB04)	99	0	0	0	0	1	389	2	1
		75	Kim (TB03)	100	0	0	0	0	0	714	0	0
		76	Kim (TB08)	96	0	0	0	0	4	557	20	4
		77	Kim (TB11)	98	0	0	0	0	2	556	9	2
		78	Kim (TB07)	100	0	0	0	0	0	401	0	0
		79	Kim (TB12)	82	0	1	0	0	17	604	109	18
		81	Kim (TB13)	100	0	0	0	0	0	77	0	0
		82	Kim (TB09)	100	0	0	0	0	0	703	0	0
Ae. squarrosa L.	D	35A	PBI	97	1	0	0	0	2	447	14	3
		41	Kim (TD18)	99	0	1	0	0	0	213	2	1
		42	Kim (TD19)	100	0	0	0	0	0	19	0	0
		44	Kim (TD13)	100	0	0	0	0	0	132	0	0
		46	Kim (TD16)	98	0	0	1	0	1	534	8	2
		48	Kim (TD12)	100	0	0	0	0	0	282	0	0
		50	Kim (TD08)	99	0	0	0	0	1	137	2	1
		53	Kim (TD24)	79	0	2	0	0	19	240	51	21
		54	Kim (TD02)	99	0	1	0	0	0	469	1	1
		55	Kim (TD04)	100	0	0	0	0	0	526	0	0
		56	Kim (TD03)	100	0	0	0	0	0	67	0	0
		69	Kim (TD21)	91	1	0	4	0	4	292	26	9
Ae. crassa Boiss.	DM^{cr}	37A	PBI	100	0	0	0	0	0	67	0	0
		38D	PBI	100	0	0	0	0	0	308	0	0
		32	Kim (TL05)	100	0	0	0	0	0	12	0	0
		38	Kim (T102)	100	0	0	0	0	0	287	0	0
		127	Kim (T104)	100	0	0	0	0	0	38	0	0
	DD^2M^{cr}	39B	PBI	100	0	0	0	0	0	78	0	0
Ae. vavilovii (Zhuk) Chenn.	$DM^{cr}S^p$	41A	PBI	100	0	0	0	0	0	51	0	0
		138	Kim (TA17)	76	5	7	5	6	1	521	124	24
Ae. ventricosa Tausch	DM^v	43A	PBI	100	0	0	0	0	0	82	0	0
		44B	PBI	95	0	0	0	0	5	62	3	5
		61	Kim (TH01)	100	0	0	0	0	0	541	0	0
		65	Kim (TH02)	100	0	0	0	0	0	945	0	0
Ae. juvenalis (Thell) Eig.	DUM^j	45A	PBI	100	0	0	0	0	0	103	0	0
		35	Kim (TJ01)	100	0	0	0	0	0	390	0	0
		130	Kim (TJ02)	100	0	0	0	0	0	381	0	0
T. aestivum cv. WL 711				22	8	14	21	23	12	1192	929	78
T. aestivum cv. Sonalika				6	18	14	11	13	38	487	457	94

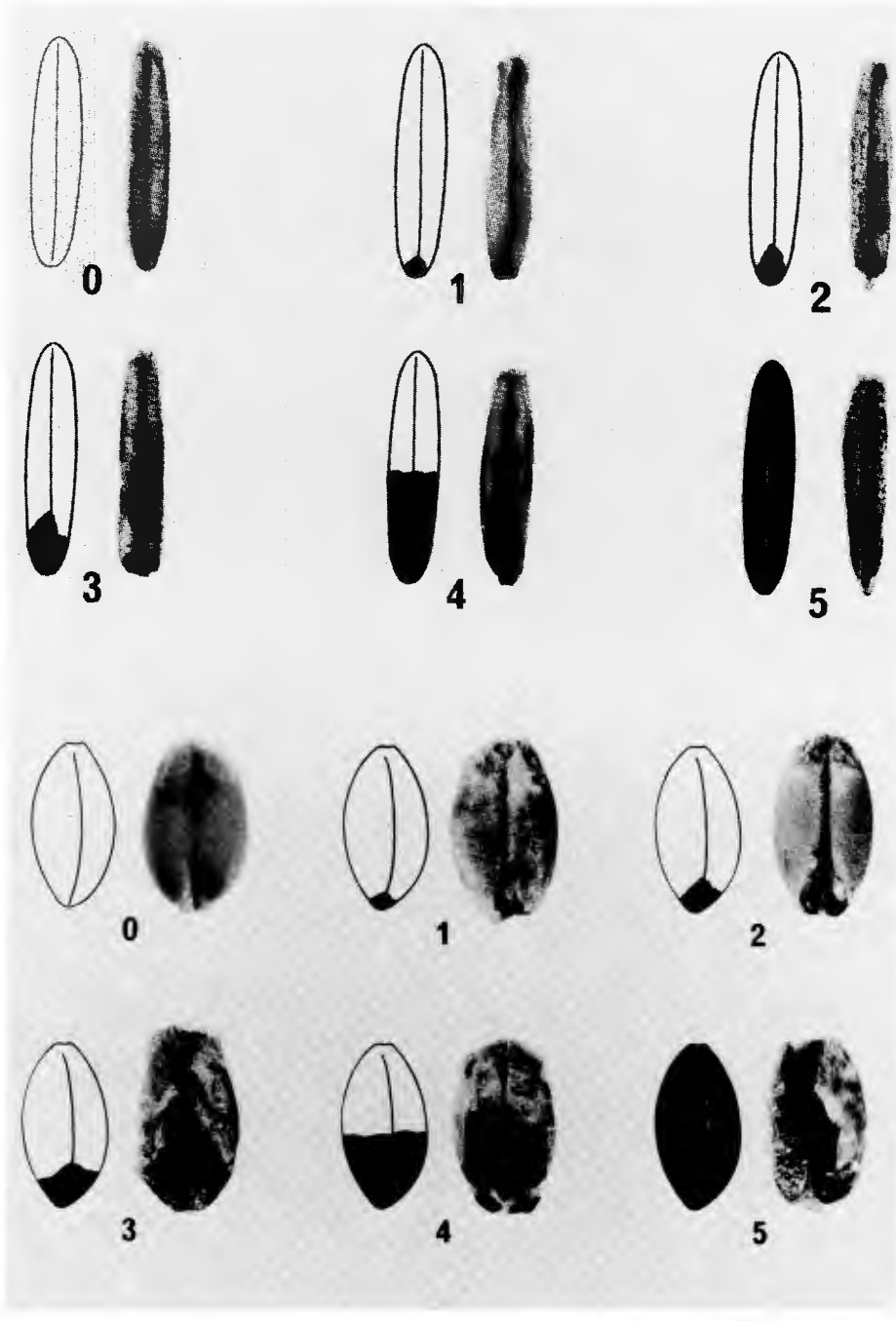

Figure 2. Scale of infection severity caused by Karnal bunt (0 for zero infection and 5 for a completely bunted grain) in *Aegilops caudata* (top) and *Triticum aestivum*.

humidity (RH). After a 4-week juvenile growth phase the plants were vernalized in growth chambers for 4 weeks at 8° C, 70% RH, and 8 h light (fluorescent and incandescent light with approximately 20 000 lux). Following vernalization the plants were returned to the greenhouse under the above mentioned conditions.

The plants were artificially inoculated with the Karnal bunt pathogen using the boot inoculation technique. Stems of spikes at awn emergence were tagged with colour coding tape to indicate the date of inoculation. The inoculum was a suspension of 10 000 secondary sporidia/mL water prepared from 4-wk-old *T. indica* cultures. A number of petri plates of the Karnal bunt cultures were used for each inoculation to ensure a genetically diverse inoculum. Using a hypodermic needle and syringe 1 mL of inoculum was injected into each tagged boot (Fig. 1). The *T. aestivum* cvs. WL 711 and Sonalika were inoculated as controls for comparison with the results on *Aegilops*. All available spikes were inoculated over a period of 2 years.

At maturity individual spikes were harvested and threshed by hand. Individual grains were then graded according to severity of infection on a 0-5 scale (0 for zero infection and 5 for a completely bunted grain) (Fig. 2.). The overall percentage infection (number of infected grains divided by the total number of grains harvested) was then calculated for each accession (Table 1).

Results and discussion

Karnal bunt infection in the *Aegilops* species ranged from 0 to 60% over a severity scale from 0 to 5 (Table 1). Compared with 78 and 94% infection in the susceptible control *Triticum aestivum* cvs. WL 711 and Sonalika, these results indicate a possible source of Karnal bunt resistance in *Aegilops*. All accessions were resistant in the species *Ae. biuncialis, Ae. columnaris, Ae. crassa, Ae. juvenalis, Ae. ovata*, and *Ae. speltoides*. Species with all accessions showing less than 10% infection were *Ae. cylindrica, Ae. kotschyi, Ae. triuncialis, Ae. umbellulata, Ae. uniaristata, Ae. variabilis*, and *Ae. ventricosa*.

The other species showed more variation in reaction to Karnal bunt between accessions. For example, when resistance screening was restricted to one accession of *Ae. longissima* from the Cambridge Plant Breeding Institute, the species would be classified as susceptible. However when more accessions were tested, 117 and 119 showed 0-1% infection. These two accessions in the future may provide an excellent source of resistance as a result of their diploid status and ability to C and N band. A similar situation also exists with *Ae. bicornis, Ae. sharonensis, Ae. squarrosa, Ae. triaristata*, and *Ae. vavilovii*. There is therefore, considerable merit for further screening to detect resistance in either more accessions or more species. Those resistant accessions already identified offer considerable choice for effectively manipulating gene transfers into *T. aestivum* since the species range from diploids to hexaploids with none or some genomic similarity to *T. aestivum*.

Future screening for Karnal bunt resistance will include addition lines in *T. aestivum* from those *Aegilops* species with accessions observed to be resistant. A complete set of *Ae. umbellulata* addition lines is available in *T. aestivum* cv. Chinese Spring (G. Kimber, personal communication with A. Mujeeb-Kazi); some additions of *Ae. variabilis* are available in limited supply (15), and *Ae. longissima* additions are also reported (10). If one or more addition lines should prove resistant, presumably due to single genes at different loci, this would indicate the relative complexity of resistance to Karnal bunt. Resistance from these lines could be incorporated into bread wheat in a shorter period of time than would be required if we have to begin with hybridization between the donor *Aegilops* species and bread wheat.

We are also in the process of producing addition lines of *Ae. umbellulata, Ae. variabilis*, and *Ae. longissima* in some commercially grown spring wheat cultivars. This procedure has the advantage that the addition lines do not have the poor agronomic characteristics of cv. Chinese Spring. The hybrids produced with the resistant *Ae. longissima* and *Ae. variabilis* ($n = 4x = 28$ or $n = 5X = 35$ chromosomes) have been advanced to the normal backcross I generation ($2n = 6X = 42 + 7$ or $2n = 6x = 42 + 14$ chromosomes). The wheat cultivars involved in these hybrids are Nacozari 76 with *Ae. longissima*, Ciano 79, Genaro 81, and Pavon "S" with *Ae. variabilis*.

The *Aegilops* species with the D genome may provide faster practical returns. Though the diploid *Ae. squarrosa* would appear to be a logical choice, tetraploid species have been equally effective in providing usable variation for bread wheat improvement as shown by the eye spot resistance transferred from *Ae. ventricosa* to *T. aestivum* (7). Since most of the *Aegilops* species can now be relatively easily hybridized with the cultivated bread wheats (26) our program will attempt hybridizations with all the *Aegilops* species with resistant accessions. The genomic relationships of the *Aegilops* species are well understood and have been elucidated by recent work (17). Once a desirable trait has been recognized in the wild species and is expressed in backcross progeny with

bread wheat, then the choice of methods for the introduction of the alien gene or genes follows logically from measurements of the relative affinity of the chromosome involved (18). Incorporation of resistance found in *Aegilops* species into the germplasm that is currently available in the CIMMYT wheat wide cross program (23,24,25) may provide additional genetic variability to complement that existing in wheat (see reviews by Sharma and Gill [32] and Driscoll [8]).

Apart from *Aegilops* species, other alien genera *Agropyron, Elymus, Eremopyron, Henrardia, Hordeum, Secale*, and *Taeniatherum* are also being screened for Karnal bunt resistance.

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