Mir RR, Kumar N, Prasad M, Girdharwal N, Kumar J, Balyan HS, and Gupta PK. 2008. Single-locus and two-locus QTL analysis to detect main-effect and epistatic QTL for grain weight in bread wheat. *In:* Proc 11th Internat Wheat Genet Symp (Appels E, Eastwood R, Lagudah W, Langridge P, Mackay M, McIntyre L, and Sharp P, Eds). Sydney University Press, Australia. Pp. 1-3. (Poster No. 296)

Mohan A, Goyal A, Singh R, Balyan HS, and Gupta PK. 2007. Physical mapping of wheat and rye EST-SSRs on wheat chromosomes. The Plant Genome, a suppl to Crop Sci 47:S1-S13.

Mohan A, Kulwal P.L, Singh R, Kumar V, Mir RR, Kumar J, Prasad M, Balyan HS, and Gupta P.K. 2009. Genome wide QTL analysis for pre-harvest sprouting tolerance in bread wheat. Euphytica 168:319-329.

DIRECTORATE OF WHEAT RESEARCH
Regional Research Station, PB No. 518, Karnal-132 001, Haryana, India.

Behavior of spring wheat genotypes under late and very late situations in northwestern India.

S.C.Tripathi.

Summary. A field experiment conducted during the winter seasons in 2000–01 to 2001–02 at the Directorate of Wheat Research, Karnal, evaluated new, promising genotypes under late and very late sowing situations. The mean of 2 years data revealed reductions of 16.96% and 17.15% in biomass and yield, respectively, when sowing was delayed from late to very late. This decline was due to 8.38% and 11.77% reductions in 1,000-kernel weight and grains/spike, respectively, and a more than 10 days less grain-filling period between late to very late sowings. Cultivar differences were observed for yield and yield-attributing parameters. For mean basis, cultivar HD 2643 produced the maximum biomass (106.95 q/ha) followed by Raj 3765 (106.77 q/ha); the lowest was by genotype WR 251 (94. 72 q/ha). Similarly, genotype PBW 435 recorded the maximum grain yield (42.86 q/ha) and lowest by UP 2425 (37.37 q/ha). Differential responses suggested different cultivars were suited for late sown conditions.

Wheat is the second most important crop after rice in India, occupying approximately 28 x 10^6 ha with a production of 78.4 x 10^6 metric tons during 2008–09, the highest level of production since the Green Revolution. Considering environmental and technological adaptation, India is broadly divided in to six wheat-growing regions, the Northern Hill Zone (NHZ; Jammu and Kashmir, Himachal Pradesh, and Uttarakhand), the North Western Plain Zone (NWPZ; Punjab, Haryana, Western Uttar Pradesh, and some parts of Rajasthan), the North Eastern Plain Zone (NEPZ; Eastern Uttar Pradesh, Bihar, West Bengal, Orissa, and Eastern states), the Central Zone (CZ; Madhya Pradesh, Gujrat, Southern Rajasthan, and the Bundel Khand region of Uttar Pradesh), the Peninsular Zone (PZ; Maharashtra and Karnataka), and the Southern Hill Zone (SHZ; Tamil Nadu). The growing period of wheat is variable from one agroclimatic zone to another, which affects vegetative growth and grain-filling duration leading to differences in attainable yield. The maximum wheat growing duration is in the Northern Hills Zone and the mininum is in the Peninsular Zone.

Farmers generally grow wheat in a cropping system that maximizes their total production. In this process, wheat is generally preceded by crops such as rice, cotton, sugarcane, maize, sorghum, potato, toria, and pigeon pea. In this plethora of cropping sequences, some crops, such as basmati rice, cotton, sugarcane, potato, toria, and pigeon pea, delay wheat sowing in different parts of the country. Due to late harvests of sugarcane, potato, and toria, wheat generally is sown in the first week of January. Under late and very late sowing conditions, low temperatures occur during seedling establishment and hot, dry spells prevail during grain-filling. Maturity is accelerated/forced because of high temperature and/or water stress, which reduces grain size and weight.

In India, wheat is sown from November to January, whereas the most appropriate time for sowing is the first two weeks of November. A delay in sowing to late mid-November to first two weeks of December resulted in decreases in yield of 15.5, 32.0, 27.6, 32.9, and 26.8 kg/ha/day in the NHZ, NWPZ, NEPZ, CZ, and PZ, respectively, for timely sown cultivars. Corresponding yield losses were 7.6, 18.5, 17.7, 17.0, and 15.5 %. For late-sown cultivars, a delay in sowing from late to very late, first two weeks of December to first two weeks of January, decreased grain yield by 42.7, 44.8, 51.6, and 44.2 kg/ha/day or 22.8, 27.1, 30.9, and 25.6 % in the NWPZ, NEPZ, CZ, and PZ, respectively (Tripathi et al. 2005). This huge reduction in yield due to delayed sowing prompted us to evaluate late and very late sown genotypes for maximum production. An effort was made to grow advance genotypes/cultivars under late (December sowing) and very late (January sowing) sowning conditions to evaluate their flowering, maturity, grain filling period, biomass, yield and yield attributes.

Materials and Methods. A field experiment was conducted for two years, from 2000–01 to 2001–02, at the Directorate of Wheat Research, Karnal (Latitude 290°43' N, longitude 760°58' E and altitude 245 m). The experimental soil was sandy clay loam in texture (22% clay), low in organic carbon (0.37%) and available N (145 kg/ha), and medium in available P (17.2 kg/ha) and available K (155 kg/ha) content. The experiment was a split-plot design and replicated three times. The main plots included two sowing times, late sown (9 December in 2000 and 10 December in 2001) and very late sown (22 January in 2001 and 9 January in 2002), and nine genotypes, PBW 435, UP 2425, HD 2643, HP 1744, DL 788-2, WR 251, WR 544, Raj 3765, and PBW 373, were grown as subplot treatments. After the rice forecrop was harvested, the field was prepared by cultivator and disk, and 250 viable seeds were seeded in each subplot. Fertilizer (120 N, 60 P_2O_5, 40 K_2O) was applied to the crop. A one-third dose of nitrogen, in the form of urea, full phosphorous, in the form of di-ammonium phosphate, and potash, in the from of muriate of potash, was applied as before sowing and the remaining nitrogen was top dressed in two splits at the first node stage (DC 31) (Zadoks et al. 1974) and at boot stage (DC 41). Irrigation was applied as needed. Weeds were controlled with the application of isoguard plus (a chemical blend of isoproturon and 2, 4-D (at 0.5 + 0.125 Kg/ha) in 500 liters of water 30 days after sowing. Observations were recorded on biomass, anthesis, maturity, grain-filling period, grain production rate, yield, and yield component characters. Standard statistical methods were were followed for the parameters under study (Gomez and Gomez 1984).

Results and Discussion. Two years of data reveals that during 2000–01 biomass, 1,000-kernel weight, spikes/m^2, and grains/spike were not significant under late and very late sowning condition, whereas during 2001–02, only spikes/m^2 was at not significant. All other parameters under study in late and very late sowning conditions were significant. From the mean of two years, we observed that biomass and yield declined 16.96 and 17.15%, with 8.38% and 11.77% reductions in 1,000-kernel weight and grain/spike and more than 10 days less grain-filling period, from late to very late sowning conditions, respectively (Tables 1 and 2, p. 67). The grain production rate under very late sowning conditions was significantly higher than that under late sowning conditions in both years, probably because of the shorter grain-filling period under very late sowing conditions.

Table 1. The effect of sowing time and genotype on biomass, yield, harvest index, 1,000-kernel weight, and spikes/m^2 for spring wheat genotypes sown at the Directorate of Wheat Research, Karnal, India (NS indicates nonsignificance).

	Biomass (q/ha)		Yield (q/ha)			Harvest index		1,000-kernel weight (g)		Spikes/m^2	
Treatment	2000–01	2001–02	2000–01	2001–02	Mean	2000–01	2001–02	2000–01	2001–02	2000–01	2001–02
Sowing time											
Late	103.31	121.58	40.19	46.55	43.37	0.415	0.384	44.77	42.78	406	406
Very late	97.35	89.38	36.65	35.21	35.93	0.371	0.395	42.65	37.08	424	435
CD at 5 %	NS	8.05	3.55	3.77		0.202	0.04	NS	3.35	NS	NS
Genotype											
PBW 435	93.25	107.04	40.27	45.45	42.86	0.432	0.427	42.93	39.80	396	456
UP 2425	84.25	108.95	34.30	40.44	37.37	0.375	0.376	49.10	44.73	378	363
HD 2643	102.77	111.12	37.32	39.61	38.47	0.370	0.356	46.96	43.27	419	363
HP 1744	108.14	104.83	39.96	40.83	40.40	0.382	0.390	43.15	35.80	415	391
DL 788-2	105.75	107.11	43.31	41.00	42.16	0.412	0.386	42.59	35.87	467	517
WR 251	93.65	95.79	36.17	37.73	36.95	0.417	0.394	47.27	50.27	378	356
WR 544	98.21	96.24	39.17	38.64	38.91	0.408	0.403	39.73	38.00	398	403
Raj 3765	102.77	110.76	39.78	44.32	42.05	0.399	0.402	41.54	36.87	439	442
PBW 373	104.17	107.51	35.53	39.91	37.72	0.342	0.375	40.08	34.80	444	491
CD at 5 %	NS	8.96	6.27	3.93		NS	0.037	3.52	2.39	NS	71

Among the cultivars under study, biomass, harvest index and spikes/m^2 were statistically similar in 2000–01, whereas all other parameters were significant (Table 1). Based on means, the maximum biomass was produced by cultivar HD 2643 (106.95 q/ha) followed by Raj 3765 (106.77 q/ha). In contrast, the lowest biomass was exhibited by genotype WR 251 (94. 72 q/ha). Similarly, genotype PBW 435 recorded the maximum grain yield (42.86 q/ha) but was

Table 2. Effect of sowing time and genotypes on grains/spike, anthesis, maturity, grain-filling period, and grain production rate for spring wheat genotypes grown in the field at the Directorate of Wheat Research, Karnal, India (NS indicates nonsignificance).

	Grain/spike		Anthesis (days)		Maturity (days)		Grain-filling period (days)		Grain production rate (kg/ha/day)	
Treatment	**2000–01**	**2001–02**	**2000–01**	**2001–02**	**2000–01**	**2001–02**	**2000–01**	**2001–02**	**2000–01**	**2001–02**
Sowing time										
Late	22.6	27.5	84	82	112	114	28	33	144.6	144.3
Very late	21.1	23.1	71	62	89	82	18	20	203.6	174.3
CD at 5 %	NS	4.3	0.8	0.3	1	0.4	1	1	16.4	14.9
Genotype										
PBW 435	23.9	25.1	79	71	106	100	28	28	149.4	162.6
UP 2425	18.8	25.5	79	72	108	100	29	28	118.2	148.6
HD 2643	19.2	25.1	82	75	106	100	25	25	152.5	163.5
HP 1744	22.7	29.3	78	72	106	100	28	28	143.5	147.6
DL 788-2	22.2	22.9	77	71	105	100	28	28	157.7	148.7
WR 251	20.9	21.2	71	67	102	94	31	27	120.2	150.3
WR 544	25.5	25.7	71	67	102	94	31	27	128.7	157.0
Raj 3765	22.3	28.4	78	75	107	99	29	24	139.4	187.9
PBW 373	20.8	24.2	83	75	107	100	24	24	145.1	167.1
CD at 5 %	5.11	4.9	2.4	0.6	1.7	0.3	2	0.7	27.1	15.3

followed closely by DL 788-2 (42.16 q/ha) and Raj 3765 (42.05 q/ha). The lowest yield was in UP 2425 (37.37 q/ha). Harvest index ranged from 0.342 to 0.432 and 1,000-kernel weight 34.80 to 50.27 g. The highest mean for grain-filling period (29 days) was recorded in genotype WR 251 and WR 544 due to early anthesis (69 days) whereas lowest grain filling period (24 days) was recorded in cultivar PBW 373 because of delayed anthesis (79 days). From the two-year mean, the maximum grain production rate was observed in Raj 3765 (163.65 kg/ha/day) followed by HD 2643 (158 kg/ha/day) the lowest was in UP 2425 (133.40 kg/ha/day). Under late sowning conditions, cultivars are more sensitive to temperature stress during grain filling, and the critical temperatures required at a specific stage for effective screening can not be repeated in the field (Chatrath at al. 2008).

References.

Chatrath R, Singh GP, and Singh SK. 2008. Breeding wheat varieties for late sown conditions of North eastern Plain Zone. **In:** Compendium of ICAR sponsored winter school 'Advances in genetic enhancement and resource conservation technologies for enhanced productivity, sustainability and profitability in rice-wheat system'. DWR Compendium 1:16-17.

Gomez KA and Gomez AA. 1984. Statistical Procedures for Agricultural Research. John Willey & Sons, New York, NY. Pp. 97-107.

Tripathi SC, Mongia AD, Sharma RK, Kharub AS, and Chhokar RS. 2005. Wheat productivity at different sowing time in various agroclimatic zones of India. SAARC J Agric 3:191-201.

Zadoks JC, Chang TT, and Konzak CF. 1974. A decimal code for growth stages of cereals. Weed Res 14:415-421.

Evaluating molecular markers associated with preharvest sprouting resistance in wheat.

Rajender Singh, Gyanendra Singh, Rekha Malik, Rajendra Kumar, Ratan Tiwari, and S.S. Singh.

Preharvest sprouting (PHS) refers to the precocious germination of grain in the spike prior to harvest as a result of moist weather conditions at harvest time. The wheat crop grown in the northeastern and far-eastern states of India (West Bengal, Assam, and other eastern hill states) is prone to PHS losses due to pre-monsoon rains and high humidity around maturity. Resistance to PHS is based on seed dormancy, i.e., the ability of the physiologically mature seed to withstand sprouting under conditions otherwise favorable for germination. PHS in wheat represents a major constraint for consistent production of high-quality grain because it causes downgrading of grain, severely limits end-use applications for wheat flour, and results in substantial economic losses to farmers and food processors. A large number of QTL have been reported and screening of diverse genotypes with the molecular markers associated with PHS resistance will help to identify diverse sources of PHS resistance. In view of this, a set of 216 wheat genotypes was phenotyped for PHS resistance and screened with two markers associated with QTL for PHS resistance on chromosomes 4A and 3B.

Phenotyping for PHS resistance. A set of 216 wheat genotypes was phenotyped for PHS resistance based on germination index (GI). A majority of the genotypes were found susceptible to PHS based on GI. Only 7.8% of the genotypes were resistant to PHS (Table 3). As expected, none of the Indian wheat cultivars were resistant, and only five germ plasm entries were resistant to PHS. However, 22% of the genotypes from the High Rainfall Wheat Yield Trial (HRWYT) and the High Rainfall Wheat Screening Nursery (HRWSN) were resistant and, thus, have potential as donor lines for improving PHS tolerance in future wheat genotypes targeted for cultivation in the regions that are otherwise favorable for PHS. The results also indicated that GI information supports assumption of susceptibility of Indian material as no selection pressure was exerted for this trait. Only one genotype in the hybridization block was found to be resistant to PHS.

Table 3. Germination index of wheat genotypes phenotyped for resistance to preharvest sprouting in various trials in India.

Entries	No. of genotypes	Germination index			
		0.00–0.25	0.26-0.50	0.51–0.75	0.75–1.00
High Rainfall Wheat Yield Trial	23	6	3	8	6
High Rainfall Wheat Screening Nursery	27	5	13	5	4
Indian cultivars	17	—	—	—	17
Germ plasm lines	88	5	7	11	65
Hybridization block	61	1	1	3	56
Total	216	17	24	27	148

Genotyping with markers associated with PHS resistance. Using diverse mapping populations in bread wheat, all chromosomes have been reported to carry QTL/genes for PHS or dormancy. These large numbers of QTL suggest a complex trait controlled by numerous genes that are influenced by environmental conditions and genetic background. However, homoeologous chromosome group 3 and chromosome 4A carry major loci for PHS resistance, which weere revealed in several earlier studies. In the present study, the genotypes were screened with two molecular markers associated with QTL for PHS resistance on chromosome 4A and 3B. One marker, *DuPw004* was mapped in the QTL region on chromosome 4A (Singh et al. 2010) and other marker, *Vp-1B3*, was derived from the vivipary gene on chromosome 3B (Yang et al. 2007). Ninety-nine genotypes amplified the PCR band associated with PHS resistance with *DuPw004*, and the remaining 117 genotypes amplified the PCR band associated with PHS susceptibility. The *Vp-1B3* marker was used in 67 genotypes and amplified three different alleles; 58 genotypes amplified the allele associated with PHS susceptibility.

Eleven out of 17 genotypes having a GI range of 0–0.25 amplified the PCR band with marker *DuPw004* associated with PHS resistance (Fig. 1), whereas, seven out of nine genotypes with a GI range of 0–0.50 amplified the PCR

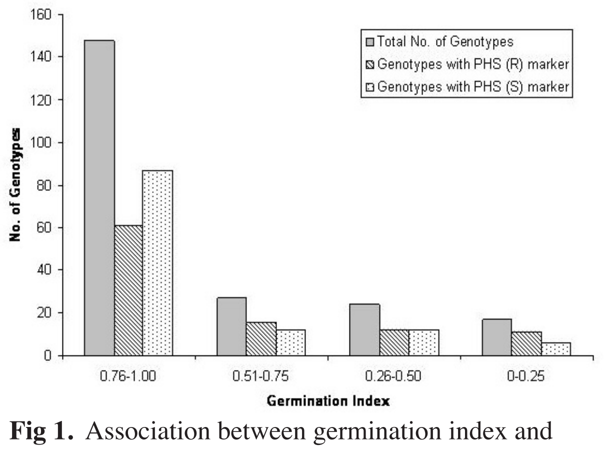

Fig 1. Association between germination index and marker *DuPw004*.

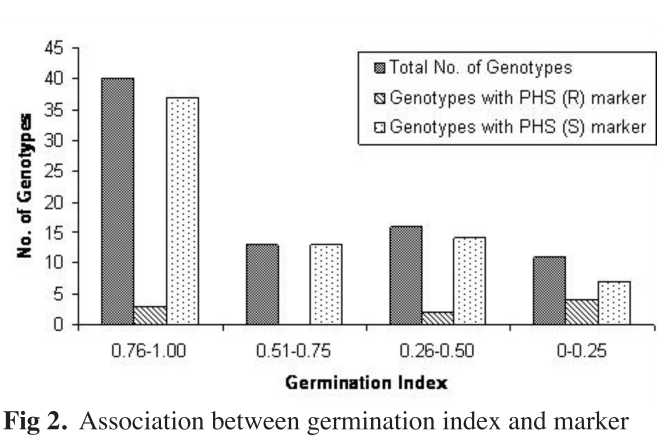

Fig 2. Association between germination index and marker *Vp-1B3*.

band with marker *Vp-1B3* associated with PHS resistance (Fig. 2, p. 68). These results give an indication of the resistance associated with these markers.

One interesting observation to come out of this study is that the combination of *DuPw004* and *Vp-1B3* markers associated with resistance showed a GI range of 0–0.25. However, the results will be confirmed when more resistant type genotypes are included. Three genotypes, lines 203 (FOW1) and 214 (CHIL/CHUM18//ARA90) from the 15th HRWYT and line 2070 (CHAPIO/FRET2) from the 18th HRWSN 2070, showed this combination.

References.

Singh R, Matus-Cadiz M, Baga M, Hucl P, and Chibbar RN. 2010. Identification of genomic regions associated with seed dormancy in white-grained wheat. Euphytica DOI 10.1007/s10681-010-0137-8.

Yang Y, Zhao XL, Xia LQ, Chen XM, Xia XC, Yu Z, He ZH, and Röder M. 2007. Development and validation of a viviparous-1 STS marker for pre-harvest sprouting tolerance in Chinese wheats. Theor Appl Genet 115:971-980.

JANTA VEDIC COLLEGE
Department of Genetics and Plant Breeding, Baraut Baghpat (UP), India.

Gene action for quantitative traits in bread wheat.

Sarvan Kumar and Dhirendra Singh.

Abstract. An experiment during rabi 2005–06 and 2006–07 estimated gene action in bread wheat. Seven wheat cultivars (DBW 14, HUW 468, HUW 533, GW 273, PBW 443, PBW 502, and DL788-2) were used for five straight crosses (DBW14/HUW468, DL788-2/PBW502, DBW14/HUW533, GW273/HUW468, and PBW443/HUW533) and six generations P_1, P_2, F_1, F_2, BC_1, and BC_2 were obatined for each cross. A generation mean analysis was made on days-to-75% heading, days-to-maturity, plant height, effective tillers/plant, spike length, spikelets/spike, grains/spike, grain weight/spike, seeds/plant, 1,000-kernel weight, grain yield/plant, and at three different stages during Helminthosporium leaf blight infection (dough, soft dough, and hard dough). A majority most of the exhibited significant additive and dominance gene effects in scaling test on different characters in all the crosses indicating the presence of nonallelic interaction.

Joint scaling tests revealed that the simple additive-dominance model was adequate for spike length, grain weight/spike in all five crosses; for days-to-75% heading, days-to-maturity in cross PBW443/HUW533; for spikelets/spike in crosses DBW14/HUW468, DBW14/HUW533, and GW273/HUW468; and for 1,000-kernel weight and grain yield/plant in cross 'PBW443/HUW533'. For the remaining crosses, the model was not adequate. The six-parameter model was used for those crosses where simple additive-dominance model was inadequate. The classification of epistasis revealed the predominance of duplicate type of epistasis in a majority of the crosses for all the traits, whereas complementary type epistasis was present for seeds/plant in crosses 'DBW14/HUW468', 'DBW14/HUW533', and 'PBW443/HUW533'; days-to-maturity and effective tillers/plant in cross 'DBW14/HUW468'; spikelets/spike in cross 'DL788-2/PBW502'; and grains/spike and HLB-3 in cross 'DBW14/HUW533'. Based on the above findings, we concluded that attributes such as spike length and grain weight/spike are controlled by fixable genes and may be improved by adopting simple selection or any other breeding approach that can exploit additive effects. Attributes such as days-to-75% heading, days-to-maturity, plant height, tillers/plant, effective tillers/plant, and other related traits included in the study were controlled by both additive and nonadditive type of gene effects. Therefore, a breeding plan that can exploit both types of gene effects, such as intermating in early segregating generations followed by selection or reciprocal recurrent selection, might be useful. Heterosis breeding might be a useful tool for improvement of grain yield in wheat because it showed a complementary type of epistasis in most of the crosses in this study.

Introduction. Wheat is one of the main food crops of India and contributes significantly to the central pool. The cultivation of wheat in India started very early during prehistoric times and, thus, the origin of wheat is still a matter of speculation. Wheat research for development of high-yielding cultivars and improving management techniques started in India long ago. A large number of valuable cultivars were bred and released for commercial cultivation. These cultivars were tall and mainly suited to low-input management with low yield potential. However, a turning point in the history