Winter Wheats as Donors of Higher Productivity Traits

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With the growing population pressure and expected 20% increase in per capita availability of wheat, India now faces a challenge of producing extra 40 million tonnes, which requires a growth rate of 1.8% per year as against the current 1%. Research efforts are in progress to increase yield levels by developing hybrid wheats, breeding cultivars with durable resistance to newly emerged diseases and pests, introgressing the higher yielding alien genes in the background of present cultivars, etc. but nothing seems to bring in the desired impetus since national average of production has been stalemating for the last few years. At this juncture, it has been envisaged to derive the genes offering promise of higher yields and robust disease resistance from various sources on a hit and trial basis and the winter wheats are the most revealing in this context. Winter wheats have already served this cause by donating *Norin 10* dwarfing gene to spring wheat cultivars which harbingered green revolution in the late sixties. Pace of higher productivity of wheat was further maintained through nineties and till date by Veery cultivars adapted for spring cultivation also find their origin in winter wheat sources. Therefore why not to tap the available winter wheat germplasm again through attempting winter x spring crosses for identifying cultivars with significantly higher yield potential as compared to the present ones. Growing winter wheats in a crossing block in Indian plains during normal wheat season (*rabi*) is an arduous task involving huge investments for artificial fulfillment of vernalisation, a prerequisite for flowering. However, the winter wheats sown in the month of October at ICAR's regional station at Lahaul-Spiti situated in temperate Himalaya of Himachal Pradesh flower in the ensuing month of July and synchronize for crossing with the spring wheat cultivars sown at the same location in the month of May. Therefore, transfer of superior traits from winter wheats to spring wheat cultivars or vice versa can be achieved economically with more feasibility.

Key words: Winter wheat, Spring wheat, Vernalisation, Photoperiod, Wheat production

Winter and spring wheats are the two groups of the same *T. aestivum* species isolated geographically by space and time. As a result of long agro-ecological isolation, they have remained as two separate diverse gene pools. Winter wheats need minimum 270 days of crop period as well as being obligate to vernalisation and photoperiod can be grown naturally in temperate areas receiving snowfall after seed germination leading to seedling burial under snow for 3-4 months before tillering sets in. On the contrary, spring wheats do not require freezing temperatures at seedling stages and being photoinsensitive require only 140 days or even lesser crop period. The agro-climatic conditions of *rabi* part of the two cropping sequences followed in India match for cultivation of spring wheats only. It is expected that by crossing between these gene pools it will be possible to create new genetic variability for selection and development of superior genotypes. These two distinct gene pools offered very good dividends earlier in the form of contribution of *Rht* dwarfing genes as well as 1B/1R translocations of winter wheat parents in spring wheat background known as "Veery" lines. Role of cultivars with dwarfing gene ushering green revolution in India is well known. The Veery cultivars played a vital role in sustaining wheat production in India after dwarf cultivars of green revolution fell prey to new pathogenic races.

Winter Wheats: Vernalisation and Photoperiodism are Critical for Growth and Flowering

Both winter and spring types of wheat may manifest sensitivity or insensitivity to photoperiod. Winter wheats have a considerable vernalization requirement but spring wheats may be insensitive or only partially sensitive to vernalisation. Between these groups, intermediate wheats (semi winter, alternative, facultative) also exist. Out of 12 global wheat growing mega environments (ME), the ME 1 to ME 6 are classified as spring wheat areas and ME 7 to ME 12 as winter and facultative wheat (WFW) areas (Rajaram, 1995). Of the 220 million ha of wheat in the world, roughly 75 million ha are sown to WFW. The stages and sub-stages of winter wheat are similar to spring wheat except that in the former, the tillering stage is interrupted. Plants normally emerge and tiller in the autumn, but the growth is arrested or delayed during the winter and tillering resumed in the spring. When wheats having the full winter growth–habit are sown in the spring,

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they do not normally head, flower, and produce seed in the same growing season (Fig. 1), if not vernalised (Crocker and Barton, 1953). Accomplishing artificial vernalisation calls for heavy investments on raising infrastructure to build low temperature regimes for two months continuously. However, natural vernalisation takes place in areas ME 7–ME 12 (Rajaram, 1995) and high altitude Himalayan location such as Lahaul-Spiti, (Himachal Pradesh), India also falls in this category.

The concepts of the genetic control of flowering in wheat as expressed by vernalisation requirement and photoperiod response as well as on other regional adaptation traits have been described in detail (Ferrara *et al.*, 1998).Qualitative differences in growth habit due to vernalisation requirement are controlled by a system of *Vrn* genes (Pugsley, 1968, 1971). The major *Vrn* genes are *Vrn1*, *Vrn2*, *vrn3* or respectively *VrnA1*, *Vrn–B1*, *Vrn–D1* according to the latest wheat gene catalogue (Mc Intosh *et al.*, 1998). Fully recessive genotypes (to *Vrn*) respond to vernalisation, while dominant alleles fully or partially inhibit this requirement. Typical alternative wheats often carry dominant *Vrn2* in a photosensitive background (Stelamakh, 1986). The genetic control of photoperiod sensitivity is complex, determined primarily by a non homoeologous series or genes *Ppd1*, *Ppd2* and *Ppd3* located on group 2 chromosomes 2D, 2B and 2A respectively (Welsch *et al.*,1973 and Law *et al.*,1978). Genes on other chromosomes particularly 3D (Miura and Worland, 1994), 4B (Halloran and Boydell, 1967) and 6B (Faridi, 1988) have also been implicated in determining photoperiod response.

Methods of *Vrn* gene manipulation including methods for winter genotype selection from spring x spring crosses have been described in detail (Stelamakh, 1998) wherein influence of *Vrn* genes was extremely studied and it was revealed that dominant allele of *Vrn* genes inhibit the vernalisation requirement. The *Vrn* genes (growth habit), the *Ppd* genes (response to photoperiod) and the genes controlling earliness per se, contribute to differences in the rate of development (early emergence and ripening time) for cultivars of common wheat (*T. aestivum* L.) making them widely adaptable. The *Vrn* genes contribute upto 70–75 % of differences in the total length of the wheat life cycle (Stelamakh, 1981). A detailed account of growth habit (spring x winter) as influenced by *Vrn 1–vrn4* genes in global set of commercial cvs. is available in a catalogue (Stelamakh *et al.*, 1987). The dominant gene *Vrn1* and/or *Vrn2* controls spring growth habit in European varieties of common wheat (Akerman and MacKey,1949 and Stelamakh, 1990), macaroni wheat (*T. durum*) (Dzhalpakova *et al.*,1995) and *T. dicoccum* (Rigin *et al.*,1994). Introgression of the *Vrn* genes from related species into cultivated wheats offer new opportunities for altering ear emergence and ripening time.

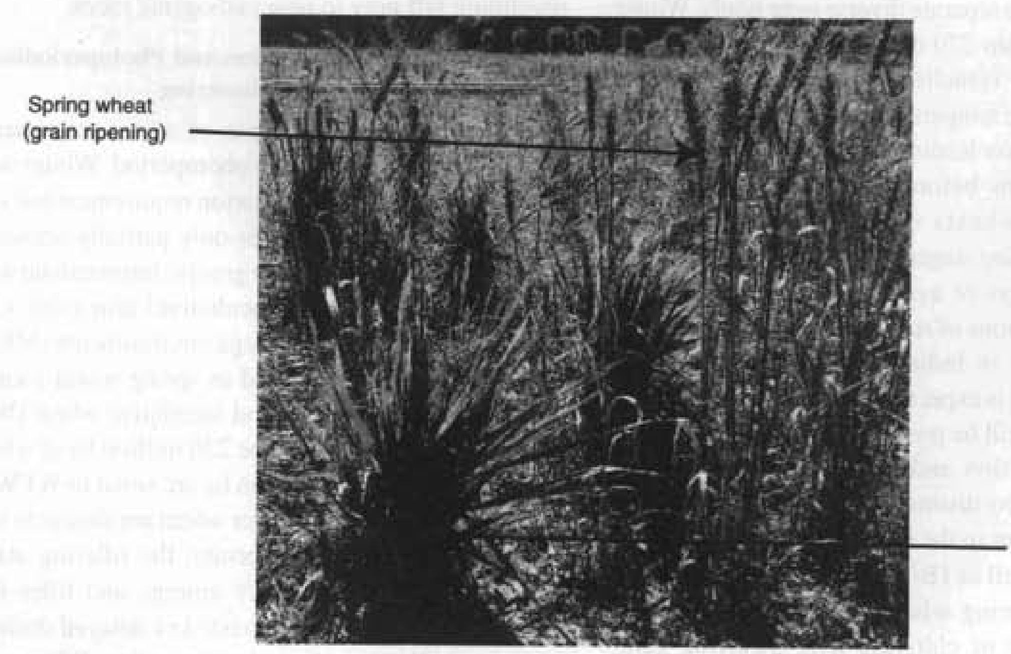

***Fig.1:** Growth disparity between winter and spring wheats after 110 days of simultaneous sowing at Dalang Maidan, Lahaul-Spiti in summer*

Strong photosensitivity is under the control of recessive alleles in the ppd gene system, while dominant *Ppd* alleles inhibit this sensitivity fully or partially (Piech, 1969 and Law *et al.*, 1978). It has been demonstrated that photoperiod response genes play a major role in determining the climatic adaptability of European wheat varieties (Worland *et al.*, 1998). Photoperiod insensitivity in majority of European wheats is probably determined by a *Ppd1* allele originally derived from the old Japanese variety Akakomugi. Analysis of the pleiotropic effects of a *Ppd1* allele from the Italian variety Mara shows that besides accelerating ear emergence time, *Ppd1* also reduces plant height, tillering and spikelet number, but increases spikelet fertilization more than compensating for reduced spikelet numbers, thus producing increased number of grains per ear. In southern Europe, early flowering *Ppd1* genotypes produce larger grain and greater yields. Alternatively weaker gene for photoperiod insensitivity *Ppd2* similar but less significant pleiotropic effects as compared to *Ppd1*.

Earlier Contributions of Winter Wheats towards Improvement of Spring Wheats

Green revolution liberated India from distressing ship to mouth situation of sixties and heralded a pride era of food self sufficiency. Major credit for bringing the success of green revolution in India can be largely attributed to *Rht1* and *Rht2* dwarfing genes obtained from a winter wheat source, the *Norin–10* (Kronstad, 1996) present in wheat cultivars introduced to India from CIMMYT in late sixties. The utilization and exploitation of *Norin–10* gene for dwarfness in wheat has resulted in tremendous increase in the productivity of wheat in other south Asian sub tropical countries also. It is well known that high yielding varieties owe their superior productivity to their dwarf stature; which gives mechanical strength and keep them erect under conditions of high fertility and irrigation in which traditional tall types would normally lodge (Kulshrestha *et al.*, 1977). Cultivars possessing dwarfing genes increased production and productivity of wheat by six folds in India. This miracle gene has its origin in a winter wheat source revealing thereby the indirect role of winter wheats played in bringing prosperity to our country.

The potential of winter x spring wheat crosses has also been widely demonstrated by the release of Veery lines which were indigenized after dwarf cultivars of green revolution era lost their charm due to susceptibility to various diseases. The Veery cultivars resulted from the cross (Kavkaz/Buho's//Kalyansona/Blue Bird) where winter wheat Kavkaz also contributed among other factors the 1B/1R translocation. These lines in common carry the 1B/1R translocated segment from rye, but otherwise differ markedly in plant height, leaf size, maturity, head size, grain size, grain color etc. (Rajaram and van Ginkel, 1996). Other agronomic characters such as many grains/m^2 and in some cases, many heads / m^2 contributing to the high yielding lines were derived from these spring x winter veery lines. The most famous Indian cultivars PBW 343 and WH 542 ruling the entire North West plain zone of India also belong to this category. Veery lines are being grown on estimated 5 million hectares under a number of different cultivar names as represented by Kauz, Attila, Pastor, Baviacora in different parts of the world. It has been estimated that 80% of the advanced spring wheat lines at CIMMYT carry some degree of winter parentage (Kronstad, 1996).

Based on the pattern of expansion and an increase of 8% yield attributed to the use of winter wheat from winter x spring crosses, a return in excess of 10 million US dollars each year in the 1980s was realized (Mitchell *et al.*, 1988). These gene pools of winter and spring wheats have remained genetically isolated due to their different growth requirements and this variability needs to be harnessed more in Indian wheat programme. There are centres available in Himalaya where winter wheats flower under natural conditions. These centres can attempt crosses between elite winter and spring wheats and segregating materials can be supplied to other centres for selection in their respective agroclimates (Rao, 2001). Spring x winter wheat crosses need to be subjected to screening both in drought prone areas as well as Kashmir and the Himalayan region (Swaminathan, 1977).

Promising Traits of Winter Wheats for Further Exploitation

Discussion on how to increase the yield potential of wheat often centers around winter wheat traits that contributed to the success of the green revolution cultivars more than 30 years ago, e.g. photoperiod and dwarfing genes (Worland *et al.*,1998 and Sears, 1998). A study by Slafer *et al.* (2001) revealed that sensitivity to photoperiod may actually be used as a tool to further rise wheat yields. This opens the possibility to attempt to manipulate the sensitivity to photoperiod during stem elongation as an alternative avenue for raising yield potential. Winter x spring genepools have provided enhanced genetic variability to several abiotic factors such as aluminium tolerance, winter hardiness, frost and sprouting tolerance. Morso possessing, durable and broad spectrum resistance to diseases and insects has also been derived from winter wheat stocks. The winter germplasm has also contributed the larger and more fertile spikes, stiffer straw, shorter plant stature etc. to spring wheat cultivars (Kronstad, 1996). The winter x spring crossing approach may prove interesting for breeders developing hybrid wheats. In limited studies where comparisons were made with winter x spring F1s and those resulting from winter x winter or spring x spring crosses, the former gave a greater expression of hybrid vigor, perhaps reflecting a greater degree of diversity between these two genepools (Kronstad, 1996)

The spring x winter gene pool recombination has transmitted a higher number of grains either through higher number of heads/m^2 or through bigger heads (Villareal *et al.*, 1991; Villareal, *et al.*, 1994; Villareal, *et al.*, 1995). It was also noted that the resulting lines keep their canopies cooler than the surrounding environment, show higher stomatal conductance and are photo-synthetically more efficient (Rees *et al.*, 1993). The spring x winter wheat populations also produce vigorous progenies, tiller profusely, have more surviving spikes, are robust in appearance and keep their leaves healthy for a longer period (Rajaram and van Ginkel, 1996). Crosses between spring and winter wheats have also been successfully used to improve germplasm of both types of wheat (Dorofeev and Udachin, 1987). At CIMMYT, photoperiod insensitive spring wheat germplasm is used to transfer short stature, high yield potential and disease resistance into winter/facultative germplasm. However, there is also a possibility to select vernalisation sensitive genotypes (winter or facultative type) directly from crosses between two vernalisation insensitive genotypes (spring type) as reported in case of phoenix variety in California, USA (Pugsley *et al.*, 1985).

Winter wheats have ability to tiller profusely after vernalisation of seedlings is successfully completed. This particular trait can find usage in popularizing these wheats as fodder crop in Himalayan deserts confronting dire scarcity of grasses in the pasteurs immediately after passage of severe winters. Forage usage of winter wheats as additional advantage has already been reported elsewhere (Epplin and Peeper, 1998)

Winter Wheat Exploitation in India–Need of the Hour

It is expected that the population of India would rise at the growth rate of 1.6% and estimated to reach a figure of 1.3 billion by 2020 AD. The per capita availability of wheat has more than doubled in the last 30 years, from 79.1g/day to 185.4g/day. Assuming a 20 per cent increase in per capita availability of wheat, India has to produce over 109 million by 2020 AD (Rao, 2001). This poses a challenge of producing extra 40 million ton, which requires a growth rate of 1.8% per year as against the current 1%. To achieve this, the national average productivity of wheat has to increase from 2700 Kg/ha to 4200 Kg/ha (Nagarajan, 1998).

It is a matter of great concern that for the last several years plateau in wheat production (Fig. 2) is being

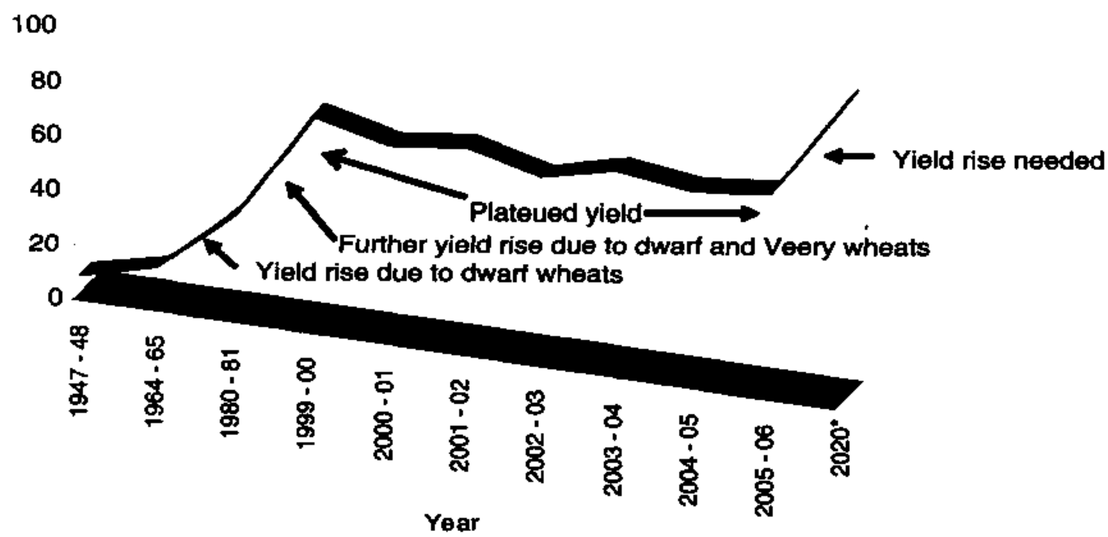

Fig. 2: Past, present and required future of wheat production (mt) in India

observed (Mishra, 2006). The major challenge is to break yield barriers. There is a very little scope for increasing the area under wheat cultivation due to growing urbanization, crop diversification, dwindling water resources, micronutrient deficiencies and soil health deterioration. It has also been realized that there is not much scope for increasing the productivity in favourable environments, because maximum exploitation, has already taken place. Various strategies based on novel and innovative approaches such as hybrid wheat, breeding for durable resistance, wide hybridisation, breeding for photosynthetically efficient genotypes and molecular marker assisted selection though show promise, yet, could not exhibit satisfactory results as yield levels remain plateued despite intensive efforts made on all these aspects in the last decade. The high yielding genotypes, which India used to get previously from international sources mainly CIMMYT through various international nurseries may be stopped in future as regulations and legalities of plant cultivar protection (PVP) and plant or gene patents will restrict access to alien germplasm.

At this juncture, hope is still upheld by realizing a fact that last 35 years of breeding work has not been successful in making any headway in improving the yield levels in the rainfed and warm climates, particularly in central and peninsular India where genotypes have to be bred with tolerance to heat and short growing period to fit in this situation. Similarly, in a large area of Indo–Gangetic plains, wheat is sown as late as middle of December. For this area, effort should be focused on developing short duration varieties which can germinate and establish at low temperature, produce effective tillers profusely, have more number of spikelets/spike and increased grain weight, have early growth vigour and heat tolerance at maturity. In prime, genotypes proposed for these situations must possess ability to germinate and establish at low temperature (December sowing) as well as yield higher and such traits can be possibly imparted by winter wheats. Genotypes identified holding capacity to survive after germination at extreme temperature may also adapt for the cold region in the upper reaches of Himalayas. Such genotypes may emerge as cultivars suitable to grow in Himalayan areas that are covered with snow during winters.

Previous Indian Work on Winter Wheats – A Review

Earlier researches carried out on winter wheats in India Joshi and Tandon (1977) have revealed that the winter x spring crosses may look unpromising in early generations yet there are great possibilities that in latter generation these will throw out desirable segregates. Several of undesirable traits like a high proportion of ineffective tillers (can be explored for fodder quality) will get eliminated either by the process of natural selection or conscious selection against the sensitive loci. It was thus recommended that winter x spring type of crosses should either be advanced as bulks or selections restricted to only against the sensitivity genes in early generations and selections for desirable combinations should be started in later generations. This conclusion was made on the basis of a trial conducted with (i) F2 and F3 of a 4x4 diallel between winter types Tadorna, Holfast and Mariswinger and a spring type VL 404; (ii) F2s of a 5x5 diallel between winter types namely Victor, Maldova and Bezostaya and two spring types VL 404 and HB 117–107; and (iii) 14 miscellaneous F2s involving crosses between winter types Heines VII, Holdfast, Rossulka, Yeoman, Gassner, NS 879/4, Laberator, Canus, Tadorna, Gaines and Mariswinger and spring types S 308, S 227 and VL 404. Among the winter types NS 879/4 and Victor are intermediate types while Maldova and Rossulka have a low chilling requirement as compared to the other varieties. A specific combining ability analysis was conducted using fixed effects model for the design which includes the crosses and their parents without the reciprocals (Griffing, 1956). In a bid to improve wheat through crossing between winter x spring types (Saini and Tandon, 1977), it was concluded that it may not produce expected results in case the desirable features of the winter types are attributable to the genes controlling photo - thermo sensitivity which is the most distinguishing feature differentiating the winter from spring wheats. The gene prolongs the life cycle of winter types and a requirement of chilling before entry into reproduction phase. Selfed population of a heterozygote Kiran (spring) x Favina (winter) for association of photo-thermo sensitivity with physiological and agronomical characters was studied. This study revealed that sensitive type was significantly superior to the non-sensitive type for flag leaf area, volume and thickness, plant height and spikelets/spike. The non-sensitive type was superior to the sensitive type in total grain yield, 1000 grain weight, harvest index and mean ear grain weight. It also matured significantly early and produced significantly less number of unproductive tillers as compared to the sensitive types.

Winter x Spring Wheat Crossing in India– A New Initiative

The Regional Station at Dalang Maidan in the district of Lahaul & Spiti, Himachal Pradesh, provides the Summer Nursery facility for the Indian wheat programme. The station is located at an altitude of 10,000 feet. It has twelve hectares of land, of which only six hectares is cultivable. The office cum laboratory and guest-house facilities has been created for the benefit of research workers. Many centres of All India Coordinated Wheat and Barley Improvement Programme (AICW&BIP) funded by Indian Council of Agricultural Research are using this facility for raising wheat between May to October when temperature in the plains exceed 45°C. This research station popularly known as Wheat summer Nursery (WSN) or Wheat off-season nursery has the following mandate:

- Advancement of the generation (growing two crops in a year, during winter in the plains and at WSN in the following summer) to reduce the time lag in the development of a variety.
- Multiplication of important selected stocks/varieties to raise seed for distribution or bulk use in the ensuing season.
- Attempting most important/corrective crosses with the view to speed up the process of developing superior lines.
- Screening the important wheat and barley material against rusts and powdery mildew diseases.
- Organise high altitude wheat and barley varietal identification trials.
- Serve as a natural repository for wheat and barley germplasm for long-term storage.

To harness the maximum potential of this station, it has been envisaged to initiate research on winter wheats at this station. As described earlier, the winter wheat stocks require vernalisation as well as longer crop period of minimum 9 months. Therefore growing winter wheats would be possible in the suitable temperate climate of this regional station. So far this facility has not been put to use for exploring winter wheat traits in Indian wheat improvement programmes. Directorate of Wheat Research, Karnal has taken an initiative for the first time in this direction by keeping the station functional even during winter months (October to April) also. Earlier, station operated only for a brief period of April to September for growing spring wheats only.

The winter x spring single crosses will be made at this station where high elevation provides crop environment that meets the vernalization requirement of the winter parents. The resulting F_1 populations will be divided with a portion staying at head office, DWR, Karnal for top and backcrossing to spring material. Following selection, the superior lines will be sent to cooperators throughout the country for evaluation in respective agro ecological situations.

The regional station will thus address the following objectives:

- Collection of winter wheat and alien species from national and international sources.
- Sowing of winter wheats in the month of September/ October every year (flowering will occur in July next year).
- Sowing of spring wheats after melting of snow in the month of May which attain flowering during July next year in synchrony with winter wheats.
- To generate database of agronomic, resistance and quality traits of various winter wheat stocks and prepare an information manual for the ready use of breeders.
- To attempt desired spring x winter or vice versa crosses.
- To keep on enriching the donor block of winter wheats with new entries every year.
- To test potential of winter wheats as fodder (owing to inherent profuse tillering ability) in temperate hilly areas.

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