J. Wheat Res. 5 (1) : 7-14

Review Article

Lodging in spring wheat –An overview

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Abstract

Lodging can be a limiting factor for spring wheat production under irrigated and high input condition. It is a complex phenomenon as it interferes with water and nutrients uptake, reduces light interception, provides more conducive environment for foliar diseases, increases harvesting cost and decreases grain yield. It can be influenced by many factors like higher nitrogen application, growing of tolerant and susceptible varieties, application of growth retardants and sowing methods. The major changes were on morphological and chemical characters of wheat culm, lodging behavior, yield and yield attributing characters. Shorter basal internodes, thicker diameter and stem wall thickness, fewer tillers per m^2, higher cellulose and lignin content, application of growth retardant like ethephon and wheat sowing on beds are parameters related with higher lodging resistance.

Received: 15 May 2013/Accepted: 05 June 2013
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Introduction

Development of semi dwarf high yielding varieties (HYV) in late 1960s led to lodging tolerant at moderate level of nitrogen application. The problem of lodging further escalates with the velocity of the wind coupled with irrigation during grain filling period. Lodging is a complex phenomenon as it interferes with water and nutrients uptake, reduces light interception, provides conducive environment for foliar diseases, increases harvesting cost and decreases grain yield. It occurs either due to root lodging, failure of anchorage system of the plant, or buckling/bending at the basal internodes (Pinthus, 1973). Wheat culms are erect, cylindrical, jointed and consist of five to six internodes. The basal internode is very short, the second internode elongates somewhat, and each internode to develop thereafter elongates progressively more. The basal culm plays an important role in lodging resistance as it provides a lever to hold the plant upright and generally lodging in wheat occurs due to structural failure (Neenan, 1975) rather than loss in anchorage. The research information on parameters related to lodging resistance under high fertility condition has remained meager. An effort, therefore, was done to review the effects of fertilizers, genotypes, application of growth retardants and planting methods on morphological and chemical characters of wheat culm, lodging behavior, yield and yield attributing characters. This will provide an insight for researchers and planners for the development of new high yielding wheat varieties.

Effect of nitrogen

Effect of fertilization on morphological characters of culm: Abundant supply of nitrogen (N) promotes vegetative growth, provides more tillering and reduces light interception at the base of plant (Pinthus, 1973; Kheiralla *et al.*, 1993; and El Debaby *et al.*, 1994) and the cumulative effect of all these factors turns culm too lanky and succulent that ultimately induces lodging. The phenomenon of lodging in wheat is promoted due to abundant N supply and could be ascribed primarily to its effects on the basal culm internodes and increasing nitrogen dose resulted in 10-25 per cent increase in length of basal internodes (Garg *et al.*, 1973; Pinthus, 1973; Knapp *et al.*, 1987; and El Debaby *et al.*, 1994). Under Egyptian condition, enhancing N rates up to 175 kg ha^{-1} increased stem diameter, dry weight per unit length and stem wall thickness and further increase in N showed negative effects on above mentioned traits (Kheiralla *et al.*, 1993). Stem wall thickness plays positive role in lodging resistance (Shafi and Hatam, 1991). Nitrogen rate has significant and negative correlation with internode dry weight per unit length and positive correlation with height (Kheiralla *et al.*, 1993). The effects of N nutrition have an impact on strength of wheat culm. On an average, strength of stems was 20 per cent weaker at 240 kg N ha^{-1} compared to 160 kg N ha^{-1} application (Crook and Ennos, 1995). In another study Garg *et al.* (1973) observed that the application of 200 kg N ha^{-1} decreased the breaking strength of 2nd internode compared at lower N levels. However, Beringer and Nothdurlt (1985) found that application of low N in combination with high K resulted in an increase in the diameter of basal culm.

Enhancing N doses resulted in an increase in shoot:root ratio, which is conducive to lodging, however, information concerning on effect of N supply on root growth is not always consistent (Pinthus, 1973). Fischer and Stapper (1987) reported that total dry weight reduced significantly in lodged plants as compared to non lodged plants at 200 kg N ha^{-1} application. Lodging risk increases with increased dry weight at anthesis (600-1500 g m^{-2}) and explained 65 per cent variation in lodging and severe lodging occurs over 900 g m^{-2} dry weights (Stapper and Fischer, 1990a, 1990b). In another study where many genotypes recorded similar dry matter at anthesis +7 days with very different

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tillers m^{-2} and lodging behavior (Tripathi *et al.*, 2003). Even, Indian cultivar HD 2329, with the lowest dry matter (963 g m^{-2}) at anthesis + 7 days recorded maximum lodging score (81). Such observation was not in line with Stapper and Fischer's findings (1990b). The disagreement with those authors was mainly the result of similar dry matter but very different tillers per m^2 and the resulting lodging scores. Therefore, it was not dry matter but tillers per m^2 that explained 79 per cent variation (R^2) in lodging scores under high N (300 kg ha^{-1}) application (Tripathi *et al.*, 2003). In a study of tall and semi-dwarf varieties, Beem *et al.* (1998) reported that shorter inter-nodal length for the lowest two internodes was associated with lodging resistance whereas Tripathi *et al.* (2003) opined that this could n't be generalized because cultivars like HD 2329 and Pavon 76 had the shortest basal internode length with high lodging scores (67-81). On the other hand, Baviacora 92 had maximum internode length with almost nil lodging. Moreover, in this study all genotypes were semi dwarf, therefore, limiting the earlier (Beem *et al.*, 1998) finding up to tall v/s dwarf genotypes. In a study at same place, under similar management conditions, Sayre and Moreno Ramos (1997) and Hobbs *et al.* (1997) also observed that shorter plant is not essential for lodging resistance.

Effect of fertilization on chemical characters of culm: Culm composition plays an important role in lodging resistance. Application of 45 kg N ha^{-1} increased the Water Soluble Carbohydrate (WSC) concentrations up to 42.5 per cent in lower internodes, 21.5 per cent in middle internode and 25 per cent in the peduncle compared to 180 kg N ha^{-1} application (Knapp *et al.*, 1987). They further opined that declining of WSC concentration resulted in more lodging. Fiber analysis of wheat culm like cellulose, hemicellulose, lignin and silica also contribute towards lodging resistance. The plants containing high amount of cellulose, hemicellulose, lignin and in some cases cellulose:lignin ratio related to lodging resistance (Pinthus, 1973). In another study, Knapp *et al.* (1987) reported that concentration of cellulose, hemicellulose and lignin in lower and middle internode (just below the peduncle) at 45 and 180 kg N ha^{-1} application and reported that significant differences in all three parameters in lower internode. High N application significantly increased the concentrations of lignin and cellulose and decreased hemicellulose in cell walls of lower internodes. Under high N application (180 to 300 kg/ha) non significant differences in Acid Detergent Fibre (ADF), cellulose, lignin, and K content for the 2nd and 3rd internodes were determined (Tripathi *et al.*, 2003). According to Gartner *et al.* (1984) silica content was abundant in lodging resistant variety and localized at the level of epidermis. However, the increasing doses of nitrogen showed some interaction with potassium. The accumulation of K and Si decreased in the stem and resulted into more lodging at 200 kg N ha^{-1} compared to 50 or 100 kg N ha^{-1} application (Garg *et al.*, 1973).

Effect of fertilization on lodging: Lodging resistance was due to shorter and stiffer straw at moderate N levels (Pinthus, 1973; Fischer and Wall, 1976; Stapper and Fischer, 1990 b, 1990 c). At CIMMYT Mexico, lodging (%) increased as N levels increased from 180 to 240 kg ha^{-1} (Tripathi *et al.*, 2003). Hobbs *et al.* (1997) observed 100 per cent lodging by basal 225 kg N ha^{-1} application whereas no lodging at early boot stage application. Kheiralla *et al.* (1993) from Egypt reported increased lodging from 3 per cent at 125 kg N ha^{-1} to 33 per cent at 275 kg N ha^{-1} application. The use of fertilizer coupled with irrigation increases the lodging and that can cause yield losses to the tune of 12 to 66 per cent (Vaidya and Ram, 1986). Even application of N and P together didn't resist lodging (Mohammad *et al.*, 1987). Authors studied five newly evolved spring wheat varieties under different combinations of N-P and found 27 per cent lodging at 90-35 application compared to 50 per cent lodging 195-85 application. These results were also confirmed by Swati *et al.* (1987).

Strengths of stem and the root are also important parameter for lodging resistance. Crook and Ennos (1995) observed that stem and root strength of wheat plants were got 20 and 17 per cent weaker, respectively at 240 kg N ha^{-1} than stem and root strength at 160 kg N/ha application. In another study the application of 200 kg N ha^{-1} decreased breaking strength of 2nd internode that ultimately increased lodging (Garg *et al.*, 1973 and Ali, 1993).

Effect of fertilization on yield and its parameters: The incorporation of dwarfing genes (rht_1, rht_2) in 1960s opened an era for use of nitrogenous fertilisers. These high yielding varieties were responsive to 120 kg N ha^{-1}. Further increase in N didn't result in improving the yield due to lower remobilising efficiency of plant and also unable to resist lodging. The genetic and agronomic contribution to yield gains in the Yaqui valley of North West Mexico for the period from 1968 -1990 was studied by Bell *et al.* (1995). Authors pointed out that after adjusting weather variation the contribution of N to the grain yield was 48 per cent.

Development of wheat varieties at lower N levels increased the chance of lodging when grown by farmers at 180 kg N/ha or more (Narang *et al.*, 1994). To avoid lodging sometimes farmers skip last irrigation which is crucial for grain filling and ultimately limiting the yield. Ali (1993) and Kheiralla *et al.* (1993) from Egypt reported 19.9 and 7.2 per cent reduction in grain yield due to lodging at 225 and 275 kg N /ha compared to 150 and 175 kg N ha^{-1} application, respectively. Similar results were obtained by El Debaby *et al.* (1994). Fischer and Stapper (1987) found the grain yield reduction to the range of 7- 35 per cent due to culm lodging with greatest effect when it occurs with in the first 20 days after anthesis. They further described that kernel number per unit area tended to be reduced by early lodging, and kernel weight by later lodging. Similar lodging experiments were conducted in Australia and corroborated these findings (Stapper and Fischer, 1990 c) and concluded that high yields under irrigation could be achieved consistently and efficiently only with genotypes that resist lodging.

Genotypic differences

Genotypic differences in morphological characters of culm: Lodging resistance has been associated with the morphological characters of the wheat culm and with the number of coronal roots. Varietal differences in lodging resistance were significantly and positively correlated with diameter and wall thickness of basal internode (Pinthus, 1973). The diameter of basal internode was also found to be closely correlated with number of coronal roots. Salem *et al.* (1992 a) from Egypt studied 6 genotypes, differing in lodging resistance, and reported the important morphological characters related to lodging resistance in wheat were plant height, stem diameter, plant height to stem diameter ratio, 2nd internode length and weight. They also reported a positive and significant correlation between lodging per cent and lodging degree with plant height, plant height to stem diameter ratio and 2 nd internode length. At CIMMYT, in a study of near isogenic lines of tall and semi dwarf wheats on stem morphology and associated lodging effects in wheat was studied by Beem *et al.* (1998) and reported that reduction in length of two lowest internodes was associated with lodging resistance. Vaidya and Ram (1984) found that shoot weight x height and root weight ratio correlated (0.829) for lodging.

Kheiralla, *et al.* (1993) observed that year x cultivar, nitrogen rate x cultivar, and year x nitrogen rate x cultivar interactions were significant for plant height, dry weight per unit of 2nd internode and stem wall thickness. They also reported that high lodging in cultivar Norin 28 (37.5%) was due to low dry weight per unit length of 2 nd internode (23.78 mg) and thin stem wall thickness (0.457mm). Conversely low incidence of lodging for cultivar Giza 160 (1.25 %) could be due to thick stem diameter, thick stem wall, medium 2nd internode length and medium dry weight per unit length. Crook and Ennos (1995) compared two varieties, Galahad (susceptible) and Hereward (resistant) for stem and root characteristics and reported that resistant variety possessed significantly higher bending strength and more number of coronal roots than susceptible one. Qaudhy *et al.* (1988) worked out chromosomal locations of genes for traits associated with lodging and said that reciprocal effects could be obtained for chromosomes 3B (number of vascular bundles and culm wall width) and 3D (basal internode diameter).

Morphological characters of twelve spring wheat (*Triticum aestivum* L.) genotypes (four Indian cultivars and eight Mexican cultivars/CIMMYT advanced lines) were studied under disease free condition with different N rates at CIMMYT, Mexico by Tripathi *et al.*, (2003). Authors reported that lodging tolerant genotype, Baviacora 92, had 31.9, 34.0, 40.7 and 34.1 per cent larger diameters for the 1st, 2nd, 3rd internodes and peduncle, respectively when compared to HD 2329, one of the most lodging susceptible genotypes. Furthermore, Baviacora 92 had 1st, 2nd, 3rd internode and peduncle stem walls that were also 31.7, 33.5, 35.4 and 37.1 per cent greater, respectively than Pavon 76, which had the thinnest stem walls. Tillers per m^2 correlated ($r=0.89$, $P<0.01$) significantly positive and stem diameter and wall thickness significantly negative with lodging score. Simple linear regression explained 79 per cent variation in lodging score could be by tillers density and 49-65 per cent by diameter of different internodes. Best sub set of regression showed that number of tillers density and/or stem diameter of internodes were the key variables while deciding two or three important characters for selecting a lodging resistant variety. Step wise regression suggested that three variables like stem diameter of 1st, 2nd internode and length of 1st internode or tillers per m^2, height and length of stem or tillers per m^2, stem diameter of 1st, 2 nd internode together explained about 89-91 per cent variation in lodging score (Tripathi *et al.*, 2003). In Canada, 13 spring wheat cultivars were evaluated under artificially lodging conditions for association of culm anatomy with lodging. Kelbert *et al.* (2004) reported that short, wide basal internodes and thick culm walls were important characters for lodging tolerant genotypes. In a similar kind of study, stem diameter explained 29, 52 and 89 per cent variation in lodging for short, medium and tall lines, respectively (Zuber *et al.*, 1999). These findings were in agreements with observations of Keller *et al.* (1999) who have studied 226 RILs of single cross and reported, in a multiple regression model, that plant height and culm stiffness explained 77 per cent of phenotypic variation in lodging. Therefore, it was suggested that selection for lodging resistant cultivars should emphasize larger stem diameter and wall thickness of basal internodes and fewer tillers per unit area with heavy spikes.

Genotypic differences in chemical characters of culm: Lodging resistant varieties possesses high content of cellulose, hemicellulose and silica (Pinthus, 1973), however, Knapp *et al.* (1987) studied two varieties namely Arthur 71 (lodging susceptible) and Auburn (lodging resistant) and found that concentration of cellulose and lignin were changed less than 5 per cent in lower and middle internodes. Furthermore, the later authors reported that variety Arthur 71 possesses 20 per cent higher WSC than Auburn.At CIMMYT, in a biochemical study of tall and semi dwarf wheat, Beem *et al.* (1998) found that cellulose and lignin content were lower in varieties having rht gene while silica content was higher as compared to tall varieties. Travis (1996) studied two cultivars, namely Riband (strong) and Norman (weak) and reported that the Neutral Detergent Fiber (NDF) content of basal internode was lower in the strong variety as compared to NDF content of weak variety. However, he didn't find any significant difference in lignin content between the two varieties.

Salem *et al.* (1992a) reported that lodging resistant wheat genotypes should possess more than 50 vascular bundles. Khanna (1991) studied seven wheat varieties and reported that tall varieties have thicker epidermis cell than dwarf varieties of wheat, which were lodging tolerant, however, dwarf wheats, WL 711 and UP 2003 with thick sclerenchyma cells were more resistant to lodging than the tall one.

In a study of 12 lodging tolerant/ susceptible spring wheat (*Triticum aestivum* L.) genotypes grown at CIMMYT, Mexico indicated that genotypic differences for ADF, cellulose, lignin and K contents were significant for 2nd and 3rd internodes (Tripathi *et al.*, 2003). ADF, cellulose and lignin contents for the 2nd and the 3rd internodes were negatively correlated with lodging score and in combined analysis of 3rd internode its phenotypic correlation was - 0.53, - 0.57 and - 0.61 with lodging score, respectively. Also, from multiple correlations study it was observed that ADF, cellulose and lignin contents had a positive impact among themselves and their cumulative effect in turn might be preventing lodging.

Genotypic differences in lodging: Generally, it is believed that taller plants will lead to more lodging. However, the high-yielding, single dwarfing gene, semi-dwarf variety, Baviacora 92, is much taller than many other cultivars with two dwarfing genes and yet lodges less (Hobbs *et al.*, 1997; Sayre and Moreno Ramos, 1997, Tripathi *et al.*, 2003).This was due to the maximum stem diameter and wall thickness possessed by Baviacora 92 (Tripathi *et al.*, 2003). Various workers have observed varietal differences in lodging resistance (Pinthus, 1973; Luthra *et al.*, 1981; Knapp *et al.*, 1987; and Crook and Ennos, 1995). Variation in lodging was reported from 0 per cent in Giza 157 to 71.5 per cent in Giza 155 under Egyptian condition (Salem *et al.*, 1992 a, 1992 b). In a similar kind of study Swati *et al.* (1987) and Mohammad *et al.* (1987) found significant variation among varieties for lodging resistance. Kheiralla *et al.* (1993) studied 8 spring wheat varieties at four N levels and found that varieties differ significantly in lodging, ranging from 1.2 per cent for Giza 160 to 50 per cent for Henta. Stapper and Fischer (1990b) did a series of six experiments during 1983-85 and find that lodging score (% area lodged x angle of lodging /90) vary from 0 to 100 depending upon variety, sowing time and density. Authors concluded that varieties having early maturity and that were shorter in nature are lodges less. Similar results were reported by Fischer and Stapper (1987). The results of trials conducted at CIMMYT under irrigated and high input condition showed the significant differences in varieties for lodging in which variety, Bacanora lodged up to 25 per cent as compared to no lodging by Baviacora 92 (Sayre and Moreno Ramos, 1997).

Genotypic differences in yield and its parameters: Yield potential progress in bread wheat was studied by Sayre *et al.* (1997) in a historical set of varieties in North West Mexico. Authors reported that average yield increased linearly from 66.8 q ha^{-1} for the earliest genotype, Pitic 62, to 84.75 q ha^{-1} for Bacanora 88, the latest. The rate of progress against year of release was 67 kg per ha per year ($r = 0.99$, $P < 0.001$) or 0.88 per cent per year. This increase in grain yield was correlated with kernel number m^{-2} ($r = 0.84$, $p < 0.01$) and harvest index. In a similar kind of study Ortiz- Monasterio *et al.* (1997) revealed that genetic progress in wheat yield for the period of semi dwarf wheat improvement (1962-1985) under four nitrogen level (0, 75, 150 and 300 kg N/ha) were 34.7, 20.6, 31.0 and 51.9 kg/ha/year in absolute term and 1.2 , 0.4, 0.6 and 0.9 per cent in relative terms, respectively.

Genetic and agronomic contributions to yield gains in Yaqui valley was studied by Bell *et al.* (1995) during 1968-1990. Authors reported that yield gains 103 kg per ha per year after adjusting weather variation (28 %). Genotypic differences in grain yield were found under Egyptian condition (Kheiralla *et al.*, 1993) and they reported the maximum grain yield by Giza 160 and lowest by Pitic 62. These findings were further confirmed by Swati *et al.* (1987). In an artificial study (plants were lodged after anthesis by flooding the field and then pushing the culms at specified angle), under no lodging condition (using mesh, 20cm x 20cm), Fischer and Stapper (1987) found the maximum yield by Yecora 70 (699 g m^{-2}) and lowest by Cajeme 71 (556 g m^{-2}) and they further pointed out that reduction in yield in lodged plots were due to reduction in kernel density. Yield potential progress of 15 spring wheat varieties/advance lines was studied under disease free, artificial lodging control by using mesh (20x20) condition and high N (300 kg/ha) application at CIMMYT, Mexico by Tripathi *et al.*, (2003). Authors reported that genetic progress, including both Indian and Mexican genotypes, was 48 kg per hectare per year in absolute term and 0.54 per cent per year in relative term.

Effect of growth retardant

Effect of growth retardant on morphological characters of culm: Application of growth inhibitor like Ethephon (Cerone i.e., 2 Chloro Ethyl Phosphonic Acid) and CCC (Chlormequat Chloride) were reported to be useful in reducing the plant height (Ali, 1993; Crook and Ennos, 1995 and Pinthus, 1973). Application of Ethephon at 0.28 kg a i / ha at DC 41 to 43 resulted in significant decrease in the length of peduncle, middle internode and also to some extent basal internode compared to internode lengths of control plot (Knapp *et al.*, 1987). Similar findings were reported by Webster and Jackson (1993) by using Ethephon at 0.56 kg/ha while Dahnous *et al.* (1982) also reported that application of Ethephon at 0.84 kg ha^{-1} at late boot stage resulted in significant reduction in peduncle length. Ethephon 480 g ha^{-1} application at DC 38 prevented lodging and was associated with reduction in plant height (10.2%), peduncle length (14.2%), length of 3rd internode (8.6%), and simultaneously increase in tillers per m^2 (9.1%), stem wall thickness for the 1st (4.3%), 2nd (6.3%) and 3rd (8.1%) internodes and peduncle (3.6%) when compared with no ethephon application (Tripathi *et al.*, 2003).Trinexapac ethyl and ethephon (280.2 g ai ha^{-1}) application in hard red spring wheat decreased the plant height (6 %) and increased the straw strength (13%) and increased lodging resistance (Wiersma *et al.*, 2011).

Effect of growth retardant on chemical characters of culm: Concentration of water soluble carbohydrate increased significantly in lower, middle and upper part of culm when ethephon was applied at 0.28 kg ha^{-1} compared to control (Knapp *et al.*, 1987). Furthermore, in 1984, ethephon application increased lignin content and decreased cellulose content significantly in lower and middle internodes as compared to control. But these differences were at par in the subsequent year. However, the effect of Cerone or CCC on chemical characters of wheat culm is not yet fully understood. Ethephon (480 g ha^{-1}) application at DC 38 prevented lodging and decreased the ADF, cellulose and lignin content by 8.47, 8.81 and 5.56 %, respectively in the basal internode and increased K content of 2nd internode by 9.6 % as compared to without its application (Tripathi *et al.*, 2003).

Effect of growth retardant on lodging: In a plant cell, ethephon acts by releasing ethylene (Crook and Randall, 1969), which is a natural hormone for growth inhibition (Burg, 1973). Lodging could be minimised by modifying anatomical characters of the plants under high input condition. The application of growth inhibitor like ethephon (Cerone i.e. 2 Chloro Ethyl Phosphonic Acid) and CCC (Chlormequat Chloride) were reported to be useful in decreasing the plant height and subsequently reducing the lodging (Pinthus, 1973; Knapp *et al.*, 1987; Ali, 1993; and Crook and Ennos, 1995). In a study from Egypt, Ali (1993) reported that application of ethephon at 0.25 kg/ha reduced the lodging up to 10 per cent. At CIMMYT, Sayre (1996) and Tripathi *et al.* (2003) observed that 480 g/ha application of cerone at DC 37-39 prevented lodging. These findings were in corroboration with Dahnous *et al.* (1982). However, in an another study it was found that ethephon did not provide complete lodging control but increase the grain yield by 5 to 21 per cent depending upon the cultivar and lodging severity (Webster and Jackson, 1993).

Effect of growth retardant on yield and its parameters: Application 250 g ha^{-1} Cerone exhibited 15 to 20 per cent increase in grain yield (Ali, 1993). This increase in grain yield was due to reduced lodging by shortening of the plants. Similar results were obtained with the use of Ethephon or CCC by other workers (Pinthus, 1973; Nafziger *et al.* 1986; Wiersma *et al.* 1986; Knapp *et al.*, 1987; Webster and Jackson,1993; and El Debaby *et al.*, 1994). The increase in grain yield was associated with lesser lodging and increase in number of grains per spike (Pinthus, 1973). Yield response of wheat, barley and triticale to different doses of ethephon was studied by Dahnous et. al. (1982). In the first year of study, the authors reported no response in grain yield of wheat to different doses of ethephon. However, in second year ethephon applied at 0.84 kg ha^{-1} resulted in significant reduction in grain yield as compare to the yield obtained at 0.55 kg ha^{-1} ethephon application or even control. Simmon *et al.* (1988) reported that effects of ethephon on grain yield of spring wheat varied from 13 per cent significant reductions to 12 per cent significant increase. The authors elaborated that increases in grain yield were more common when control plot lodged. When lodging did not occur, ethephon treatment tended to result in reduced yields. Similarly, in a study in winter wheat, application of ethephon at 0.56 kg/ha decreased the grain yield by 6 per cent (Nafziger *et. al.*, 1986). Ethephon (480 g ha^{-1}) application controlled lodging by reducing plant height but also decreased average grain yield by 8.3 per cent, which was primarily associated with a significant reduction in number of kernels per spike (Tripathi *et al.*, 2004).

Morphological characters of culm

Effect of sowing methods on morphological characters of culm: Bed sowing increased stem weight (8.1 %), spike weight (7.2 %), diameter of first (3.8 %), second (7.1 %), third (8.2 %) internode and peduncle (9.0 %) compared to flat planted crop and this lead to 70-75 per cent reduction in lodging score (Tripathi *et al.*, 2002). Raising on beds also gave significantly higher biomass (18.48 t ha^{-1}), grain yield (8.75 t ha^{-1}), thousand grain weight (41.1 g), grains per spike (42) and grains/m^2 (19154) compared to other sowing methods, despite lodging during last irrigation (25-30 days after anthesis). Baviacora 92 produced significantly higher biomass (17.1 t ha^{-1}), grain yield (8.5 t ha^{-1}) and had significantly higher stem and spike weight, diameter and stem wall thickness of different internodes than other varieties. It also recorded 7 % higher grain yield with bed sowing (9.5 t ha^{-1}) as compared to flat planting (8.8 t ha^{-1}). Since this variety didn't lodge in either planting system therefore it could be said that increase in yield was due to sowing on beds. So, it can be said that wheat growing on beds reduces lodging by way of more vigorous stem development and enables to exploit potential yield.

Effect of sowing methods on chemical characters of culm: Effect of planting methods on ADF, cellulose, lignin, K and ash content of 2nd and 3rd internode was non significant whereas Si content was increased in bed planting compared to flat planting (Tripathi *et al.*, 2002). Research information on this aspect is also very meagre.

Effect of sowing methods on lodging: Methods of planting play an important role on lodging severity of the crop. Pinthus (1973) pointed out that wheat crop sown under no till condition lodges less as compared to the crops grown on well ploughed land. Sayre and Moreno Ramos (1997) at CIMMYT, Mexico studied 9 spring wheat genotypes under conventional and bed (80 cm) planting systems and reported genotypic differences in lodging. Advance lines like Roek //Maya…/3/ Tepoca and Vee /Pjn // Kauz lodged 75 and 100 per cent under conventional planting system as compared to 50 and 37.5 per cent lodging under bed planting system, respectively. Bed planting lead to 70-75 per cent reduction in lodging score (Tripathi *et al.*, 2002) due to thicker basal culm. The incidence of lodging was increased as number of rows per bed increased from two to three or four. However, variation in lodging was observed from one year to another year.

Effect of sowing methods on yield and its parameters: At CIMMYT, in a study of 8 bread wheat genotypes grown under conventional and bed (90 cm) planting system concluded that conventional planting produces approximately 5 per cent more grain yield as compared to the bed sowing (Sayre and Moreno Ramos, 1997). The authors further pointed out that genotypes performing well under conventional planting might not do well under bed planting. But, it's rare, to find the reverse, unless differential lodging is involved. However, in a yield survey in Yaqui valley conducted in 1994, the average wheat yields for farmers planting on beds were 56.15 q ha^{-1} (47 farmers), whereas farmers still planting wheat conventionally had an average yield of 49.23 q ha^{-1} (17 farmers). Similar results were reported from a study conducted at PAU, Ludhiana in 1994-95, which recorded higher grain yield (61.50 q ha^{-1}) under bed planting (3 rows per bed) as compared to grain yield (58.20 q ha^{-1}) under conventional planting system (Hobbs *et al.*, 1997). This finding was also corroborated by Chauhan *et al.* (1997).

Raising wheat on beds gave significantly higher biomass (18.48 t ha^{-1}), grain yield (8.75 t ha^{-1}), thousand grain weight (41.1 g), grains/spike (42) and grains m^{-2} (19154) as compared to other sowing methods, despite lodging during last irrigation (25-30 days after anthesis). Baviacora 92 produced significantly higher biomass (17.1 t ha^{-2}), grain yield (8.5 t ha^{-2}) and had significantly higher stem and spike weight, diameter and stem wall thickness of different internodes than other varieties. It also recorded 7 per cent higher grain yield with bed planting (9.5 t ha^{-1}) as compared to flat planting (8.8 t ha^{-1}). Since this variety didn't lodge in either sowing system therefore it could be said that increase in yield was due to sowing on beds. So, it can be said that wheat growing on beds reduces lodging by way of more vigorous stem development and enables to exploit potential yield (Tripathi *et al.*, 2002, 2005).

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