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Genetic analysis of stem solidness in wheat (*Triticum aestivum* L.)

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Abstract

Inheritance of stem solidness was studied in common wheat using three crosses involving a solid stemmed genotype Selection 1093-1 and hollow stemmed stocks, HD 2667, NP 12 and selection 111. The internodes of two F_1 hybrids were solid completely filled with pith, while one hybrid produced internodes with partially filled pith. Stem solidness in selection 1093-1 is a dominant trait inherited monogenically. However, incomplete dominance of solidness was also recorded in the cross Sel. 1093-1 × Sel. 111. The presence of an epistatic gene for hollowness over gene governing solidness of stem reported to be present in D genome of hollow stemmed cultivars is negated. Differences in means between solid and hollow stemmed true breeding and segregating F_3 families were non-significant. However, significant mean difference in grain number/main spike were noted in true breeding solid and hollow families, whereas in segregating families the two means did not differ significantly. It is presumed that significant differences in grain number/main spike in true breeding solid and hollow families may be due to inadvertent selection which favored high grain number in hollow families. The identification of single gene governing solidness of culm may be a useful marker trait for genetic studies and in breeding for saw fly resistance since solidness of culm does not affect agronomic traits. The gene symbol *Sc* is proposed for solidness of culm in wheat.

Key words: Wheat, stem solidness, hollowness, genetic marker, agronomic traits

Introduction

Only few genetic markers, particularly at morphological level are available in wheat [1]. One such character which may be useful for basic and applied research is solidness of culm in bread wheat (*Triticum aestivum* L.), and this trait can have potential utility as genetic marker. The culm of cultivated wheat is generally hollow, but some stocks which have pith at least in some internodes are reported from very early times. Solid stem trait was found to reduce the cutting and feeding damage caused by wheat stem saw fly (*Cephus cinctus* Nort.), which is a serious pest of wheat in many countries [2]. Despite considerable efforts to control wheat stem saw fly (WSS) proliferation and migration with cultural, chemical and biological methods, only host-plant resistance has proven to be effective as the pith impedes larval growth and migration. The character is also associated with environmental stress tolerance [3]. However, some researchers have shown significant negative correlation [4] while others have reported non-significant genetic correlation [5] between stem solidness and yield. The expression of stem solidness in durum (*Triticum turgidum* L. var. *durum* Desf.) has been described as being controlled by a single dominant gene [6]. Since breeding high yielding WSS resistant cultivars is problematic because of the subjectivity of solid stem scoring and variation of expression due to environmental effects [7], molecular markers (microsatellite) for efficient use of marker assisted selection have also been developed [8]. Inconsistent reports on genetics of this trait prompted the present investigation to be carried out in Indian germplasm. This communication reports the mode of inheritance of the stem solidness and its associations with some agronomic traits in a hexaploid wheat stocks.

Materials and methods

Wheat genotype in which most of the culm of the various internodes are filled with pith is referred to as 'solid stemmed wheat' and where the culm is not filled with pith the stem is termed as 'hollow'. The material in present study comprised of bread wheat genotypes, namely HD 2667, NP 12 and Selection (Sel.) 111 all having hollow stem and a solid stem stock Sel. 1093-1. Genotypes having hollow stem were crossed with sel. 1093-1. The resulting three F_1 hybrids were studied for solidness of culm. The F_1 and F_2 generations were planted at IARI, New Delhi farm during 1999-2000 and 2000-01 crop seasons keeping plant to plant distance of 10 cm at 30 cm apart in rows of 5m length. The F_3 families from randomly selected F_2 plants from one cross were grown during *rabi* 2001-02. Individual plants were scored for stem solidness and hollowness by taking first or main tiller, which was tagged at the time of ear emergence. For recording observation, sharp cuts were made at the middle of each internode of the main culm and three cuts in peduncle at equal distance. The rating of solidness was done on the basis of degree of pith development on the scale of one to five, where one indicates the internode is hollow while five indicates the internode is completely filled with pith. Internode one is the first internode at the base of the plant, internode two is the second internode from the base and so on. Plants showing solid stem character with 3-5 score at any internode barring two lower most internodes were considered solid stemmed, while hollowness of culm was classified under 1-2 category. The data was subjected to χ^2 test for analyzing the mode of inheritance. Data on a few characters such as plant height, number of kernels per main spike, main spike weight and kernel weight/main spike were also recorded but only in one cross to see whether solidness of culm has any association with these characters. The data of ten F_3 families grouping into solid (3), hollow (3) and segregating (4), were subjected to statistical analysis for comparing means of plant height, number of kernels/main spike weight and kernel weight/main spike. Significance of difference between the means of solid and hollow stemmed true breeding and segregating families was determined by applying 't' test.

Results and discussion

The results of genetic analysis obtained from three crosses are presented in Tables 1 and 2. The expression of solid and hollow stem phenotypes of the parents and F_1 plants have been shown in Fig. 1. All the F_1 plants, in each cross analyzed, showed solid stem indicating that solid stem trait is dominant over hollow stem (Table 1). However, the expression of solidness in F_1 of the cross Sel. 111 × Sel. 1093-1 was partial indicating incomplete dominance. The F_2 populations derived from the crosses HD 2667 × Sel. 1093-1 and NP12 × Sel. 1093-1 segregated into a ratio of three solid stem and one hollow stem plants (Fig. 2), which confirmed the monogenic dominant nature of the trait (Table 1). However, it was also observed that all the solid stem F_2 plants did not develop the same degree of solidness in all the internodes and ranged between the score of 3-5. This may be attributed to the fact that the genetic background of each F_2 plant would be different and this may affect the expressivity of the solid stem trait. Clarke *et al.* [9] also found variation in expression of solidness in F_1 hybrid was thought to have arisen due to cytological instability, which however is not the case in present study. Genetic and cytogenetic analyses have provided inconsistent results regarding inheritance of solidness of stem with one to several dominant or recessive genes hypothesized by different investigators [6, 10-11]. A dominant epistatic gene on D genome for hollowness epistatic to solidness has also been reported. The F_2 population derived from Sel. 111 × Sel. 1093-1 segregated into three categories, completely solid with 4-5 score; incompletely solid with 3-4 score and hollow with 1-2 score. However, the frequency of the plants having 3-4 score under

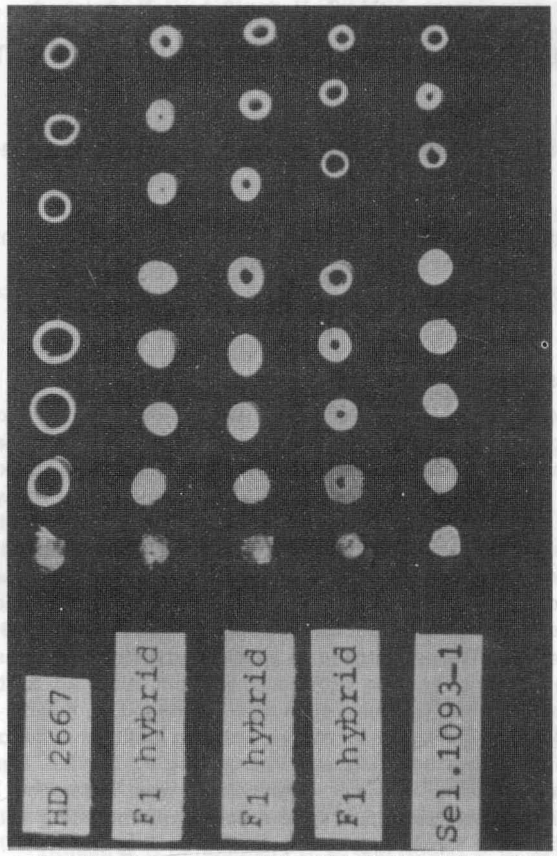

Fig. 1. (i) Hollow internodes of HD 2667, (ii) F_1 hybrid of HD 2667 × Sel. 1983-1, (iii) F_1 hybrid of NP 12 × Sel. 1093-1, (iv) F_1 hybrid of Sel. 111 × Sel. 1093-1 and (v) Solid stemmed parent Sel. 1093-1

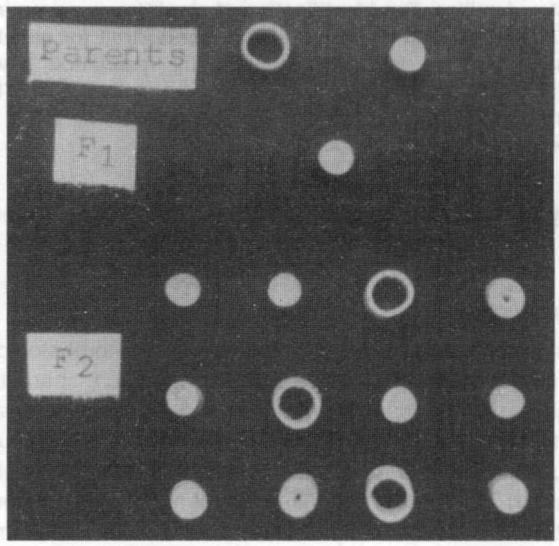

Fig. 2. Depecting segregation in F_2 generation from the cross HD 2667 x Sel 1093-1

segregating population was more and the fit was acceptable. But upon the pooling of homozygous and heterozygous plants the χ^2 value was 0.0677 for 1 d.f, which is much less than the table value (Table 1). Suppressors for many traits are also known in D

Table 1. The segregating pattern for solidness of stem in F_2 generation in wheat

Parents/cross	Generation	Number of plants			Total	Expected ratio	χ^2	P value
		Completely solid	Incompletely solid	Hollow				
HD 2667	P_1	0	0	15	15			
Sel. 1093-1	P_2	15	0	0	15			
HD 2667 × Sel. 1093-1	F_1	10	0	0	10			
	F_2	159	0	45	204	3:1	0.943	030-0.50
NP 12	P_3	0	0	12	12			
NP 12 × Sel. 1093-1	F_1	15	0	0	15			
	F_2	170		68	238	3:1	1.596	0.20-0.30
Sel. 111	P_4	0	0	17	17			
Sel. 111 × Sel. 1093-1	F_1	0	12	0	12			
	F_2	23	68	32	123	1:2:1	2.689	0.20-0.30
	F_2*	91	-	32	123	3:1	0.067	0.80-0.90

*Pooled the category of completely and incompletely filled F_2 individuals

genome [12]. Moreover, Sel. 111 is a wheat × rye derivative and may carry some alien chromatin, which might have not allowed the gene for solidness to express fully. The present study ruled out the possibility of the solid stem trait being recessive at least in the stock studied, since all the F_1 plants in two crosses had solid internodes, while in one F_1 hybrid the degree of solidness, though not as good as the other two, fell in the category of solid stem. The investigation also ruled out the possibility of a dominant gene in the hollow stem cultivars being epistatic over the genes conferring solid stem character, as in that case all the F_1 plant should have hollow stem. In a study of synthetic wheats, the possibility of suppressor in *Aegilops squarrosa* (genome DD) used in creating of synthetic hexaploid wheat do not exist [9]. The observation that the character is polygenic with about 14 genes spread over different chromosomes was possibly made because the degree of solidness at different internodes has been considered in quantitative terms while studying the trait. In our study we found that internode of majority of solid stemmed F_2 plants were completely filled with pith. Even the peduncle of more than 50% of F_2 plants derived from HD 2667 × Sel. 1093-1 cross showed solidness in first two cuts. The location of stem solidness has not been done precisely but the chromosomes of homoeologous group 2 tend to make the culm hollow [2]. They also identified that there are genetic factors on chromosomes, 3B, 3D, 5A, 5B and 5D affecting stem solidness expression and that chromosomes 6D and 7D inhibit the pith development. It was also concluded that the F_2 of chromosome 2B segregate for a difference of at least three genes. The present study indicated that there is a single dominant gene governing solidness of culm in Sel. 1093-1. However, in a cross Sel. 111 × Sel. 1093-1 varying degree of solidness in F_2 generation was observed, which may be due to genetic background of each individual or the environmental factors affecting the trait. Molecular analysis of solidness of stem has indicated that a single chromosome region on 3BL Qss.msub-3BL controls most of the variation for stem solidness in wheat [8]. The gene symbol *Sc* is proposed for solidness of culm in wheat.

Further confirmation of a single gene control of solidness of culm was obtained through the genetic analysis of F_3 progenies. The classification of F_3 families with solidness and hollowness of culm (internodes) in the group was based on behavior and performance with regards to parents, F_1 and the degree of solidness within the family. The F_3 segregation data from the progenies of 30 randomly selected F_2 plant showed seven families true breeding for solid stem trait, 13 families segregating for solid and hollowness while remaining 10 families were true breeding for hollowness. The observed data for number of families have a good fit to expected 1:2:1 ratio with χ^2 value of 1.33 (P value 0.50-0.70). Number of plants scored in each family varied from 26 to 67. Within the individual F_3 segregating family, the expected segregation ratio of 3 solid : 1 hollow fitted well except for two families. This was probably because of modifying factors, which create an array of genotypic backgrounds influencing the expression of solidness.

Association analysis of solidness of culm with other agronomic traits in true breeding solid and true breeding hollow and segregating families were worked out. The data presented in Table 2 indicated that plant height of solid stem families did not differ significantly with hollow stem families both in true breeding and segregating families. It was interesting to note that even the tall plants with 135cm length had solid culm indicating the full penetrance of the gene controlling pith formation. Similarly, the mean difference for other traits, except kernel number/main spike in true breeding solid and hollow families did not show significant differences in either family. However, the mean difference in kernel number/main spike in segregating F_3 families did not differ significantly (Table 2) and this discrepancy of

Table 2. Association of solid stem with other agronomical traits in wheat

Characters	Mean ± SE		't' value	Status of F_3 generation
	Solid	Hollow		
Plant height	100.25±0.972 (104)	102.49±1.047 (115)	1.10	True breeding
	105.59±1.08 (128)	106.73±1.32 (49)	0.68	Segregating
Number of kernels/spike	50.23±1.58 (104)	63.19±1.05 (115)	6.70**	True breeding
	54.05±1.38 (128)	51.12±1.67 (49)	1.36	Segregating
Main spike weight (g)	2.62±0.075 (104)	2.75±0.072 (115)	1.80	True breeding
	2.76±0.06 (128)	2.77±0.07 (49)	0.09	Segregating
Kernel weight/main spike (g)	1.86±0.056 (104)	1.97±0.055 (115)	1.42	True breeding
	1.96±0.05 (128)	2.01±0.04 (49)	0.58	Segregating

() = Number of plants studied; SE = Standard Error; ** = Significant at 1 per cent

mean difference indicate the inadvertent selection in true breeding solid and hollow F_3 families favored high kernel number per main spike. It can therefore, be concluded that the solidness of culm does not affect the grain number/main spike. It can also be presumed that solidness of culm does not affect other agronomic traits studied and that the trait solidness of culm is segregating independently.

Earlier research showed a significant negative correlation between stem solidness and yield [4], whereas later studies have indicated a non-significant genetic correlation between stem solidness and yield [13, 5]. Low yield and adverse quality in solid stemmed cultivars is attributed to the poor genetic background of the solid stem source rather than pleiotropy or deleterious linkage [5]. No relationship between plant height and stem solidness has been observed, but when plant height and stem solidness were compared, all correlation values were found to be negative though at low magnitude [14]. Damania et al. [3] reported that the solid stem character is associated with tolerance to environmental stress, while Carlson *et al.* [15] developed a solid stem cultivar 'Vanguard' which was superior to most hollow stem cultivars under moderate to heavy saw fly infestation. The region identified on chromosome 3BL for stem solidness is not associated with decreased yield potential suggesting that high yield solid stem cultivars can be developed [8]. A useful conclusion can be drawn from the study that solidness of stem may be a useful marker trait both for genetic studies and wheat breeding.

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