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Inheritance of the triple-spikelet character in a Tibetan landrace of common wheat

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Abstract

The Tibetan triple-spikelet wheat (TTSW) (*Triticum aestivum* L. concv. *tripletum* nom. nud.) is a landrace of common wheat collected from Tibet, China. It possesses a genetic stable character of triple-spikelets, and produces more than 50 spikelets and about 150 florets per spike. The plant has normal number of tillers, normal length of spikes, and well-developed seeds. The inheritance of the triple-spikelet trait in TTSW was genetically analyzed. The results indicate that the triple-spikelet character in TTSW is controlled by two recessive genes. Therefore, we suggest designating the genes controlling this character of triple-spikelets as *Ts1* and *Ts2*. These genes could be used for increasing the number of spikelets per spike for high-yield breeding in common wheat.

Introduction

Wheat is the world's most widely cultivated and consumed crop species, it represents the staple food for nearly 35% of the global population. The future demand for wheat is estimated to increase more than any other major crops when the world population increases (Mitchell et al. 1997; Ruttan 1993; Rajaram 2002). The forecasted global demand for wheat in the year 2020 varies between 840 (Rosegrant et al. 1995) and 1050 million tons (Kronstad 1998).Therefore, research on the enhancement of wheat productivity is still an important task for wheat breeders. However, the frequent use of a few parental genotypes in the modern wheat breeding programs and the monotonous plantation of only a few wheat varieties in wide areas have caused serious genetic erosion in cultivated wheat (Porceddu et al. 1988; Nevo 1995), which has significantly reduced genetic diversity of wheat varieties and constrained their further improvement.

Exploiting new genetic variation in elite and special wheat germplasm to restructure the ideal genotype for breaking yield barriers has widely been considered in wheat breeding (Millet 1987; Yen et al. 1995; Singh et al. 2001; Rajaram 2002). Two types of special wheat germplasm (uni-culm wheat and wheat with branch-eared spikes) were considered as the ideal genotype for super high-yield breeding (Donald 1968; Yen et al. 1995). To date, the attempt of using such traits as branch-eared spikes and uni-culm for high-yield breeding has been found to be unsatisfactory (Yen et al. 1995). Hopefully, new types of wheat germplasm with multiple numbers of spikelets per spike, and an optimum combination of tiller number, high grain weight, and number of grains per spike, are expected to be the ideal types for high-yield wheat breeding (Yen et al. 1995; Singh et al. 2001; Rajaram 2002). Among these ideal characters, germplasm with multi-spikelets per rachis node provides greater opportunities for wheat yield

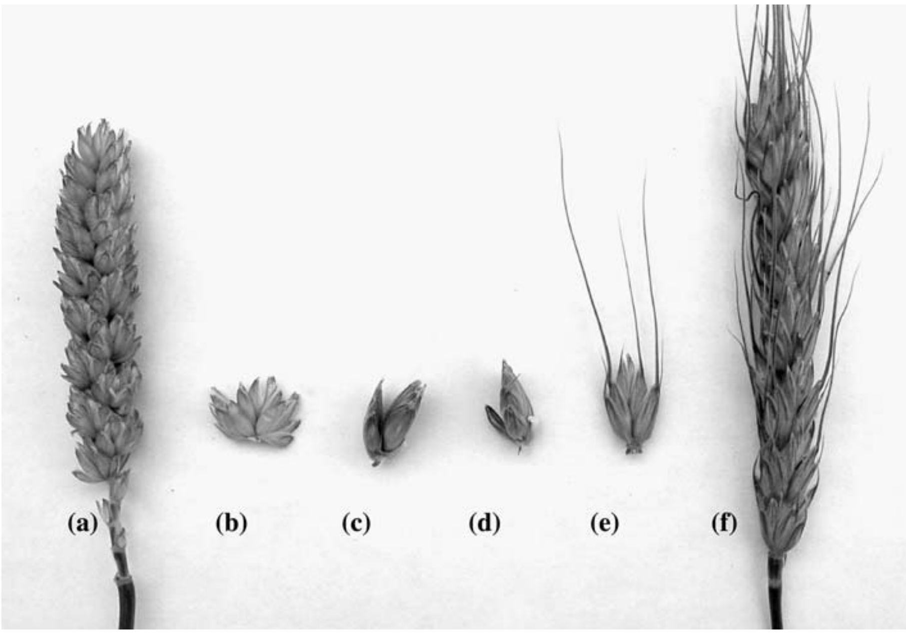

Fig. 1 Spikelet types in the F2 populations of TTSW × 99–607. A: a spike of TTSW; B: a triple-spikelet; C: a normal spikelet with a opposite supernumerary spikelet; D: a normal-spikelet with an expanded and compressed spine; E: normal spikelet; and F: a normal spike of 99–607.

increase, although germplasm with this character is very rare.

A type of common wheat landrace, i.e. Tibetan triple-spikelet wheat (TTSW) (*Triticum aestivum* L. concv.[1] *tripletum* Yen and Yang nom. nud.), has been found in Tibet, China (Yen and Yang 1999). In this TTSW landrace, three spikelets are consistently found to develop from each rachis node, and the triple-spikelet character is genetically stable in this landrace (Figure 1B), which is similar to the six-row barley, with consistent triple-spikelets on each rachis node. Importantly, the TTSW landrace produces more than 50 spikelets per spike and about 150 florets in a spike of normal length, and well-developed seeds, even when individuals produce a normal number of tillers. However, most of the TTSW individuals produce relatively small seeds with low frequency of seed set. The questions arise as to whether the character of triple-spikelets is linked with those poor productive features. In order to evaluate the potential value of the character of triple-spikelets for wheat breeding, this TTSW landrace was crossed with wheat varieties having normal spikes. The objectives of this study were to (1) investigate the inheritance of triple-spikelet characteristics, and (2) determine whether the character of triple-spikelets is tightly linked with poor productive traits, such as small seeds and low seed production.

[1]concv. is an unusual rank which cannot be found presently under ICBN and ICBNCP. In a similar case with double spikelets from Armenia (Dorofeer V. F. and Korovina O. N. (eds.) 1979. Kul' turnaja Flora SSSR – pšenica p. 265) has been used the category "forma" – i.e. *Triticum aestivum* var. *aureum* (Link) Mansf. f. *kurduculense* (Thum.) Dorof. et A. Filat.

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Materials and methods

The Tibetan triple-spikelet landrace of common wheat (TTSW) provided by Professor C. Yen and Dr D.C. Liu from the Triticeae Research Institute, Sichuan Agricultural University, Sichuan, China, and two normal-spikelet types of wheat varieties, 99-607 and SW8488 from Crop Research Institute, Sichuan Academy of Agricultural Sciences, Sichuan, were used in this study. The TTSW landrace was hybridized with 99-607 and SW8488 under field conditions in Chengdu of Sichuan. For seed multiplication during the summer season, the F_2 and BC_1 populations were planted at Yunnan Agricultural University, Kunming, China. During the winter season, the F_2 and BC_1 populations, obtained from Yunnan Agricultural

University, together with their parents and F_1's were grown as individual plants for analysis in the field of Chengdu.

Observation of the triple-spikelet character in F_1 hybrids and their progeny was performed on plants at the heading stage in field from March to June in 2002. Chi-square analyses were carried out to test distribution of the observed F_2 phenotypic frequencies against those expected for one-gene or two-gene segregation models (Table 1). Around 10 plants of the 3 parents (TTSW, 99-607 and SW8488) and individuals with triple-spikelet character in F_2 populations were harvested and subject to further investigation. Measurement of the agro-morphological characters, such as plant height, tillers per plant, number of spikelets per spike, number of florets per spike, number of seeds per spike, and grain weight were conducted during the entire life cycle (Table 2). The average values were recorded from 10 plants for each of the 3 parents.

Results and discussion

As indicated in Table 1, the number of spikelets per rachis node of all the F_1 hybrids of TTSW with 99-607 and SW8488 was normal, similar to their parents

Table 1. Segregation for number of normal-spikelets (NS) and triple-spikelets (TS) in the F_1, F_2 and BC_1 progeny.

Cross	NS	TS	Total	X^2 15 : 1	P	X^2 3 : 1	P	Estimated gene no.
F_1 (TTSW × 99-607)	32	0	32					
F_1 (TTSW × SW8488)	27	0	27					
F_2 (TTSW × 99-607)	124	8	132	0.008	> 0.900			2
F_2 (TTSW × SW8488)	196	10	206	0.685	0.250–0.500			2
BC_1 (TTSW/99-607//99-607)	107	0	107					
BC_1 (TTSW/ SW8488//SW8488)	89	0	89					
BC_1 (TTSW/99-607//TTSW)	83	32	115			0.351	0.500–0.750	2
BC_1 (TTSW /SW8488//TTSW)	66	27	93			0.606	0.250–0.500	2

Table 2. Mean values of yield components of the triple spikelet individuals (P1 and P2) in the F_2 population derived from TTSW crossed with normal-spikelet wheat (99–607 and SW8488).

Parents and lines*	Plant height (cm)	Tillers/plant	No. of spikelets spike	No. of florets/spike	No. of seeds/spike	Seed set rate (%)	Grain weight/1000 kernels (g)	Grain weight/spike (g)
TTSW	125.3	7.6	51.2	151.3	39.7	26.24	27.3	1.01
99-607	90.2	6.9	19.7	54.4	40.2	73.9	39.5	1.52
SW8488	83.4	5.7	21.5	67.2	48.3	71.88	45.8	2.09
P1-1	93.6	7	52	153	68	44.44	36.4	2.41
P1-2	134.1	8	47	142	77	54.23	38.2	2.79
P1-3	89.5	8	54	156	101	64.74	37.5	3.69
P1-4	116.3	7	50	151	50	33.11	39.4	1.90
P1-5	120.6	9	53	157	63	40.13	33.1	1.98
P1-6	98.5	8	49	140	82	58.57	32.7	2.62
P1-7	101.6	7	55	159	92	57.86	36.1	3.25
P1-8	110.7	9	51	151	74	49.01	31.5	2.27
P2-1	120.3	7	56	163	121	74.23	42.4	5.01
P2-2	96.3	8	49	145	76	52.41	34.7	2.61
P2-3	84.5	6	48	140	79	56.43	39.2	2.99
P2-4	92.7	7	47	141	82	58.16	37.3	2.87
P2-5	111.5	7	54	159	98	61.64	43.7	4.09
P2-6	129	8	50	137	65	47.45	44.6	2.83
P2-7	85.5	8	52	153	75	49.2	35.1	2.57
P2-8	102.0	8	55	160	103	64.38	36.2	3.66
P2-9	119.4	7	42	115	57	49.57	34.5	1.92
P2-10	100.3	8	44	119	61	51.26	39.3	2.25

* P1 represents the individual plant from the cross of TTSW × 99-607, and P2 represents the individual plant from the cross of TTSW × SW8488.

99-607 and SW8488. This result evidently indicated that the triple-spikelet character of TTSW was controlled by a recessive gene (genes). Individuals in the F_2 populations derived from the F_1 hybrids between TTSW and 99-607 or SW8488 segregated into two types, i.e. the normal-spikelet and triple-spikelet types (Figure 1). Chi-square test confirmed that the frequencies of normalspikelet versus triple-spikelet individuals were in accordance with a 15 : 1 ratio (Table 1). This result strongly suggests that there are two independent genes that control the triple-spikelet trait. In addition, there was no segregation observed in the BC_1 individuals of TTSW/99-607//99-607 and TTSW/SW8488//SW8488 (Table 1), confirming the recessive inheritance of the genes controlling the triple-spikelet trait. The BC1 individuals of TTSW/99-607//TTSW and TTSW/SW8488// TTSW also segregated into the triple-spikelet and normal-spikelet types. Chi-square test confirmed that frequencies of the normal-spikelet versus triple-spikelet individuals were in accordance with a 3 : 1 ratio (Table 1). These results together justify that the triple-spikelet character of TTSW is controlled by two independent recessive genes. Since no information about the inheritance of the triple-spikelets character has yet been reported, we propose to designate the new genes controlling the triple-spikelets of TTSW as *Ts1* and *Ts2*.

In addition to the parental types (i.e. typical triple-spikelet and normal-spikelet types), two new types, i.e. the normal spikelet with an opposite supernumerary spikelet (Figure 1C) and normal spikelet with an expanded and compressed spine (Figure 1D), were observed in the F_2 populations of TTSW crossed with 99-607 and SW8488. Such new type of spikelets was described as opposite "supernumerary spikelet" by Yen and Yang (1992). In this case, an additional spikelet develops at the distal side of the base of normal spikelet and piles up with it. The additional spikelet can be a dome-like protuberance, a spine, an expanded, compressed spine, an expanded compressed, splitting a protoglume, protoglume spikelet, or a normal spikelet (Yen and Yang 1992). Morphologically, the triple-spikelet character is significantly different from the opposite supernumerary spikelet character. However, the opposite supernumerary spikelet character was segregated from the F_2 population of the triple-spikelet landrace crossed with normal-spikelet varieties. Therefore, the relationship between the triple spikelets and opposite supernumerary spikelets needs further analyses.

During the comparative study of agromorphological variations of the TTSW landrace, the two normal-spikelet parents (SW8488 and 99-607), and the F_2 individuals from the TTSW/99-607 and TTSW/SW8488 hybrids, some excellent lines with the characters of triple spikelets, high seed production (>120 seeds per spike), and normal 1000 grain weight, were identified in the F_2 population (Table 2). Apparently the character of triple spikelets is not associated with the poor productive characters, such as low seed production and low grain weight. Therefore, with proper recombination and selection, the triple-spikelet trait could be useful for improving the yield of common wheat. As presented in Table 2, the TTSW landrace produces approximately 51.2 spikelets and 151.3 florets per spike. This number is about 2–3 times higher than that of the normal-spike parents, SW8488 and 99-607. Noticeably, the seed production rate and 1000-grain weight of the TTSW landrace were much lower than those of SW8488 and 99-607. This can result in significantly low grain yield of the TTSW landrace. Yen et al. (1995) crossed a uni-culm strain with branch-eared wheat and developed a uni-culm and brancheared wheat line with more than 150–180 florets. However, the grain weight per spike of brancheared wheat was very low because of its poor productivity, and small seeds that lacked of plumpness (Yen et al. 1995).

In the present study, all the individuals with triple-spikelet character from the TTSW × 99-607 and TTSW × SW8488 hybridization produced higher grain weight per spike than the parent TTSW (Table 2). Some individuals, such as P1-3, P1-7, P2-1, P2-5, and P2-8 produced more than 50 spikelets and 150–170 florets, and had a very high rate of seed set (98–121 seeds per spike) and grain weight per spike (3.25–5.01 g/spike) (Table 2). This result indicated that the disadvantage of small seeds and low floret fertility observed in the TTSW landrace could be overcome by introgressing it into other wheat genotypes having normal spike and ideal yield performance. The high-yielding lines with triple spikelets could be created through suitable breeding programs. In the present experiment, the line P2-1 (derived from TTSW × SW8488) produced 56 spikelets, 163 florets, and 121 seeds per spike with 42.4 g of 1000-grain weight and 5.01 g of grain weight per spike, and was selected. In conclusion, the triple-spikelet germplasm provides a trait suitable for high-yield breeding, in addition to that of multi-spikelets per spike (or super spike wheat).

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