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Breeding and Evaluation of a New-Bred Semi-Leafless Pea (*Pisum sativum* L.) Cultivar Longwan No. 6

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Abstract: The pea (*Pisum sativum* L.) is an excellent protein source for livestock and human nutrition. However, its growth is hampered by several factors including powdery mildew (*Erysiphe pisi* DC) and lodging in irrigation areas. These limitations may be solved through combining a Canada powdery mildew-resistant pea (Mp1807) with green cotyledon cultivar (Graf) by means of sexual hybridization. A bred semi-leafless pea, cultivar Longwan No. 6, was selected and evaluated in multiple ecological zones to investigate and evaluate high-yield, adaptability, and resistance to root rot (*Aphanomyces euteiches* Drechs. f. sp. *pisi*) and powdery mildew from 2012 to 2014. The results revealed that Longwan No. 6 was characterized by lodging resistance and moderate powdery mildew resistance. The average grain yield of Longwan No. 6 is 2855.3 kg/hm^2 in spring sowing and is increased by 18.4% compared to the control cultivar (Longwan No. 1). The average grain yield of Longwan No. 6 is 2349.9 kg/hm^2 in winter sowing and is increased by 12.8% when compared to the control cultivar. The results indicated that Longwan No. 6 has a greater potential to increase yield and wide adaptability. Adopting the Longwan No. 6 pea cultivar contributes to improvements in pea production in irrigation areas.

Keywords: semi-leafless pea; pea breeding; cultivar characteristics; yield; adaptability

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Citation: Yang, X.; Gou, Z.; Zhu, Z.; Wang, C.; Zhang, L.; Min, G. Breeding and Evaluation of a New-Bred Semi-Leafless Pea (*Pisum sativum* L.) Cultivar Longwan No. 6. *Agronomy* **2022**, *12*, 850. https://doi.org/10.3390/agronomy12040850

Academic Editor: Jane K. Dever

Received: 21 February 2022
Accepted: 28 March 2022
Published: 30 March 2022

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1. Introduction

Pea (*Pisum sativum* L.) is an annual cool-season legume. It is a valuable raw material for starch processing and also a source of essential proteins and amino acids in human diets [1,2]. Due to the pea's strong diversity and adaptability, it has a long history of utilization globally in diverse agroecology [3,4]. The pea is the fourth most important food legume in the world and has been cultivated for more than 2000 years in China [5]. The countries with the highest pea cultivations include Canada, China, India, Russia, and France. The yield of dry peas and green peas in China accounts for 15.2% and 23.1%, respectively, in the world production of peas [6]. More than 5000 pea germplasm resources have been collected in China, and about 80.0% are domestic and local and are genetically stable [7,8]. The continuous improvement in people's living standards and diet, the higher market demand, and diversification have increased the demand for peas [9,10]. Germplasm resources are the basis for crop genetic improvement, which directly affects sustainable development of the modern seed industry [11,12]. Most countries attach great importance to the protection and utilization of germplasm resources around the world. Therefore, breeding a batch of pea cultivars to meet different needs is one of the ways to promote the development and production of peas.

Pea production is also faced with many biotic and abiotic stresses that seriously limit production capacity [11,13]. It is becoming increasingly difficult to plant legume crops due to the effects of climate change [14]. However, the development of new breeding

technologies has increased during the last decade, providing opportunities for world pea production. For a long time, key breeding objectives in peas were mainly focused on improving biotic and abiotic stress resistance [15], including root rot and powdery mildew control [12,16,17]. Adapting to diversified germplasms as parents and performing extensive crossbreeding for major gene traits under conducive conditions help in the yield testing of a large number of breeding lines [15,18]. Currently, powdery mildew and lodging resistance in peas have been improved through the deployment of the single recessive gene *er-1* and the *afila* gene for semi-leafless types [9,12]. Semi-leafless peas dominate worldwide modern dry pea production. For instance, more than 80.0% of pea cultivars are of a semi-leafless type that is resistant to powdery mildew and lodging in the United States, Canada, and France [13,19]. Compared with conventional pea cultivars, semi-leafless peas significantly enhance the shoot standing ability and ensure equally efficient dry matter accumulation by the plant [20,21]. Nevertheless, compared with the major crops, there is a lack of pea cultivars with high multi resistance, high yield, and good quality in China [22]. Meanwhile, utilization and breeding of semi-leafless pea germplasms started relatively late in China [23]. The common cultivars are mainly trailing peas, which are suitable for planting in arid land but are not resistant to lodging [21,24]. To enhance pea cultivar traits (e.g., high-yield, dwarf stalk and lodging-resistance), it is of great significance for pea production to develop the breeding of semi-leafless peas.

The aims of this study, therefore, were to breed a pea cultivar that is lodging-resistant, high yield, and good quality. It is of practical significance to improve pea productivity in irrigation areas. The specific breeding objective is to achieve a pea yield of more than 3000 kg/hm^2, an increase of more than 8.0%, a crude protein content of more than 23.0%, and a crude starch content of more than 50.0%.

2. Materials and Methods

2.1. Plant Materials

The plant material introduced by the Institute of Crop Sciences, Gansu Academy of Agricultural Sciences was used for the experiment. The Canadian pea cultivar (Mp1807) was the female parent, a semi-leafless pea. It had yellow-white cotyledons, was 90–105 cm high, and was late maturing (90–015 days) (Figure 1a). The significant traits of the female line included better resistance to powdery mildew, high node position at the beginning of the flower, and lodging resistance. The line bred by Gansu Academy of Agricultural Sciences was the male parent. It was a trailing pea. The cotyledons of the male parent were green (Graf). The plant was 55–65 cm high, early-maturing (75–85 days), and susceptible to powdery mildew (Figure 1b). The significant traits of the male line were sturdy dwarf stalks.

2.2. Experimental Site

The final tests of the resulting cultivar Longwan No. 6 were carried out from 2009 to 2011 at Qinwangchuan Field Station (36°30′ N, 103°40′ E) and Tangjiabu Field Station (35°35′ N, 104°36′ E). Plant materials were sown in a randomized complete block design with three replicates. Qinwangchuan Field Station is known to be infested by pea powdery mildew and has been used as a screening nursery for such mildew for many years. Tangjiabu Field Station has a high incidence of root rot. There were thirteen spring sowing regional sites and eight winter sowing regional sites, respectively (Table 1).

Table 1. The fourth round of regional trial sites of China pea cultivars in the spring sowing group and the winter sowing area group.

	Regional Trials Sites	Latitude (N)	Longitude (E)	Altitude (m)	Precipitation (mm)
Spring sowing sites	Zhangbei, Hebei	41°9′	114°42′	1450	300
	Liaoyang, Liaoning	40°42′–41°36′	122°35′–123°41′	70	572
	Zhuoni, Gansu	35°12′	102°45′	2650	487

Table 1. *Cont.*

	Regional Trials Sites	Latitude (N)	Longitude (E)	Altitude (m)	Precipitation (mm)
	Dingxi, Gansu	35°32′	104°37′	1920	350
	Dalat, Inner Mongolia	40°24′	110°21′	1010	282
	Yulin, Shanxi	38°26′	108°14′	1053	440
	Guyuan, Ningxia	35°48′	106°02′	2230	458
	Yanchi, Ningxia	37°48′	107°23′	1349	243
	Longde, Ningxia	35°35′	105°59′	1920	766
	Xining, Qinhai	36°43′	101°45′	2309	380
	Hualong, Qinhai	35°30′	101°36′	2765	470
	Lasa, Tibet	29°39′	91°07′	3658	345
Winter sowing sites	Wuhan, Hubei	31°22′	114°05′	20	1320
	Nanjing, Jiangsu	32°01′	120°51′	5.3	1106
	Rugao, Jiangsu	32°01′	120°51′	5.3	1120
	Ankang, Shanxi	32°44′	109°04′	295	1050
	Chengdu, Sichuan	30°36′	104°06′	438.1	1092
	Yongchuan, Chongqin	105°53′	29°22′	386.3	1015
	Kunming, Yunnan	25°18′	103°02′	1906	1035
	Yuxi, Yunnan	24°24′	102°31′	1630	965

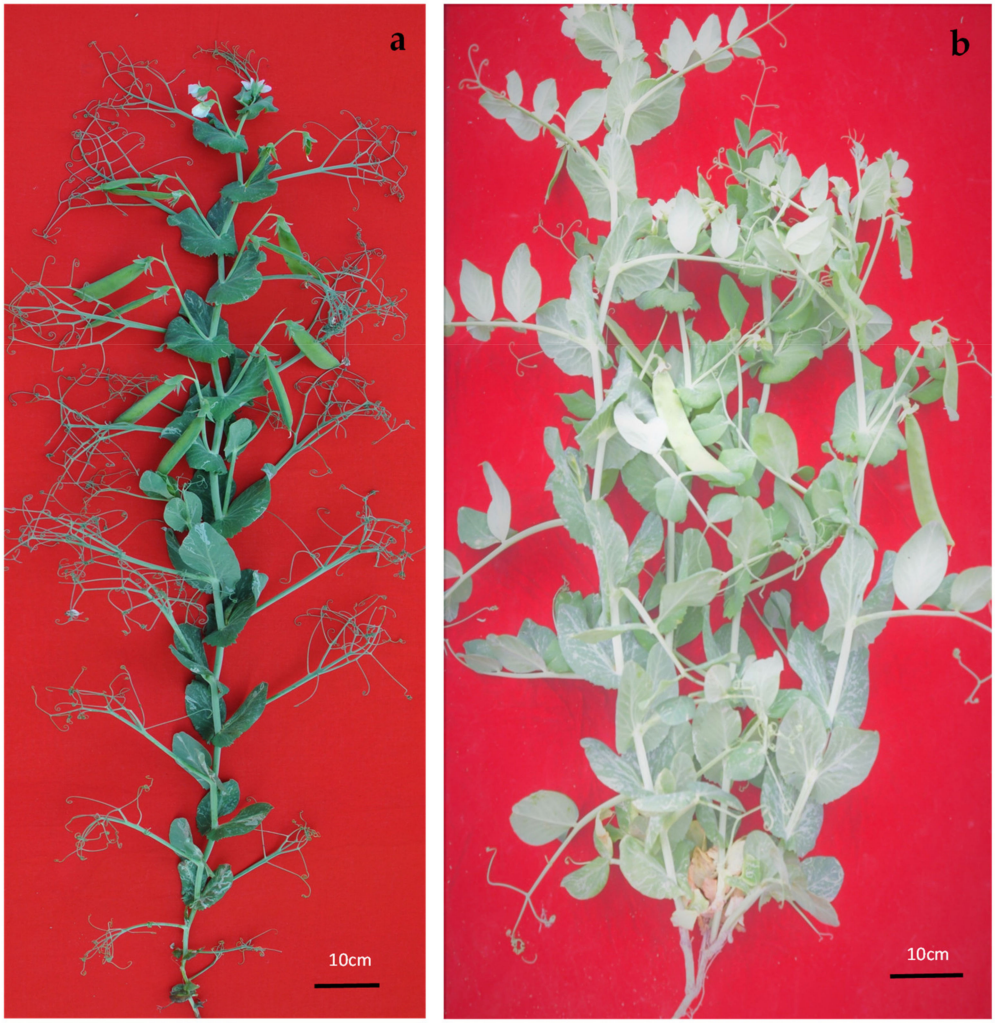


Figure 1. The parent of Longwan No. 6; (**a**) is the female parent (Mp1807), and (**b**) is the male parent (Graf).

2.3. The Evaluation of Disease Resistance

The evaluation of powdery mildew and root rot resistance was carried out under natural susceptibility at Qinwangchuan Field Station and Tangjiabu Field Station, respectively. Dingwan No. 1 (a trailing pea cultivar) and Longwan No. 1 (a semi-leafless pea cultivar) were used as a sensitivity control and resistance control, respectively. Identification of powdery mildew resistance referred to the method of Wang et al. [25], and identification of root rot resistance referred to the method of Xiang et al. [26].

2.4. Breeding Process

The cross of Mp1807×Graf was prepared by the traditional breeding method in 2000 (Figure 2). The F_1 and F_2 generations were planted in 2001 and 2002, respectively. The F_3, F_4, and F_5 generations were selected from the high-incidence area of root rot and powdery mildew at Tangjiabao Field Station and Qinwangchuan Field Station from 2003 to 2005. In 2006, the stable material (F_6 generation) was evaluated in terms of comprehensive traits, population structure, growth, and other factors in the plant-line area. The excellent lines were selected in orderly and consistent plant rows with a seed test. In 2007, the final selection line (F_7) was selected based on field performances and indoor seed tests for the preliminary determination of yield. The excellent line named 1702 was subjected to the yield and resistance identification test of the semi-leafless pea group in 2008. It participated in the cultivars comparison test to identify its main characteristics and yield traits in 2009. Multi-ecology adaptation was carried out in Baiyin, Lanzhou, Kangle, Dingxi, Gannan, and Wuwei Gansu provinces from 2010 to 2011. The pea cultivars participated in the fourth round of regional trials of China pea cultivars in the spring and winter sowing area groups from 2012 to 2014. There were 11 tested cultivars (lines) in the spring sowing group and 13 experimental sites. The winter sowing group participated in 11 cultivars (lines) and 8 experimental sites (Table 1). The test code of Longwan No. 6 is WD04-02. The original line code is 1702.

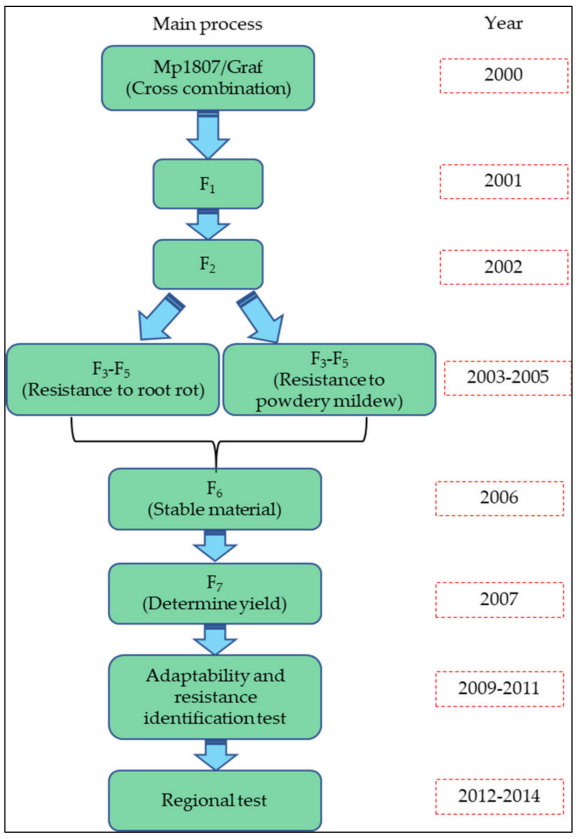


Figure 2. Breeding process of Longwan No. 6.

3. Results

3.1. Botanical and Biological Characteristics

Longwan No. 6 is a semi-leafless pea with limited pods. It has semi-dwarf stems and an erect growth pattern (Figure 3). The height of Longwan No. 6 ranges from 51.7 to 69.1 cm. Its main stem has 12.3–16.5 nodes with the first flower nodes at the 9th node. The flowering period of Longwan No. 6 is about 18–23 days (Figure 4a). The seeds are smooth and round in shape and have clear coats, good color, faint yellow cotyledons, and yellowish-white hilum. The stipules are rabbit-ear-shaped, the leaf surface has fewer denudation spots, and there is no cyanotic spot in the leaf axils. The pods are straight, blunt, and green and not easy to split (Figure 4b). The fresh stems and pods are green. Each plant has 16.0–18.6 pods, with a double-pod rate of 40.0–75.0%. The pods are concentrated, the maturity is consistent, and the seeds bulge quickly. The number of flowers per inflorescence is 1 to 2. The pod length of the plant is 5.6–6.5 cm, the number of pods is 3.5–4.4, and the pod splitting rate is 20.0%. The number of grains per plant is 21 to 65, and the yield per plant is 5.0 to 12.5 g. One hundred grain weight (100-grain) is 22.1–28.8 g, and the seed coat rupture rate is 1% (Figure 4c). Longwan No. 6 has cool and humid ecological habits, moderate cold resistance, strong lodging resistance, and weak drought resistance. It is a mid-early-maturing pea cultivar, with a growth period of 84–86 d for spring sowing sites in the north and 172–180 d for winter sowing sites in the south.

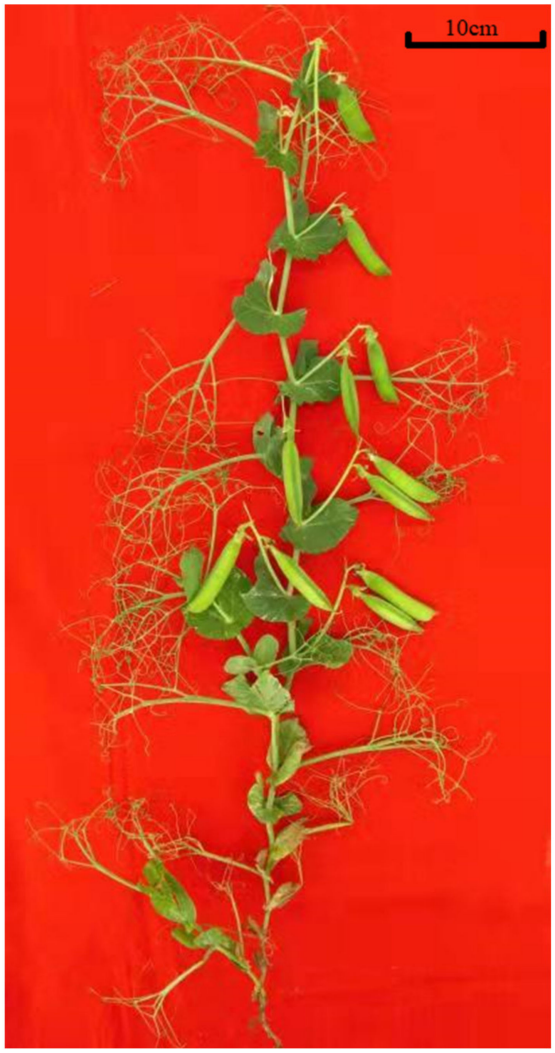


Figure 3. Plant characteristics of Longwan No. 6; the height of Longwan No. 6 ranges from 60.0 cm.



Figure 4. Characteristics of the flower, pod, and grain of Longwan No. 6; (**a**) is the flower of Longwan No. 6; (**b**) is the green pod of Longwan No. 6; and (**c**) is the dry grain of Longwan No. 6.

3.2. Quality

Quality analysis was conducted from mixed grains of three sampling points from the spring (Zhangbei, Lanzhou, and Lasa) and winter sowing group (Wuhan, Chongqing, and Nanjing) pea sites by the Food Quality Supervision, Inspection and Testing Center (Yangling) of the Ministry of Agriculture. In the spring sowing group pea sites, the results showed that the average grain protein content of Longwan No. 6 was 21.2% (Table 2). The average protein content was 3.4% lower than the national average (24.6%). The carbohydrate content was 57.1%, which is 10.5% higher than the national average (46.6%). Fat and water content were 1.9% and 10.3%, respectively. The results of the quality analysis of the three sampling points in the winter sowing group pea sites showed that the average protein content was 24.1%, which is 0.5% lower than the national average. The carbohydrate content was 56.9%, which 10.3% higher than the national average. Fat and water content were 3.1% and 10.2%, respectively.

Table 2. Quality analysis of regional trial sites of Longwan No. 6 pea cultivars.

Sites	Protein	Carbohydrate	Fat	Water Content
Spring sowing sites	21.2%	57.1%	1.9%	10.3%
Winter sowing sites	24.1%	56.9%	3.1%	10.2%
The national average	24.6%	46.6%	2.5%	10.3%

Note: The national average quality index of the peas (46.6%) was determined by regional trial sites of China pea cultivars.

3.3. Disease Resistance

A field evaluation of natural susceptibility by the Institute of Plant Protection, Gansu Academy of Agricultural Sciences at Qinwangchuan experimental site was conducted on 28 June 2014 (pod filling stage of pea) [11,12]. The results showed that the powdery mildew incidence rate of Longwan No. 6 was 12.5% and the disease index was 10 (Table 3). The powdery mildew incidence rate of the control cultivars (Longwan No.1) was 20.8%, and the disease index was 32. Longwan No. 6 exhibited moderate powdery mildew resistance. In 2014, the occurrence and prevalence of root rot in the field were identified during the pea growing period at Tangjiabu Field Station. The root rot incidence rate of Longwan No. 6 was 17.3%, with a disease index of 4.6. The root rot incidence rate of the control cultivars was 24.8%, with a disease index of 5.9. This indicates that the root rot disease of Longwan No. 6 is lower than that of the control cultivars.

Table 3. Analysis of disease resistance in Longwan No. 6 pea cultivars.

	Powdery Mildew		Root Rot	
	Incidence Rate	**Disease Index**	**Incidence Rate**	**Disease Index**
Longwan No.1	20.8%	32	24.8%	5.9
Longwan No. 6	12.5%	10	17.3%	4.6

Note: Longwan No.1 is the control cultivar.

3.4. Yield

The grain yield of 11 pea cultivars in spring and winter sowing is shown in Figures 5 and 6 (WD04-2 is the test code for Longwan No. 6). In the spring sowing group, the average grain yields of WD04-2 are 3193.2, 2796.7, and 2739.3 kg/hm^2 from 2012 to 2014, respectively (Figure 5). Across the three years, grain yields increased by 18.8, 16.8, and 19.8% in WD04-2 as compared to the control cultivar (Longwan No. 1), respectively. Compared with other cultivars, grain yields increased by 1.6–72.0%, 2.3–63.7%, and 2.6–73.1% from 2012 to 2014, respectively. In view of the winter sowing group, the average grain yields of WD04-2 are 2826.0, 2570.7, and 1944.6 kg/hm^2 in the three years, respectively. Grain yields increased by 11.3, 12.9, and 14.1% on WD04-2 as compared to the control cultivar, respectively. Grain yields increased by 0.4–138.3%, 1.2–95.6%, 1.9–83.8% in three years, respectively, compared to other cultivars. Longwan No. 6 ranked second out of all the 11 tested cultivars (lines) in the spring and winter sowing groups. The results indicated that the Longwan No. 6 pea cultivar has great potential for increasing yield and wide environmental adaptability. It is suitable for planting in the spring and winter sowing.

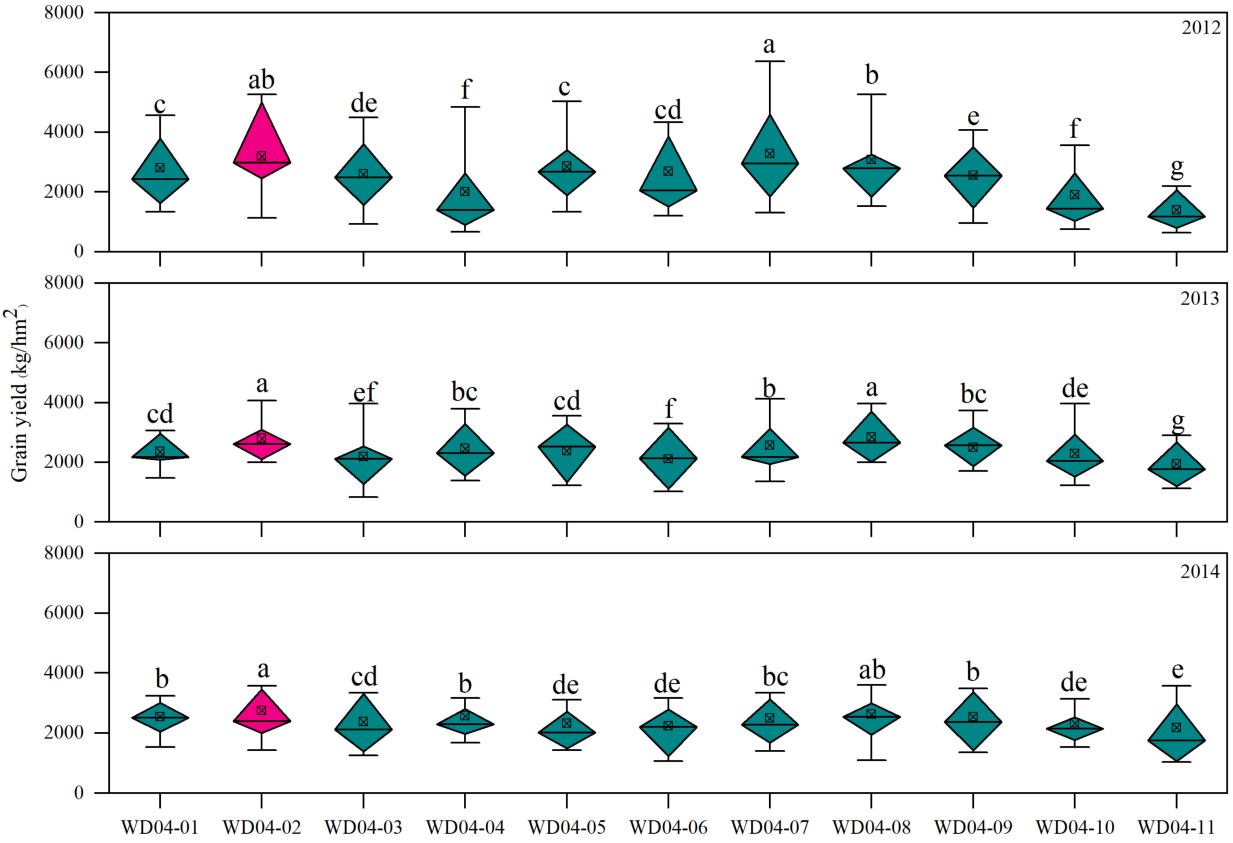


Figure 5. Grain yields of the fourth round of regional trials of China pea cultivars in the spring sowing group. The different lowercase figures above indicate significant differences between treatments (p = 0.05).

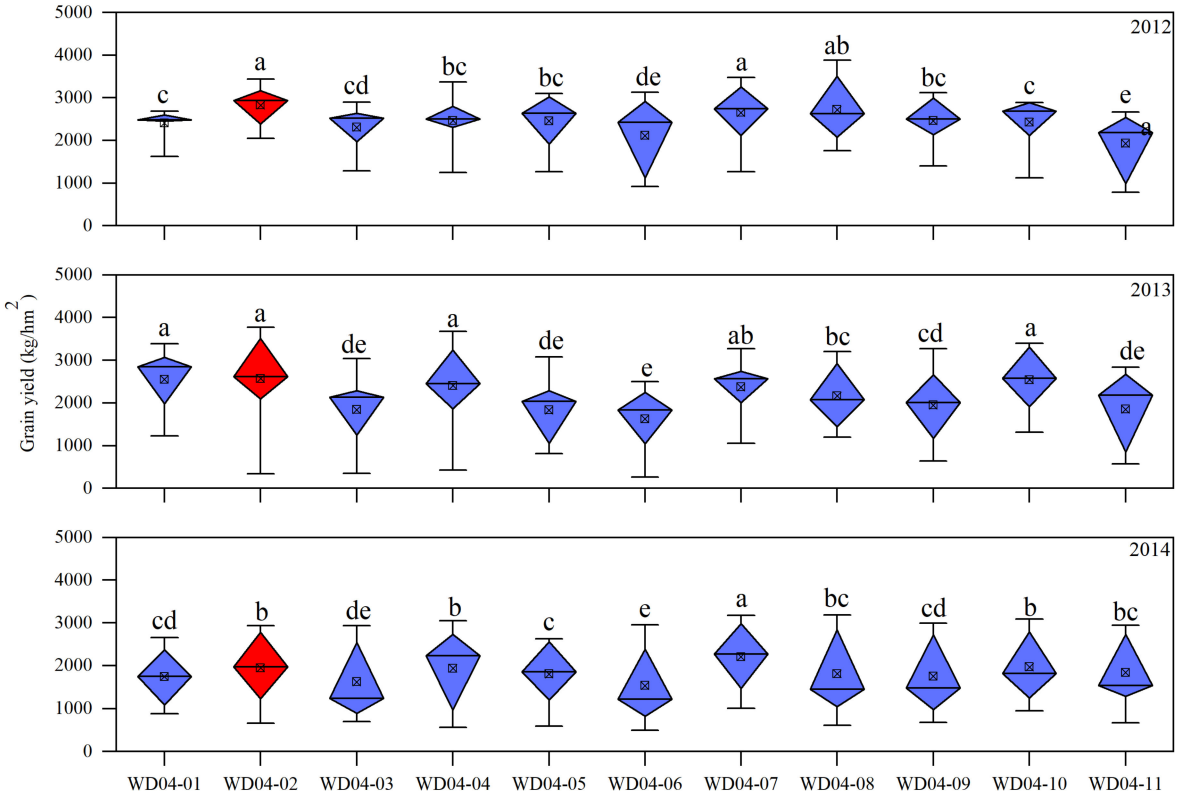


Figure 6. Grain yields of the fourth round of regional trials of China pea cultivars in the winter sowing group. The different lowercase figures above indicate significant differences between treatments (p = 0.05).

3.5. Comparison with Parental Characteristics

The Longwan No. 6 pea cultivar inherited some of its excellent characteristics from its female parent (Mp1807) and male parent (Graf). It is consistent with the female parental traits in terms of plant type, flower color, pod size, pod shape, and powdery mildew resistance. Longwan No. 6 is a semi-leafless, white-flowered, hard-podded pea cultivar. It is between the two parents in terms of plant height, number of nodes per plant, number of nodes at first flower, double pod rate, 100-grain weight, and days to maturity (85–90 days).

3.6. Cultivation Techniques

The suitable sowing period of Longwan No. 6 is from mid-to-late March to early-to-mid April. It can be sowed when the average surface temperature is stable at 3–5 °C and the soil is thawed at 12–15 cm. The row spacing is 22–25 cm, and the plant spacing is 2–3 cm. The seeding rate is 270–330 kg/hm^2, and the seedlings are maintained at 90–120 plants/m^2. In terms of fertilizer requirements, in plots with premature senescence, topdressing N 30.0–45.0 kg/hm^2 is combined with irrigation or rainfall at the beginning of flowering. Spray 1 to 2 times with potassium dihydrogen phosphate 7.5 kg/hm^2 mixed with 450 kg of water at the final flowering stage. Trifluralin EC 48.0% was used as a pre-emergence herbicide for soil surface treatment to control weeds in the field.

4. Discussion

Leguminous crops are important to human and animal life. They occupy a vital role in the global food supply chain and sustainable agricultural production systems [18]. Leguminous crops have prominent biological features owing to their inherent ability to fix atmospheric nitrogen [27]. These crops become an indispensable part of the sustainable agriculture strategy throughout the world. Improving the production of leguminous crops requires a breeding investment on a large number of species [28]. However, the grassland

and Dingwan series of traditional pea cultivars are trailing peas in China for the most part. These cultivars are suitable for planting in dryland [6,7]. They are not suitable for planting in irrigation areas and often cause late maturity, lodging, rotten seedlings, and root rot in years with high rainfall. Serious powdery mildew was caused by planting traditionally bred pea cultivars in irrigation areas, thereby affecting yield and quality [4,12]. In addition, it is difficult to meet the needs of agricultural rotation and intercropping in rain-fed agricultural areas and irrigated areas. In fact, lodging is present in all cultivars with classical leaf structure irrespective of stem length and maturing [9]. The semi-leafless type of pea was artificially mutagenized, and all pinnate compound leaves were mutated into tendrils [21]. Tendrils are intertwined between plants to form a scaffold structure with excellent lodging resistance [9]. This has important utilization value in the breeding of peas, such as lodging resistance, water saving, and disease resistance [4,29]. Meanwhile, a previous study showed that it is possible to successfully recombine the homozygous leafless gene with already achieved desired traits within late-maturing genotypes without losing disease resistance and resistance to lodging [9,21]. Our study also has similar results. Longwan No. 6 inherit quality and days to maturity from their parents with normal leaf (the male parents Graf) but at the same time acquire lodging resistance and powdery mildew resistance from the semi-leafless pea (the female parents Mp1807).

In this study, the traditional drought-resistant and trailing pea breeding objectives were adjusted to the semi-leafless pea breeding with concentrated pods, lodging resistance, and suitability for mechanized operation. There is need for the development of large-scale production of peas. In the selection of breeding technology of Longwan No. 6, drought resistance and high-yield identification were carried out using the cycle of irrigation and dryland. The powdery mildew resistance evaluation was carried out at the Qinwangchuan Experimental Station in Lanzhou. The problem of single resistance or unstable resistance in bred varieties was solved. The multi-ecological joint regional test of China indicated that Longwan No. 6 has good disease resistance and high yield performance. Longwan No. 6 exhibited outstanding yield performance in all planting areas. The breeding of Longwan No. 6 is a breakthrough in pea lodging resistance breeding in Northern China. Compared with trailing pea cultivars, Longwan No. 6 has five highlighted agronomic traits: early maturity, concentrated flowering, shade tolerance, dwarf culm, and lodging resistance. These characteristics meet the needs of pea cultivars for rotation and intercropping in rain-fed agricultural areas and irrigated areas. It has contributed toward developing the rotation and intercropping systems in irrigation areas (Figure 7) and to developing the traditional pea monoculture systems to an intercropping system. Even more importantly, the popularization and application of this cultivar have expanded the pea production areas from traditional dry farming areas to irrigated agricultural areas and rain-fed agricultural areas in Gansu, Ningxia, and Qinghai provinces.

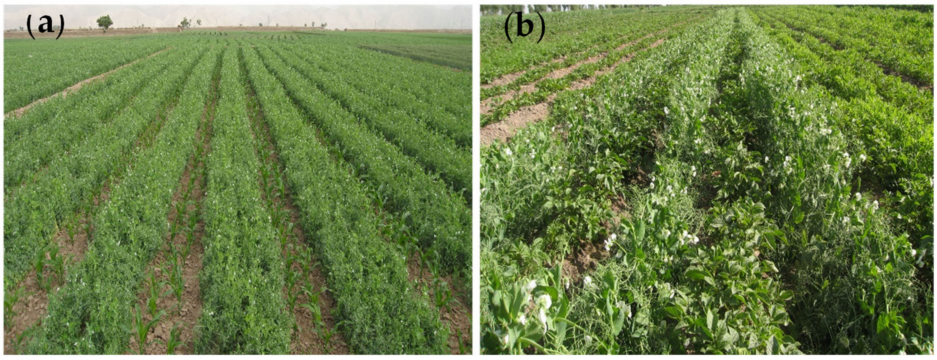


Figure 7. Intercropping patterns of Longwan No. 6 in Northern China; (**a**): maize-pea intercropping pattern; (**b**): potato-pea intercropping pattern.

5. Conclusions

Longwan No. 6 is resistant to powdery mildew and as such has contributed to solve the prominent problems of pea powdery mildew in China. Meanwhile, Longwan No. 6 is resistant to lodging and has contributed to develop pea-based intercropping systems. Thus, adopting the Longwan No. 6 pea cultivar will contribute to improvements in pea production in arid irrigation and rain-fed areas and other similar ecological conditions.

Author Contributions: Conceptualization, X.Y. and Z.Z.; methodology, X.Y.; formal analysis, X.Y. and Z.G.; investigation, X.Y., C.W. and Z.G.; data curation, X.Y. and Z.Z.; writing—original draft preparation, X.Y. and Z.G.; writing—review and editing, X.Y., Z.Z. and Z.G.; supervision, Z.G., G.M., and L.Z.; project administration, X.Y.; funding acquisition, X.Y. and G.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the China Agriculture Research System of MOF and MARA—Food Legumes (CARS-08).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Santalla, M.; Amurrio, J.M.; De Ron, A.M. Food and feed potential breeding value of green, dry and vegetable pea germplasm. *Can. J. Plant Sci.* **2001**, *81*, 601–610.
2. Petr, S.; Gregoire, A.; Judith, B.; Clarice, J.C.; Noel, T.H.E.; Andrew, J.F. Pea (*Pisum sativum* L.) in the Genomic Era. *Agronomy* **2012**, *2*, 74–115.
3. Graham, P.H.; Vance, C.P. Legumes: Importance and constraints to greater use. *Plant Physiol.* **2003**, *131*, 872–877. [CrossRef]
4. Ondrej, M.; Dostalova, R.; Hybl, M.; Odstrcilova, R.; Tyller, R.; Trojan, R. Utilization of *afila* types of pea (*Pisum sativum* L.) resistant to powdery mildew (*Erysiphe pisi* DC.) in breeding programs. *Plant Soil Environ.* **2003**, *49*, 481–485.
5. Long, J.C.; Zhang, J.J.; Gong, W.Z.; Chen, H.; Wang, P.; Zong, X.X. Field collection and genetic diversity analysis of pea (*Pisum sativum* L.) germplasm resource in Chongqing. *J. Plant Genet. Resour.* **2019**, *1*, 137–145. (In Chinese)
6. Chen, H.L.; Tian, J.; Zhu, Z.D.; Zhang, Y.W.; Chen, Q.M.; Zhou, S.M. Current status and future prospective of food legumes production and seed industry in China. *Sci. Agric. Sin.* **2021**, *54*, 493–503. (In Chinese)
7. Zong, X.X.; Guan, J.P.; Wang, S.M.; Liu, Q.C. Genetic diversity among Chinese pea (*Pisum sativum* L.) landraces revealed by SSR markers. *Acta Agron. Sin.* **2008**, *34*, 1330–1338. (In Chinese)
8. Zong, X.X.; Redden, R.J.; Liu, Q.C.; Wang, S.M.; Guan, J.P.; Liu, J. Analysis of a diverse global Pisum sp. collection and comparison to a Chinese local P. sativum collection with microsatellite markers. *Theor. Appl. Genet.* **2009**, *118*, 193–204. [CrossRef]
9. Radisa, D.; Pedja, M.; Vladan, P.; Predrag, J. Influence of the *afila* gene on grain yield in pea (*Pisum sativum* L.). *Afr. J. Agr. Res.* **2013**, *8*, 1513–1519.
10. Li, Y.; Li, Y.H.; Yang, Q.W.; Zhang, J.P.; Zhang, J.M.; Qiu, L.J. Genomics-based crop germplasm research: Advances and perspectives. *Sci. Agric. Sin.* **2015**, *48*, 3333–3353. (In Chinese)
11. Ghafoor, A.; McPhee, K. Marker assisted selection (MAS) for developing powdery mildew resistant pea cultivars. *Euphytica* **2012**, *186*, 593–607. [CrossRef]
12. Fondevilla, S.; Rubiales, D. Powdery mildew control in pea. A review. *Agron. Sustain. Dev.* **2012**, *32*, 401–409. [CrossRef]
13. Cernay, C.; Ben-Ari, T.; Pelzer, E.; Meynard, J.; Makowski, D. Estimating variability in grain legume yields across Europe and the Americas. *Sci. Rep.* **2015**, *5*, 11171. [CrossRef] [PubMed]
14. Bishop, J.; Potts, S.G.; Jones, H.E. Susceptibility of faba bean (*Vicia faba* L.) to heat stress during floral development and anthesis. *J. Agron. Crop Sci.* **2016**, *202*, 508–517. [CrossRef]
15. Tayeh, N.; Aubert, G.; Pilet-Nayel, M.; Lejeune-Hénaut, I.; Warkentin, T.D.; Burstin, J. Genomic tools in pea breeding programs: Status and perspectives. *Front. Plant Sci.* **2015**, *6*, 1037. [CrossRef]
16. Vladimir, A.; Oksana, Y.; Alexey, Y.; Tikhonovich, I.A. Breeding to improve symbiotic effectiveness of legumes. In *Plant Breeding from Laboratories to Fields*; InTech: Rijeka, Croatia, 2013; pp. 167–207.
17. Zhukov, V.A.; Zhernakov, A.I.; Sulima, A.S.; Kulaeva, O.A.; Kliukova, M.S.; Afonin, A.M. Association study of symbiotic genes in pea (*Pisum sativum* L.) cultivars grown in symbiotic conditions. *Agronomy* **2021**, *11*, 2368. [CrossRef]
18. Pratap, A.; Das, A.; Kumar, S.; Gupta, S. Current perspectives on introgression breeding in food legumes. *Front. Plant Sci.* **2021**, *11*, 2118. [CrossRef]

19. Bohra, A.; Pandey, M.K.; Jha, U.C.; Singh, B.; Singh, I.P.; Datta, D. Genomics-assisted breeding in four major pulse crops of developing countries: Present status and prospects. *Theor. Appl. Genet.* **2014**, *127*, 1263–1291. [CrossRef]
20. Nemeskéri, E.; Molnár, K.; Vígh, R.; Nagy, J.; Dobos, A. Relationships between stomatal behaviour, spectral traits and water use and productivity of green peas (*Pisum sativum* L.) in dry seasons. *Acta Physiol. Plant.* **2015**, *37*, 34. [CrossRef]
21. Szablińska-Piernik, J.; Lahuta, L.B. Metabolite profiling of semi-leafless pea (*Pisum sativum* L.) under progressive soil drought and subsequent re-watering. *J. Plant Physiol.* **2021**, *256*, 153314. [CrossRef]
22. Duan, C.X.; Zhu, Z.D.; Su, S.L.; Wang, X.M. Advances in study on food legumes resistance breeding in China. *Sci. Agric. Sin.* **2013**, *46*, 4633–4645. (In Chinese)
23. Fu, J.F.; Wang, F.B.; Dong, L.F. Germplasm research and breeding utilization of semi-leafless Pea. *Crops* **2006**, *6*, 29–31. (In Chinese)
24. Mikic, A.; Mihailovic, V.; Cupina, B.; Kosev, V.; Warkentin, T.; Mcphee, K. Genetic background and agronomic value of leaf types in pea (*Pisum sativum* L.). *Field Veg. Crop Res.* **2011**, *48*, 275–284. [CrossRef]
25. Wang, Z.Y.; Fu, H.N.; Sun, S.L.; Duan, C.X.; Wu, X.F.; Yang, X.M.; Zhu, Z.D. Identification of powdery mildew resistance gene in pea line X9002. *Acta Agron. Sin.* **2015**, *41*, 515–523. (In Chinese) [CrossRef]
26. Xiang, N.; Duan, C.X.; Xiao, Y.N.; Wang, X.M.; Zhu, Z.D. Identification of the pathogen causing *Fusarium* root rot of pea and diversity of pathogenicity genes. *Sci. Agric. Sin.* **2012**, *45*, 2838–2847. (In Chinese)
27. Viola, D.; Pooran, M.; Gaur, M. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. *Field Crop Res.* **2013**, *142*, 9–19.
28. Coyne, C.J.; Kumar, S.; Wettberg, E.J.B.V.; Marques, E.; Jens, D.B.; Robert, J.R.; Noel, E.T.H.; Jan, B.; Lenka, Z.; Smkal, P. Potential and limits of exploitation of crop wild relatives for pea, lentil, and chickpea improvement. *Legume Sci.* **2020**, *2*, e36. [CrossRef]
29. Kielpinski, M.; Blixt, S. The evaluation of the *afila* character with regard to its utility in new cultivars of dry pea. *Agric. Hort. Genet.* **1982**, *40*, 51–74.