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Recent Progress in Perennial Buckwheat Development

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Abstract: Grains in the genus *Fagopyrum* have benefits to human health and are an excellent gluten-free raw material. Of all cereal foods, this genus has the highest total content of amino-acid nutrients necessary for humans; nutrients that are resistant to digestion (protein and starch) resulting in their sustained release; higher dietary fiber content than key cereals, and is rich in a special healthy ingredient (flavonoids). *Fagopyrum* includes 24 species of which five are perennial. Among them, golden buckwheat (*F.cymosum* complex) is the most important perennial buckwheat, which is not only used in Chinese medicine, but also has great potential in healthy food crop. In order to provide some clues for perennial crop studies and their industry development, this paper presents the state of perennial buckwheat research in terms of taxonomy; natural chemical products and pharmacological and health functions; genetics and evolution; breeding; and product development and utilization. The great advances such as successful interspecific crossing and its subsequent new perennial buckwheat varieties will speed up the development of the perennial buckwheat industry.

Keywords: golden buckwheat; taxonomy; genetics and breeding; natural chemical products; health functions; product development and utilization

1. Introduction

Grains in the genus *Fagopyrum* are an excellent gluten-free raw material and contain a range of nutrients including bioactive carbohydrates, essential amino-acid, proteins, phytosterols, vitamins, carotenoids, and minerals. Buckwheat, compared to other cereals, has both the highest content and distribution of essential amino-acid for humans [1–3], resulting in balanced nutrition without excesses or deficiencies. Furthermore, buckwheat has a higher content of albumin protein and starches resistant to digestion, resulting in the sustained release of nutrients, which is very important for people with diabetes and other diseases. Most importantly, buckwheat has the highest content of rutin with multiple phenolic hydroxyl groups in cereals [4], which can provide protection from diseases such as cardiovascular disease and cancer. In a traditional agricultural production model, the establishment of annual crops has both economic and agronomic implications such as high seed and nutrient inputs, ploughing, and may involve a number of sowings each year. Perennial crops have an important property, that is, "plant once and harvest always", indicating a lower seeding cost and workload. Agriculture based on perennial crops may provide a model with high output and with lower inputs [5].

There are many perennial crop examples in vegetable and fruit crops, but few in grain and oilseed crops. There are some perennial species in the genus *Fagopyrum*, which have been studied for perennial food crop use for the last decade [1,5–7]. This paper will present the current state of perennial buckwheat development in China and may provide some clues for studies on other perennial food crops.

2. Taxonomy

Gross (1913) first classified the species of the Polygonaceae native to Asia including buckwheat [8]. Steward (1930) later classified ten buckwheat species in the Polygonaceae native to Asia [1]. Among them, *F.suffruticosum* Schm. is native to Sakhalin and the rest are all native to southwest China. Miyabe and Miyake (1915) [1] suggested that *F.suffruticosum* is the same species as *F.tataricum* in their book (Flora of Sakhalin). Ohnishi's research group collected cultivated and wild buckwheat resources native to China and the Himalaya region beginning in 1988 [9,10] and suggested one big-achene species (*F.homotropicum* Ohnishi = *F.esculentum* var. *homotropicum*) and five new small-achene species (*F.callianthum* Ohnishi, *F.pleioramosum* Ohnishi, *F.capillatum* Ohnishi, *F.rubifolium* Ohsako et Ohnishi, *F.macrocarpum* Ohsako et Ohnishi). Chen (1999) suggested three new big-achene species, tetraploid annual *F.zuogongense* Q.F. Chen, diploid perennial *F.megaspartanium* Q.F. Chen and *F.pilus* Q.F. Chen [6,7]. Krotov (1973) [11] made a new annual species (*F.giganteum*) by crossing the tartary buckwheat and *F.cymosum* complex. Due to the similarity in morphology, the three large-achene perennial buckwheat species are normally called the *F.cymosum* complex. Liu et al. (2008) [12,13] reported two new species (*F.crispatifolium* Liu, *F.densiovillosum* Liu) in the small-achene group. Chen (2016) [14] made a new perennial species (*F.tatari-cymosum* Q.F. Chen) by crossing annual autotetraploid tartary buckwheat and perennial tetraploid *F.cymosum*.

So far, there are about 24 buckwheat species (Table 1), including two groupings: the big-achene group (namely *F.cymosum* group) consisting of eight; and the small-achene group (namely *F.urophyllum* group) consisting of sixteen species. The species in the big-achene group have much longer seeds than their persistent perianths, and bigger seeds than those in the small-achene group. Among all buckwheat species, only common buckwheat (*F.esculentum*) and tartary buckwheat (*F.tataricum*) are cultivated for grain food production. Common buckwheat is distributed in almost all grain crop countries including Asia, Europe, America, and Austria and tartary buckwheat is largely distributed only in Asia. Many aspects of the natural species in the big-achene group have been studied and proved to be biological species with reproduction isolation by means of interspecific hybridization [1,6,7]. There have been few studies on the species in the small-achene group as they have less agronomic importance.

In the big-achene group, there are three perennial species (diploid *F.megaspartanium*, diploid *F.pilus*, and allotetraploid *F.cymosum*) and a man-made perennial allotetraploid *F.tatari-cymosum* (perennial tartary buckwheat). In the small-achene group, there are two perennial species (*F.urophyllum* and *F.statice*).

Historically, *F.cymosum* was a mixture of diploid *F.megaspartanium*, diploid *F.pilus*, and tetraploid *F.cymosum* until Chen (1999) [6,7] subdivided them and called the over-grouping the *F.cymosum* complex. The *F.cymosum* complex has perennial rhizomes which are commonly known as golden buckwheat.

Due to the agronomic importance of the big-achene group, Li et al. (2013) [15] established a phylogeny (Figure 1) among the species in the group based on morphology, cytology, reproduction, isozymes, seed protein subunits, and DNA markers.

Table 1. The classification and key properties of the genus *Fagopyrum* (Chen, 2012) [1].

Section	Species	Key Distribution	Annual/Perennial	Ploidy	Genome	Properties
Big-achene group	1. Common buckwheat, *F.esculentum* Moench	Worldwide	Annual	2x = 16, 4x = 32	2x = 16, EE 4x = 32, EEEE	Big flower and achene, cross-pollination
	2. Tartary buckwheat, *F.tataricum* (Linnaeus) Gaertner	Southwest China	Annual	2x = 16, 4x = 32	2x = 16, TT; 4x = 32, TTTT	Small green flower and bigger achene, self-pollination
	3. *F.megaspartanium* Chen	South China	Perennial	2x = 16	2x = 16, MM	*F.cymosum* complex. Big flower and achene, cross-pollination, bulbous caudex
	4. *F.pilus* Chen	Tibet, China	Perennial	2x = 16,	2x = 16, PP	*F.cymosum* complex. Bigger flower and achene, cross-pollination, bulbous caudex
	5. *F.cymosum* (Trev.) Meisner	Southwest China	Perennial	4x = 32	4x = 32, MMXX	*F.cymosum* complex. Bigger flower and achene, cross-pollination, with subsurface transverse stem
	6. *F.zengongense* QF Chen	Tibet, China	Annual	4x = 32	4x = 32, EEE'E'	Bigger flower and achene, self or cross-pollination
	7. *F.giganteum* Krotov	Man-made	Annual	4x = 32	4x = 32, TTXX	Bigger flower and big achene, cross or self-pollination
	8. *F.tatari-cymosum* Chen	Man-made	Perennial	4x = 32	4x = 32, TTXX	Bigger flower and big achene, self-pollination
Small-achene group	1. *F.gracilipes* (Hemsley) Dammer ex Diels	Southwest China	Annual	4x = 32	/	small flower and achene, self-pollination
	2. *F.leptopodum* (Diels) Hedberg	Southwest China	Annual	2x = 16	/	small flower and achene, cross or self-pollination
	3. *F.gilesii* (Hemsley) Hedberg	Southwest China	Annual	2x = 16	/	small flower and achene, cross or self-pollination
	4. *F.lineare* (Samuelsson) Haraldson	Yunnan, China	Annual	2x = 16	/	small flower and achene, cross or self-pollination
	5. *F.urophyllum* (Bureau et Franch) Gross	Southwest China	Perennial	2x = 16	/	small flower and achene, cross pollination, perennial sub-shrubs
	6. *F.statice* (Lev.) Gross	Southwest China	Perennial	2x = 16	/	small flower and achene, cross pollination, perennial herbs
	7. *F.caudatum* (Samuelsson) Li	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	8. *F.pleioramosum* Ohnishi	Southwest China	Annual	2x = 16	/	small flower and achene, cross or self-pollination
	9. *F.capillatum* Ohnishi	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	10. *F.calliansum* Ohnishi	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	11. *F.macrocarpum* Ohsako & Ohnishi	Southwest China	Annual	2x = 16	/	small flower and achene, cross or self-pollination
	12. *F.gracilipedoides* Ohsako& Ohnishi	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	13. *F.jinshaense* Ohsako& Ohnishi	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	14. *F.rubifolium* Ohsako& Ohnishi	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	15. *F.crispatifolium* Liu	Southwest China	Annual	/	/	small flower and achene, cross or self-pollination
	16. *F.densiovillosum*Liu	Southwest China	Annual	16	/	small flower and achene, cross or self-pollination

Note: X is an unknown number.

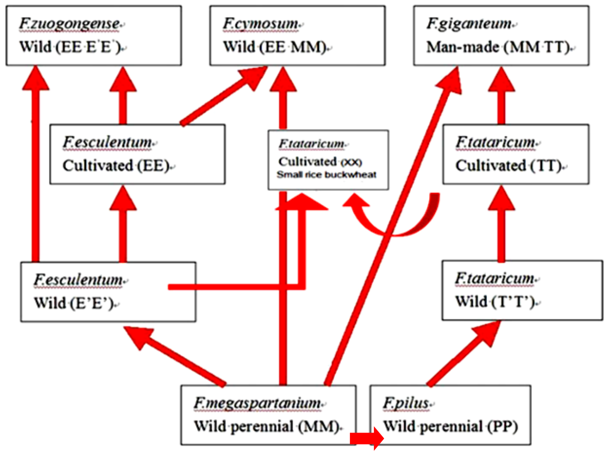

Figure 1. A diagram of possible relationships among seven buckwheat species in the big-achene group (Li et al. [15]).

3. Genetics and Evolution

Some early reports on buckwheat chromosome number [2,16,17] identified diploid *F. esculentum* (2n = 2x = 16), diploid *F. tataricum* (2n = 2x = 16) and tetraploid *F. cymosum* (2n = 4x = 32).

The phylogeny of the genus *Fagopyrum* including perennial buckwheat and the origins of cultivated buckwheat species have been studied using morphology [6–8], cytology [6,7,18,19], isozymes [6,7,20–24], seed protein content and subunit composition [25,26], molecular genetic markers such as AFLP/RAPD [27,28], and interspecific reproduction [6,7]. These works have established the *F.cymosum* complex and promoted the hypothesis that diploid perennial *F.megaspartanium* and diploid perennial *F.pilus* maybe the ancestral species of common buckwheat (*F. esculentum*) and tartary buckwheat (*F.tataricum*), respectively. At present, the genomes (Table 1) of most of buckwheat species are known or hypothesized [6,7,18,19,29].

There are some reports regarding golden buckwheat molecular genetics. Zhang et al. [30] studied the genetic diversity of 92 individuals from eight golden buckwheat populations using ISSR marker, and found high genetic diversity with the majority of the genetic variation occurring within the populations. Wu et al. [31] showed the sequence variation of the intergenic transcribed spacer region between the 16SrRNA and 23S rRNA genes (ITS).

Since the leaves of *F. cymosum* have high contents of flavonoid and high antioxidant activity than those of cultivated buckwheat [4], it is significant to study their genes. Li et al. [32,33] identified some genes from the *F.cymosum* complex using transcriptome sequencing, including Ocopherol cyclase (TC) and Flavanone 3′5′-hydroxylase. Meng et al. [34] obtained the chalcone synthase gene (1650bp, 395 amino acids) from the *F.cymosum* complex by homology cloning, genome-walking and RT-PCR. Using similar technology, Bu et al. [35] and Li et al. [36] cloned the anthocyanin synthase gene and phenylalanine ammonialyase gene FdPAL, respectively, in the *F.cymosum* complex. Liang et al. [37] studied the MAPK gene sequence and its variation among buckwheat species.

Li et al. [15] established the fluorescent chromosome in situ PCR technology for buckwheat and located 16S rDNA, 4.5S rDNA and psbAcpDNA genetic markers which were found with different abundances and physical distributions in the nuclear genomes of the seven buckwheat species including golden buckwheat.

With the development of transcriptomics and genomics, related technologies are entering the buckwheat field. Li et al. (2015) [38] used transcriptomics data of young tartary buckwheat seeds to develop EST-SSR. Yasuo et al. (2016) [39] established a common buckwheat genome database (BGDB) and generated a draft assembly of the common buckwheat genome using short reads obtained by next generation sequencing (NGS). Zhang et al. [40] reported a high-quality, chromosome-scale tartary buckwheat genome sequence of 489.3 Mb that is assembled by combining whole-genome shotgun sequencing of both Illumina short reads and single-molecule real-time long reads; sequence tags of a large DNA insert fosmid library; Hi-C sequencing data; BioNanogenome maps, and annotated 33,366 high-confidence protein-coding genes based on expression evidence.

4. Natural Chemical Products and Pharmacological and Health Functions

Studies on the chemical properties of perennial buckwheat have mainly focused on golden buckwheat (*F.cymosum* complex) because it is an important Chinese medicine. To date, many monomer compounds have been identified by infrared spectrometry (IR), ultraviolet spectrometry (US), the nuclear magnetic resonance (NMR) method and mass spectrometry (MS) and spectrum analysis [41].

Polyphenols are the most important active components in golden buckwheat, which are mainly a kind of mixture of primary anthocyanine tannins [42] and some flavonoids. Liu et al. (1980) [43] isolated the dimeric procyanidin from golden buckwheat, that is, the C4–C8 dimer of 5,7,3,4-four hydroxyl flavanols. Zhang et al. (1994) [44] reported that the extract medicine "Wei Manning" from the golden buckwheat included 3,4-dihydroxybenzoic acid, gallic acid, (-)epicatechin, (-)epicatechin-3-0 gallic acid ester, procyanidin B-2, procyanidin C-1, of which procyanidin B-2 is the main ingredient with the concentration of 0.19%. Shao et al. (2005) [45,46] discovered protocatechuic acid, *trans*-*p*-hydroxycinnamic methyl ester, 3,4-dihydroxybenzamide, and protocatechuic acid methyl ester. Wang et al. (2005) [47] obtained diboside A and lapathoside A from a golden buckwheat water acetone extract. Golden buckwheat also contains luteolin [45,46], quercitrin and rutin [48]. Wu et al. (2008) [49] first discovered pratol and luteolin-7′4′-dimethylether and rhamnetin, 3,6,3′,4′-tetrahydroxy-7-methoxyflavonetc flavonoids. Golden buckwheat contains some steroids such as Hecogenin and β-sitosterol [43] and some triterpenes such as glutinone and glutinol [45,46].

Golden buckwheat also contains glycerol monopalmitate, *n*-butyl-β-D-fructopyronoside [45,46], emodin, and β-daucosterol [49]. Bai et al. (2007) [50] isolated and identified thirteen hydrocarbons and thirty hydrocarbon oxides from golden buckwheat volatile components. They mainly contained palmitic acid, (Z,Z)9,12-eighteen diolefinic acid,1,4,4a,5,6,7,8,8a-eight hydrogen-2,5,5,8a-four methyl-1-naphthalene ene methanol; camphor and naphthalene; [lar(la,α,4a,α,7.β,7α.β,7b.α)] -dehydrogenation-1,1,7-three methyl-4-methylene-1*H*-Ciprofloxacin [e] azulene-7-alcohol; *n*-pelargonic aldehyde, and linalool, etc.

As stated above, golden buckwheat (*F.cymosum* complex) is rich in natural chemical products. Many scientists have studied golden buckwheat's health promoting and curative functions with respect to human health. Modern pharmacological studies have found that golden buckwheat can inhibit cancer cells, enhance human immunity, reduce the level of blood sugar and blood lipid, and can be clinically used to cure cancer, diabetes, hyperlipidemia and aid in the treatment of rheumatism. Therefore, it has high medicinal value and health care function [51–54].

5. Breeding of Perennial Buckwheat—the *F.cymosum* Complex

Buckwheat breeding is focused on seed yield and the quality of cultivated common and tartary buckwheat. Cultivated types of buckwheat are annual. At present, the average yields of common and tartary buckwheat are about 1050kg/ha (with the highest yield of 4200kg/ha) and 1800kg/ha (with the highest yield of 4800kg/ha) respectively.

All natural perennial buckwheat are wild type; they have many negative traits including shattering, high sensitivity to light and temperature, indeterminate flower and fruit development, low fertility in spring and summer seasons, non-compact plant, low yield, strong seed dormancy and uneven germination, etc.

It is clear that perennial buckwheat is not fit for harvesting seeds, and most buckwheat has not yet been cultivated, except the *F.cymosum* complex. The traditional utility of the *F.cymosum* complex is mainly found in its perennial caudex which has medicinal applications in China. The *F.cymosum* complex in the big-achene group contains perennial buckwheat, has big seeds, higher yield potential, and much stronger adaptability and regenerative capacity than annual common and tartary buckwheat and the perennial buckwheat in the small-achene group. Consequently, Russia, Japan and China are trying to improve annual cultivated buckwheat by wide crossing with the *F.cymosum* complex.

The interspecific hybridization has proved to be very difficult [7,55–58] for producing normal hybrid seeds; the reasons for this maybe the lack of an ideal female parent with high crossability and compatibility. In order to improve the yield of buckwheat varieties, many hybridizations between buckwheat species have been attempted, but most of the interspecific crosses have not been successful in obtaining interspecific hybrid progenies as yet, with the exception of the following crosses: autotetraploid *F.esculentum* × tetraploid *F. zuogongense* (Chen [7]) and tetraploid *F. tataricum* × tetraploid *F. cymosum* [11,16,59–62]. Among them, Krotov and Dranenko's (1973) wide hybridization involved the perennial buckwheat parent of the *F.cymosum* complex and produced an annual man-made new species of buckwheat (*F.giganteum*) with white hetero-style flowers [11]. Furthermore, the new species has not been cultivated because of reduced size seeds and much more shell than common and tartary buckwheat.

Chen (1999) [6,7] started to carry out perennial buckwheat breeding, including the perennial buckwheat, by selective breeding, cross breeding and interspecific hybridization breeding.

One way to improve perennial wild buckwheat is by selective breeding. There are many mutations that have occurred in natural populations of perennial buckwheat. In order to develop many varieties with a high flavonoid content in the leaves and flower of the *F.cymosum* complex, we collected 360 accessions nationwide in China and estimated their flavonoid content in leaves and flowers including *F.megaspartanium*, *F.pilus*, and *F.cymosum*. The first perennial variety from natural perennial species is Gui Jinqiaomai No.1 developed in 2005. It is from diploid (2x = 16) perennial *F.megaspartanium* populations native to Guiyang by single selection. Because it has high flavonoid content of up to 10.2% in leaves, much higher than the average 4.5%, it was used for harvesting leaves and making leaf tea products. Seed harvest is difficult due to shattering therefore it is reproduced via cutting from branches. Adaptational difficults due to high temperature and the sensitivity to light intensity and length of day limits it range.

A second method is to double the chromosome number. A 0.2% colchicines solution was used on the stem tips of Gui Jinqiaomai No.1 (Figure 2) plants for one week. As the new branch became thick, cuttings were used to reproduce a new variety Gui Ai Jinqiaomai No.1 (Figure 3) with dwarf stems, dark green thick leaves and high flavonoid content in leaves, which can be used for leaf tea products and as a vegetables.

(**a**) (**b**)

Figure 2. Plant (**a**) and inflorescence (**b**) of Gui Jinqiaomai No.1, a perennial Golden buckwheat variety (*F.megaspartanium*).

In order to improve its seed set and shattering, a tetraploid variety "Hongxin Jinqiao" was developed in the autumn of 2007 by crossing among *F. cymosum* accessions with less shattering. "Hongxin Jinqiao" has a leaf flavonoid content of about 8% and better seed set in autumn but low seed yield due to some light shattering. We can reproduce the variety by both seed production and shoot cuttings. The variety can be used for vegetable and tea production.

(**a**) (**b**)

Figure 3. Plant (**a**) and inflorescence (**b**) of Gui Ai JinqiaomaiNo.1, a dwarf perennial Golden buckwheat variety (*F.megaspartanium*).

The above perennial buckwheat varieties all have the same key problems: (1) strong shattering resulting in a difficulty in seed harvest; (2) strong sensitivity to light and temperature leading to narrow adaptability, sterility in the spring. (3) out-breeding and low seed set leading to low seed yield and genetic instability. (4) variability in flowering and seeding giving rise to maturity differences.

Cultivated tartary varieties normally can avoid the above problems. It is clear that cultivated tartary buckwheat varieties are one of best parents for improving perennial golden buckwheat by means of wide hybridization.

In order to increase the possibility getting fertile interspecific hybrids, an autotetraploid variety Daku No.1 bred by ourselves was used as female parent and crossed to tetraploid perennial buckwheat variety Hongxin Jinqiaomai on a large scale.

In spring of 2014, we identified a hybrid plant (Figure 4) with good set seed by self-pollination, little shattering, and larger full achenes (1000 grain weight = 38g).

Populations are segregating for shattering, seed size, plant height, style type, flower colour, stem regeneration and perennial habit etc. We currently got 20 F6 lines from the hybrid with three growth seasons a year. These new lines (Figures 5–7, Chen, 2016, 2017) [5,14] are different from *F. giganteum* (Figure 8) on following traits: (1) high plant, 1.0–1.6 m; (2) woody base stem with strong regenerating ability and certain overwintering; (3) larger achenes without groove, 1000 grain weight of up to 30 g or more; (4) non-shattering, up to the yield of 2250 kg/ha or more.

Figure 4. The comparision of morphology among autotetraploid tartary buckwheat "Daku No.1", tetraploid perennial Golden buckwheat variety HongxinJinqiaomai; and their hybrid. (**a**) tetraploid tartary buckwheat plant; (**b**) hybrid plant between tartary buckwheat and golden buckwheat; (**c**) golden buckwheat plant; (**d**) tetraploid tartary buckwheat inflorescence; (**e**) hybrid plant inflorescence between tartary buckwheat and golden buckwheat; (**f**) inflorescence of golden buckwheat.

Figure 5. A perennial tartary buckwheat variety—Guiduoku003. (**A**) plant; (**B**) inflorescence; (**C**) Fruit branch; (**D**) achenes [14].

Figure 6. A perennial tartary buckwheat variety—Gui Duoku60. (**A**) plant; (**B**) inflorescence; (**C**) Fruit branch; (**D**) achenes [14].

Figure 7. Field of Gui Duoku No.003, a perennial tartary buckwheat variety.

Figure 8. A comparison of perennial *F.tatari-cymosum* and annual *F.giganteum* plants [14]. (**a**) *F.tatari-cymosum* plant; (**b**) *F.giganteum* plant.

Here, we name a new species, *F.tatari-cymosum* QF Chen nsp., which may become a new cultivated buckwheat species and form a new production model for buckwheat grain with the property of "plant once and harvest always". There are currently three perennial tartary buckwheat varieties which have already been spread for next year: Gui Duoku 003, Gui Duoku 60, and Gui Duoku 74, with the yield to be about 3000 kg/ha or more.

The above success of wide hybridization between tartary buckwheat and perennial buckwheat indicated good crossability and compatibility of tartary buckwheat with perennial golden buckwheat, which stimulates us to attempt wider hybridizations. By autumn 2014, we had additional F1 hybrids, including: *F.giganteum* × *F.cymosum* Hongxin Jingqiao, *F.giganteum* × *F.megaspartanium* (Figure 9), *F.giganteum* × rice tartary buckwheat, rice tartary buckwheat × *F.cymosum* Hongxin Jingqiao (Figure 10), *F.giganteum* × common buckwheat, and wing rice tartary buckwheat rice × *F.cymosum*.

Figure 9. F1 perennial hybrid of the cross *F.giganteum*/*F.megaspartanium* [14].

(a) (b) (c)

Figure 10. F1 annual hybrid plant of rice tartary buckwheat/*F.cymosum* and their inflorescence and shrink seeds [14]; (**a**) hybirid plant; (**b**) inflorescence; (**c**) shrink seeds.

It is interesting that all hybrids show complete sterile and perennial properties except two crosses (rice tartary buckwheat × *F.cymosum* Hongxin Jingqiao, and wing rice tartary buckwheat rice × *F.cymosum*) with annual properties and a high seed-setting percentage (but of reduced size and lacking germinating capacity). All hybrids were crossed with common buckwheat, tartary buckwheat, rice tartary buckwheat, *F.megaspartanium* accession and *F.cymosum* Hongxing Jinqiao. However, we could not obtain any fertile seeds except the backcross *F.giganteum/F.megaspartanium //F.megaspartanium* (Figure 11).

(a) (b)

Figure 11. F1 perennial hybrid plants of the cross *F.giganteum/F.megaspartanium//F.megaspartanium* [14]; (**a**) plant; (**b**) inflorescence.

We now have some progenies of the backcross, which show strong perennial properties similar to *F.megaspartanium*. The above advances will provide a strong support for the buckwheat industry.

6. Product Development and Utilization

6.1. Food Products from Perennial Buckwheat Seeds

The reports regarding buckwheat rice and flour products all concern common buckwheat and tartary buckwheat. Because of shattering and low seed yields, not all perennial buckwheat have industry applications; perennial golden buckwheat has been used for its caudex in Chinese medicine.

Chen (2016, 2017) [5,14] reported a new type of perennial tartary buckwheat—a food crop type. It is an allotetraploid, bred by wide hybridization between annual autotetraploid tartary buckwheat and perennial tetraploid *F.cymosum*. The flour can be used in a similar fashion as wheat, common buckwheat and tartary buckwheat, etc. There are not, however, any food products on the market, because perennial tartary buckwheat has not yet been produced on a large scale. However, next year, there will be many foods from perennial tartary buckwheat seeds in Guizhou, China.

6.2. Perennial Buckwheat Drink

Common and tartary buckwheat seeds or powder can be used as raw and auxiliary materials in common beverages such as milk beverage, protein beverage, and tea beverage. Due to the higher medicine value and reports on high flavonoid content [63–70], golden buckwheat leaves and caudex has been studied for use such as leaf green tea, leaf red tea, and root slices [54,71–74]. Huang and Tang (2015) [70] reported the preparation techniques on the golden buckwheat flower tea and its optimal steeping conditions (the rate of tea to water = 1:50, steeping at 90 °C for 30 min, repeated three times).

6.3. Golden Buckwheat Caudex Slices and Chewable Tablets

Golden buckwheat caudex slices are prescribed as Chinese Medicine, for fever reduction and toxin removed, removing abscess and stasis, as a cough expectorant, used in acute lung abscess, acute or chronic bronchitis, bronchial asthma and bacillary dysentery [75]. They are common products in medicinal supermarkets and used as a common tea drink.

A technique for the extraction of the medicinal component(s) from fermented golden buckwheat has allowed for the development of a chewable tablet [76]. This advancement has allowed for greater ease in used of golden buckwheat by public.

6.4. Commercial Medicines from Golden Buckwheat

Commercial medicinal products are manufactured from the underground caudex of golden buckwheat, including syrups, capsules and water aqua. The largest demand for golden buckwheat is for "Acute Bronchitis Syrup", made by Chongqing Taiji Industry Co. Ltd. (Chongqing, China), a key medicine for acute bronchitis treatment.

"Golden buckwheat capsule" is a traditional Chinese medicine made from Cheng Yun Long's secret recipe handed down from ancestors via the traditional Chinese medicine hospital of Nantong in Jiangsu. It has been used for 40 years, has unique curative effects on lung abscesses and good curative effects on bronchitis, pneumonia, bacillary dysentery, cholecystitis, and pelvic inflammatory disease, etc. Recently, it has been found to have anticancer activity and obvious clinical effects [77].

"Wei manning" capsule is a new drug in Group II of traditional Chinese medicines, made from extraction and purification of Golden buckwheat rhizome. It has significant curative effects on lung cancer (such as non-small cell lung cancer (NSCLC) at the middle and late period) and decreases the adverse reactions to radiation and chemotherapy [78–80].

Tao et al. (2008) [81] reported that the effect of "Golden buckwheat water aqua" from the Golden buckwheat caudex on the cytokines and lung function of chronic obstructive pulmonary disease was better than that of ambroxol; they also discovered the key reason for the improvement of weas and inflammation.

Buckwheat seed sprout, buckwheat leaves and young stem tips from cultivated buckwheat such as common buckwheat and tartary buckwheat are common vegetables in China. They are crisp, tender, and healthy; they contain rich nutrition and healthcare ingredients (such as flavonoids) and few farm chemicals; they are used to make dishes such as vegetable soups, hot foods, fried dish, and cold vegetable dishes in sauce. He et al. (2016) [82] reported the cultivation technique of golden buckwheat to achieve high vegetable quality and yield. The higher vegetable quality of Golden buckwheat suggests great potential for market penetration.

6.5. Forage

Vegetables used for human consumption are often used as forage. High quality vegetative golden buckwheat is an excellent forage for animal production. Golden buckwheat can produce a high quality silage [83] with crude protein content of 21.46%, amino content of 19.2%, ash of 10.41%, calcium of 1.72%, and phosphorus 0.49%, however the low sugar content of 0.6% indicates its best use model mixed with rice (by 30%) or corn (by 40%). Xu et al (2016) [84] discovered that the silage quality of gold buckwheat can be improved by adding lactobacillus and sucrose. Zhang et al (2017) [85] reported that fresh leaves of Golden buckwheat fed to Zangxiang pigs, had greater gains and quality. Golden buckwheat can also replace cabbage as forage for swine.

Ruan et al (2015) [86,87] showed that additive amount of 2% Golden buckwheat can improve the immune response of Avian influenza and duck rinderpest vaccines at both the humoral and cellular immunity level in ducks.

7. Problems and Prospect

At present, there remain some key unknown problems in the perennial buckwheat field: (1) The inheritance basis with regard to buckwheat perennial properties. (2) Shattering. (3) Low seedset in spring or summer. (4) Key factors in terms of overwintering. (5) Key medicinal compounds and their inheritance; (6) Differential flowering and seed set of branches; (7) The ecosystem properties.

Research on perennial buckwheat has focused on the breeding and quality of the plant materials. Future work will include the use of transcriptomics and genomics to aid in both the breeding of and in the identification and production of medicinal compounds in perennial buckwheat. The growth of the perennial buckwheat industry will be enhanced as these issues are addressed and overcome.

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