Promoting the conservation and use of underutilized and neglected crops. 19.

Buckwheat

Fagopyrum esculentum Moench

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Institut für Pflanzengenetik und Kulturpflanzenforschung
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Contents

Foreword

Humanity relies on a diverse range of cultivated species; at least 6000 such species are used for a variety of purposes. It is often stated that only a few staple crops produce the majority of the food supply. This might be correct but the important contribution of many minor species should not be underestimated. Agricultural research has traditionally focused on these staples, while relatively little attention-has been given to minor (or underutilized or neglected) crops, particularly by scientists in developed countries. Such crops have, therefore, generally failed to attract significant research funding. Unlike most staples, many of these neglected species are adapted to various marginal growing conditions such as those of the Andean and Himalayan highlands, arid areas, salt-affected soils, etc. Furthermore, many crops considered neglected at a global level are staples at a national or regional level (e.g. tef, fonio, Andean roots and tubers, etc.), contribute considerably to food supply in certain periods (e.g. indigenous fruit trees) or are important for a nutritionally well-balanced diet (e.g. indigenous vegetables). The limited information available on many important and frequently basic aspects of neglected and underutilized crops hinders their development and their sustainable conservation. One major factor hampering this development is that the information available on germplasm is scattered and not readily accessible,. i.e. only found in 'grey literature' or written in little-known languages. Moreover, existing knowledge on the genetic potential of neglected crops is limited. This has resulted, frequently, in uncoordinated research efforts for most neglected crops, as well as in inefficient approaches to the conservation of these genetic resources.

This series of monographs intends to draw attention to a number of species which have been neglected in a varying degree by researchers or have been underutilized economically. It is hoped that the information compiled will contribute to: (1) identifying constraints in and possible solutions to the use of the crops, (2) identifying possible untapped genetic diversity for breeding and crop improvement programmes and (3) detecting existing gaps in available conservation and use approaches. This series intends to contribute to improvement of the potential value of these crops through increased use of the available genetic diversity. In addition, it is hoped that the monographs in the series will form a valuable reference source for all those scientists involved in conservation, research, improvement and promotion of these crops.

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Introduction

Common buckwheat *(Fagopyrum esculentum* Moench) has been a crop of secondary importance in many countries and yet it has persisted through centuries of civilization and enters into the agriculture of nearly every country where cereals are cultivated. The main producers are China, Russian Federation, Ukraine and Kazakhstan. The species *F. tataricum* - or Tartary buckwheat - is also produced in many areas of the world but generally is consumed or traded locally.

The crop is not a cereal, but the seeds (strictly achenes) are usually classified among the cereal grains because of their similar usage. The grain is generally used as human food and as animal or poultry feed, with the dehulled groats being cooked as porridge and the flour used in the preparation of pancakes, biscuits, noodles, cereals, etc. The protein of buckwheat is of excellent quality and is high in the essential amino acid lysine, unlike common cereals. This, coupled with the plant's ability to do well on poorer soils, probably accounts for its widespread usage. It is also a multipurpose crop. The small leaves and shoots are used as leafy vegetables, the flowers and green leaves are used for rutin extraction for use in medicine. The crop produces honey of a very good quality.

Buckwheat is grown throughout a large area of Asia and Southeast Asia as a crop that fits the farming system on marginal and fairly unproductive land. It is used as a subsistence crop in many of the more mountainous areas where it is often grown with barley at the higher altitudes. Tartary buckwheat, because of its frost tolerance, is generally grown at the higher altitudes whereas common buckwheat is grown at the lower altitudes. In many areas the trend is for replacement of common buckwheat, which has lower yielding ability and lacks frost tolerance, with finger millet or other crops. Tartary buckwheat production in most areas appears to be remaining constant.

1 Taxonomy and names of the species

1.1 Classification of the genus

Buckwheat belongs to the family Polygonaceae. This plant group is generally referred to as the buckwheat, rhubarb or sorrel family. There has been a great deal of interest generated over the past 10 years regarding the classificationof *Fagopyrum* species. Much of this has occurred as a result of Ohnishi's work in the finding of six new species in China and his work on their classification. Ye and Guo (1992) suggested a key to the classification of 15 species that occur in the temperate areas of Euro-Asia, with approximately 10 species occurring in China. However, the key to classification of the genus *Fagopyrum* by Ohnishi (1995) is more complete and is given in Box 1.

1.2 Accepted botanical names and synonyms of the cultivated species

The accepted botanical name of the species and synonyms according to Hammer (1986) are:

Fagopyrum esculentum Moench, Methodus (1794) 290. - *Polygonum fagopyrum* L., Sp. Pl. (1753) 522; *Fagopyrum vulgare* Hill, Brit. Herb. (1756) 486, nom. illeg.; *Polygonum tataricum* Lour., Fl. cochinch. (1790) 242, non L.; *F. sagittatum* Gilib., Exerc. phyt. 2 (1792) 435, nom. illeg.; *Polygonum cereale* Salisb., Prodr. (1796) 259; *Fagopyrum sarracenicum* Dumort., Fl. Belg. Prodr. (1827) 18; *F. cereale* (Salisb.) Raf., Fl. Tellur. 3 (1836) 10; *Kunokale carneum* Raf., l.c., 12; *Phegopyrum esculentum* (Moench) Peterm., Fl. Bienitz (1841) 92; *Fagopyrum fagopyrum* Karst., Deutschl. Fl. (1883) 522; *Helxine fagopyrum* Kuntze, Revis. 2 (1891) 553.

Fagopyrum sagittatum Gilib. also has been designated a distinct species based largely on a sagittate leaf shape (Govil and Rathar 1981). Buckwheat has been divided into subspecific taxa as *F. esculentum* var. *himalianum* and *F. esculentum* var. *emarginatum* (see Fig. 1). However, they are generally regarded/treated as being conspecific with *F. esculentum.*

Fagopyrum tataricum (L.) Gaertn., Fruct. Sem. pl. 2 (1791) 182, t. 119, f.6. - *Polygonum tataricum* L., Sp. Pl. (1753) 364; *Fagopyrum subdentatum* Gilib., Exerc. phyt. 2 (1792) *436; F. dentatum* Moench, Methodus (1794) *290; F. triangulare* Meissn. in Wall., Pl. As. Rar. 3 (1832) 63, p. p. (quoad descr. fruct.); *F. rotundatum* Babingt. in Trans. Linn. Soc. 18 (1841) 117; *F. tataricum* var. *vulgare* Alef., Landw. Fl. (1866) 287; *F. tataricum* var. *rotundatum* (Babingt.) Alef., 1. c., 287; *Phegopyrum tataricum* (L.) Peterm., ET. Bienitz (1841) *92; Helxine tatarica* (L.) Kuntze, Revis. 2 (1891) 553; *Fagopyrum tataricum var. edentulum* Waisbecker in Mag. Bot. Lap. 7 (1908) 54; *F. tataricum* subsp. *tubercualtum* Krotov in Kul't. Flora SSSR 3 (1975) 32, subsp. *rotundatum* (Babingt.) Krotov, 1. c., 32, subsp. *himalaicum* Krotov, l.c., 33.

Box 1. Key for the determination of *Fagopyrum* species as described by Ohnishi (1995)

1	thick plaited cotyledons lie in the centre of the achene	*(Fagopyrum)*	**2**
2	cotyledons horizontally long, large lusterless achene is partially covered with persistent perianths		**3**
2*	cotyledons laterally long or round, small lusterless grains are completely covered with persistent perianths		**4**
3	cotyledons in endosperm are colourless, blade veins are transparent		**5**
3*	cotyledons in endosperm are yellowish, blade veins are transparent		**6**
5	heterostylous and cross-pollinating species	*F. esculentum*	
5*	homostylous, self-fertilizing species	*F. homotropicum*	
6	surface of achene is smooth	*F. cymosum*	
6*	surface of achene is rough, with a canal in the centre	*F. tataricum*	
4	five perianths are equal in size, the lower two lack a green stripe		**7**
4*	perianths consist of two smaller and three larger: the lower small perianths have greenish stripes		**8**
7	perennial with well-developed roots	*F. statice*	
7*	annual with a poor root system		**9**
8	ochrea is green and not transparent	*F. urophyllum*	
8*	ochrea is transparent with greenish stripes		**10**
9	achene are relatively large and plants are vigorous	*F.* u_e	
9*	achene are very small and plants are small and slim		**11**
10	ochrea is not pubescent, main blade vein number is 5		**12**
10*	ochrea is pubescent, main blade vein number is 7		**13**
11	blades are ovate or cordate	*F. leptopodum*	
11*	blades are linear	*F. lineare*	
12	plants are erect	*F. callianthum*	
12*	many branches are creeping on the ground	*F.* u_f	
13	ochrea is not heavily pubescent, stem is not pubescent, it has many creeping branches	*F. pleioramosum*	
13*	ochrea are heavily pubescent, stems also pubescent		**14**
14	ochrea and stems heavily pubescent, blades are cordate or sagittate, inflorescences are drooping	*F. gracilipes*	
14*	pubescence in ochrea and stems is not as heavy as *(F. grac.),* blade cordate or ovate, branches are erect	*F. capillatum*	

Munshi (1982) has described *F. kashmirianum* as a separate taxa but morphologically close to *F. tataricum;* however, it is generally treated as the same species.

All buckwheat species found to date have eight chromosomes, *n*=8, as their base complement. The species *F. cymosum* and *F. gracilipes* are also found as tetraploids with 4n=32.

1.3 Vernacular names in major languages

Buckwheat has been named by many people during the history of its development. According to Li and Yang (1992) the ancient Yi people of Yunnan province called buckwheat *er,* common buckwheat *er chi* and Tartary buckwheat *er ka.* Common wild buckwheat was called *qi chi er luo* and wild Tartary buckwheat *chi ruo er luo.* The various names given to buckwheat have been used to trace its migration through Europe and Asia and str still being used to confirm the origin of buckwheat. Today common buckwheat is called *ogal* in India, *mite phapar* in Nepal, *jare* in Bhutan, *grecicha kul'furnaja* in Russia and *tatarka gryka* or *poganka* in Poland. In French it is called *sarrasin, blé noir, renouée, bouquette;* in Italy *fagopiro, grano saraceno, sarasin, faggina* and in Germany *Buchweizen* or *Heidekorn* (Hammer 1986). It is referred to as *soba* in Japan where the same word also refers to buckwheat noodles. In Mandarin common buckwheat is called *tian qiao mai* while Tartary buckwheat is referred to as *ku qiao mai.*

Tartary buckwheat is called *phapar* in India, *tite phapar* in Nepal and *bjo* in Bhutan It is interesting to note that in both China and Nepal, common buckwheat is referred to as sweet buckwheat while Tartary buckwheat is called bitter buckwheat. This probably relates to the taste of the flour as Tartary buckwheat leaves a very bitter taste after being eaten.

2 Description of the crop

2.1 General description

The Polygonaceae family have leaves that vary in size, arrangement and shape, but the leaf stalk is always surrounded by a membranous or chaffy sheath at the base. The flowers are often grouped in clusters that are showy owing to the colour of the sepals or bracts, for there are no petals (Fig. 1). The fruit is a triangular nut, sometimes prominently winged (Fig. 1). The common buckwheat plant is a broadleaved, erect annual with a single main stem and a branching habit. The main stem is grooved, succulent and smooth except at the nodes. The plants generally grow to 0.6-1.3 m tall. The stems are hollow and therefore are subject to breakage by high winds. They are also subject to breakage due to hail as they snap off where struck. They can recover from hail damage by branching from lower leaf axils if the hail occurs when the plants are relatively immature. The plants have a short taproot and fine lateral roots producing a root system that is about 3-4% of the weight of the total plant. The plants can therefore suffer from extreme drought conditions which usually results in delayed maturity. Prior to maturity, the stems and branches vary from green to red. They become reddish brown at maturity.

Common buckwheat is an indeterminate species in photoperiodic response. The flowers of *F. esculentum* are perfect but incomplete. They have no petals, but the calyx is composed of five petal-like sepals that are usually white, pink or dark pink. The flowers are showy and densely clustered in racemes at the ends of the branches or on short pedicels that arise from the axils of the leaves. This species is dimorphic, having plants bearing one of two flower types. The pin flowers have long pistils and short stamens while the thrum flowers have short pistils and long stamens (Fig. 1c). Flowers with pistils and stamens of similar length (Esser 1953; Marshall 1969) and lines with only one floral type (Marshall 1969; Fesenko and Antonov 1973) have been reported. The pistil consists of a one-celled superior ovary and a three-part style with a knoblike stigma and is surrounded by eight stamens. Three of the stamens closely surround the pistil and open outwards, while the other five are closer to the outside and open inward. Nectar-secreting glands are at the base of the ovary. New flower forms such as the one found by Marshall (1969) have short stamens and pistils and are well adapted to self-pollination. Dahlgren (1922) and Garber and Quisenberry (1927) reported the inheritance of the flower type in common buckwheat as monogenic. A ratio of 1:1 of the flower types occurs owing to the incompatibility system. Although genetic control of the flower type, either pin or thrum, appears monogenic, the locus probably is a complex one resembling the model proposed by Ernst (1936). Marshall (1969) found eight distinct classes of style length in F_2 populations derived from crosses between inbred lines of pin flowers with differing style length. He also developed self-fertile lines that bred true for reduced style length.

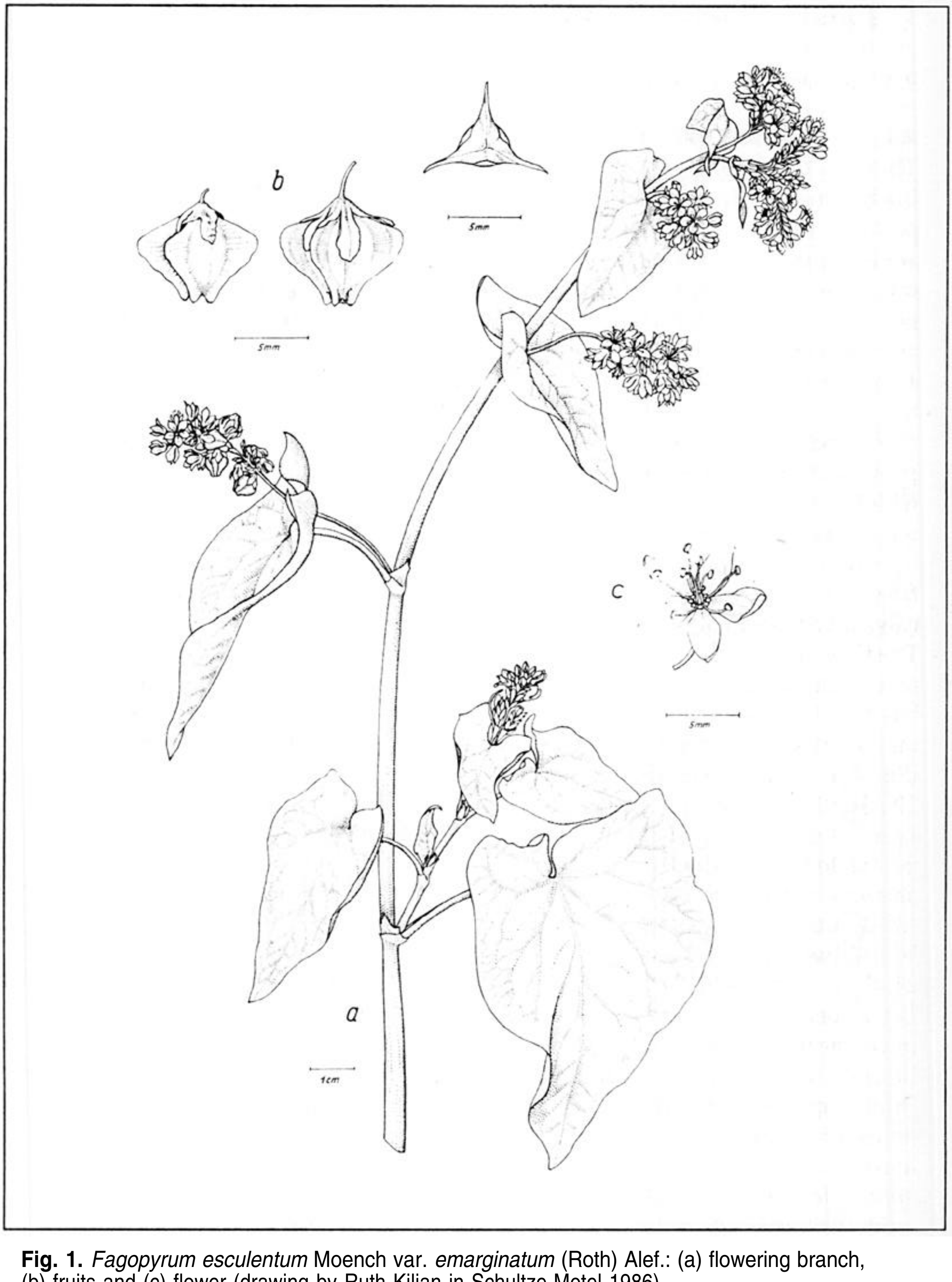

Fig. 1. *Fagopyrum esculentum* Moench var. *emarginatum* (Roth) Alef.: (a) flowering branch, (b) fruits and (c) flower (drawing by Ruth Kilian in Schultze-Motel 1986).

Two sizes of pollen are associated with the heteromorphic system. Large pollen grains approximately 0.16 mm in diameter are produced by thrum flowers while pin flowers produce smaller pollen grains that are approximately 0.10 mm in diameter.

2.2 *Fagopyrum esculentum* Moench

This is an annual herb, up to 1 m tall, branched, glabrous (Fig. 1). Leaves are petiolate, blades are ovate-triangular to triangular, 2-8 cm long, with acuminate tips, bases are cordate or approximately hastate; upper leaves are smaller, sessile. Inflorescences are terminal and auxiliary, branch in dense corymbose or paniculate cyme. Flowers are white or pink, 6 mm in diameter; pedicel is 2-3 mm long, articulate; perianths are 3 mm long; 8 nectaries are yellow, alternating with stamens; being heterostyly, capitate stigma. Achene is triquetrous, acute angle, longer than 5 mm, more than twice the length of the persistent perianths, brown or black-brown, lucid.

This species is common buckwheat and is widely cultivated over the northern and to some extent the southern hemisphere. There are many cultivars or landraces in this species. Their achene forms can vary greatly, some of them being winged on the angles.

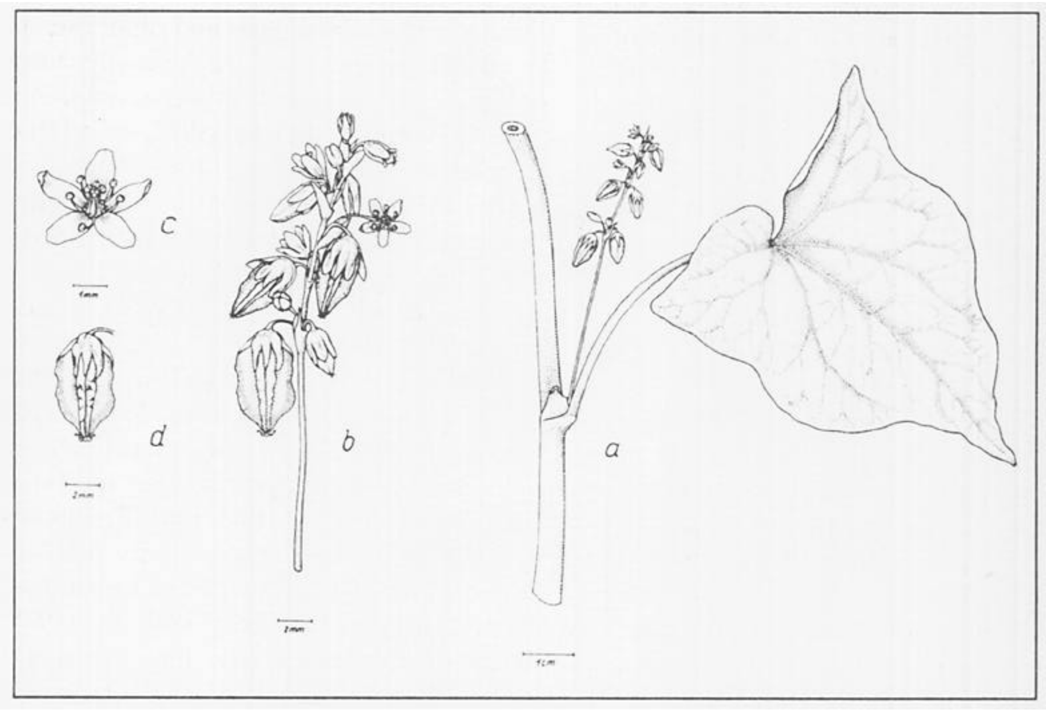

Fig. 2. *Fagopyrum tataricum* (L.) Gaertn.: (a) fruiting branch, (b) inflorescence with fruits, (c) flower and (d) fruit (drawing by Ruth Kilian in Schultze-Motel 1986).

2.3 *Fagopyrum tataricum* (L.) Gaertn.

This is an annual herb, up to 1 m tall, branched or unbranched with stem, which is striate, always having papillate on branchlet (Fig. 2). Leaves are petiolate, most blades are triangular, width equals length, 2-8 cm, bases are cordate or hastate. Inflorescences are dense spicate or corymbose. Flowers are yellow-green, 2.5 mm in diameter, pedicels are nonparticulate; perianths are 2 mm long; 8 nectaries are yellow, alternating with stamens being homostyly, stigmas are capitate. Triquetrous achene is about 5 mm long, exserting more than twice the length of the persistent perianths, with three deep grooves and the angles are rounded, except at the tip.

This species is now cultivated in the high-altitude mountainous areas of Asia and to a much lesser extent elsewhere. It has many cultivars or landraces. Its achene forms and sizes differ greatly, some of them are winged or spinous on the angles and some with hulls that split between the angles on maturity.

The plants of *F. tataricum* are usually less husky in growth than those of *F. esculentum.* They are more branched and the leaves are more arrow-shaped. The flowers are smaller, have inconspicuous greenish-white sepals and do not appear to be attractive to insects. The flowers are homomorphic, self-fertile and are cleistogamous, with pollination occurring before the flower opens.

2.4 Reproductive biology

Flowers of cross-pollinating species of buckwheat are attractive to insects because of the nectar secreted by the glands at the base of the ovary. Bees and other insects contribute to the distribution of pollen. The glands secrete nectar only in the morning and early afternoon and therefore if honey bees are introduced to increase seedset they must be forced to work the buckwheat. Cooke and Dalgleish (1969) found that the alfalfa leafcutter bee is a satisfactory pollinator of buckwheat. In studies at the University of Pennsylvania, however, seedset was not reduced when bees and other relatively large insects were excluded by caging plots of buckwheat (Hartly 1964). Microscopic examination of pistils collected in the field revealed that essentially all flowers were pollinated, even on days unfavourable for insect activity, and pollen tubes had reached the vicinity of the micropyle (Morton 1966).

In a 1964 growth chamber experiment Marshall reported that buckwheat pollen is transported by wind. Plants that were 30 cm from a wind source set 53 seeds per plant compared with 12 seeds per plant at a distance of 330 cm (Marshall 1969).

After cross-pollination between pin and thrum flowers, pollen tubes reach the base of the short styles in 5-15 minutes and the base of the long styles in 15-20 minutes (Schock-Bodmer 1930; Morris 1952; Tatebe 1956). Information on the time to fertilization is inconsistent. Stevens (1912) reported that a three-celled proembryo was present 18 hours after compatible pollination. However, Mahony (1935) reported that fertilization required 48-60 hours after such pollination. Guan and Adachi (1992) reported that under summer conditions zygotes of diploid buckwheat at 1 day after pollination had divided 1-4 times, and free endosperm nuclei were dividing around the proembryo at the micropylar pole. At 3 days after pollination,

the embryo was in the globular or heart-shaped stage and the suspensor could be observed clearly at the micropylar pole. At this stage the width of the embryo was 41-142mm. On the other hand they reported that development of embryos in autumn was slower than in summer. The zygotes at 1 day after pollination had divided only twice. After 3 days, they developed into early globular or globular stage embryos. At this stage the width of the embryos was 25-80 mm, They also-found that no differences could be found between diploid or tetraploid embryos in the autumn, although almost all ovules of the tetraploid varieties examined were more or less abnormal in summer.

Fertility of buckwheat has been reported to be quite low. Guan and Adachi (1992) reported that the rate of abnormal embryo sacs in diploid buckwheat at 1 day after pollination was 56-58% for a summer type and 73% for an autumn type buckwheat. This compared with 91-100% in the tetraploid varieties. In autumn the rate of abnormal embryo sacs at 3 days after pollination was 9-25%. The ultrastructure of the mature embryo sacs before fertilization was studied with transmission electron microscopy (Adachi et al. 1992). Mature embryo sacs consisted of a central cell and egg apparatus that included an egg cell and two synergies. Polar distribution of the egg apparatus cytoplasm and the fusion nucleus of the central cell was observed. Enervative sterility in mature embryo sacs was observed, especially under high summer temperatures. The egg cell apparatus showed various features of degeneration, i.e. the accumulation of osmiophilic deposits in the egg cells and the synergies. These degeneration phenomena created functional alterations that did not allow normal fertilization to proceed favourably.

The developmental processes of the fertilized embryo sac were compared with that of the abortive embryo sac at appropriate and high temperatures. beginning with early globular embryos, the border cell walls of the suspensor began to develop some small projections. This ultrastructure image of the suspensor supports the conclusion that the function of the suspensor is to absorb symplastic and apoplastic nutrients from the surrounding tissue. In the globular embryos, border cell walls developed toward a thin layer of endosperm and formed strong outside walls with projections. The formation of these structures might mean that the embryo border expands in absorptive areas and begins to absorb nutrients at the globular stage. In contrast to the normal embryos they found that these features were not found in the abortive embryo sacs that developed under high temperatures. These embryos developed slowly and produced large vacuoles. Around the vacuolated embryo the degenerated endosperm was present in two types: (1) the endosperm was displayed as a dark electron density and the membrane systems of the organelles were broken down, and (2) as the number of ribosomes decreased drastically, the endosperm became less dense, the organelles were dispersed or gathered around the nuclei. The endosperm is an important source of nutrients for the developing embryo and has been classically assigned the function of nourishing the embryo. The degeneration of the endosperm resulted in a less inherent function of the nutrient source and possibly directly affected the developing embryo.

3 Centre of origin and distribution of the species

As pointed out by Ohnishi (1995), Nakao (1957) first noticed that DeCandolle's (1883) hypothesis of the origin of buckwheat in Northern China or Siberia was contradictory to the distribution of wild *Fagopyrum* species enumerated by Steward (1930). At this point many people believed that the wild ancestor of common and Tartary buckwheat was the perennial species *F. cymosum* (Campbell 1976). However it has been found that the ctDNA (Kishima *et al.* 1995) and the isozyme patterns (Ohnishi 1983) differed greatly between common buckwheat and the perennial species. After the discovery of the species *F. esculentum* subsp. *ancestralis* and *F. homotropicum* by Ohnishi (1991) it became clear that both species are closely related to common buckwheat and therefore are the most probable candidates for the wild ancestor of common buckwheat. As the general trend of evolution in the plant kingdom is in the direction of a self-incompatible outcrossing species to a self-compatible self-fertilizing species, this tends to eliminate the species *F. homotropicum as* it is a homostylous, self-fertilizing species. This then indicates that the species *F. esculentum* subsp. *ancestralis* is the wild ancestor of common buckwheat. Therefore, the origin of common buckwheat should be at the location of this species which is the northwest corner of Yunnan province, as this is the distribution of *F. esculentum* subsp. *ancestralis*

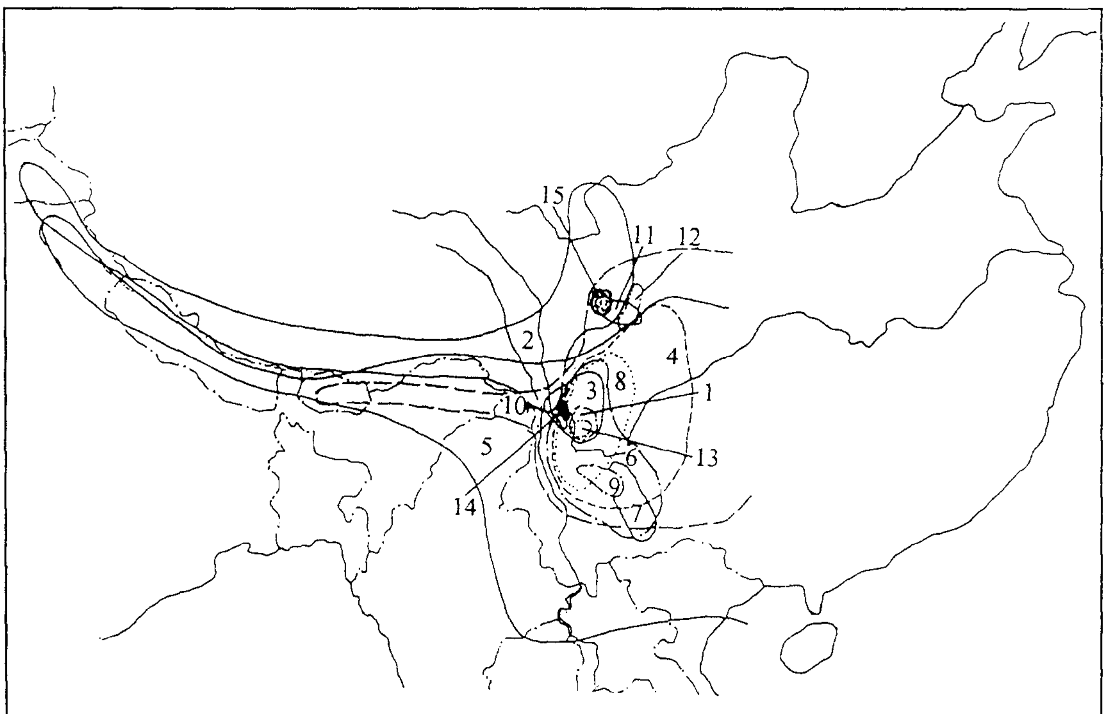

Fig. 3. Distribution of wild *Fagopyrum* species in southern China and the Himalayan region (source Ohnishi 1995).

in nature as found to this point (Ohnishi 1995). Li and Yang's (1992) study of the origin of buckwheat supports Ohnishi's hypothesis that the province of Anion is the area in which common buckwheat originated. Ohnishi (1995) has found several other species in the same area and has developed a map of the distribution of each species (Fig. 3).

According to Ohnishi (1995) there are two hot spots where *Fagopyrum* species probably have frequently differentiated. One is the northwest corner of Anion province, the other is the upper Min river valley. In both places there are many different species and all of the new species as found by Ohnishi have come from these areas. The only common wild species that occurs in both areas that has been found to date is *F. cymosum.* This could imply that speciation in *Fagopyrum* might have taken place in these two areas independently (Ohnishi 1995).

It is postulated by Ohnishi (1995) that a shift from a self-incompatible outbreeder to a self-compatible self-pollinator occurred independently in several branches of the phylogenetic tree. The finding of the self-pollinating species *F. homotropicum,* closely related to wild common buckwheat, by Ohnishi (1991) at Yonsheng town suggested that evolution from an outcrossing species to a self-pollinating species could have occurred. The subsequent finding of the species at Deqin and Chondian of Anion province and at Luding of Sichuan province (Ohnishi and Yasui, unpublished) showed that the populations were morphologically different. The plants from Yonsheng more closely resemble *F. esculentum* subsp. *ancestralis* while the plants from the other locations appear to be. more primitive. A shift from an outbreeding species to a selfing one also took place in *F. gracilipes,* where we still can find populations containing both homostylous self-pollinating plants and heterostylous outbreeding plants. In the case of *F. gracilipes,* self-fertilization probably has arisen after duplication of the chromosome number (Ohnishi 1995). It would also appear that the species *F. tataricum,* a homostylous self breeder, originated from an ancestral heterostylous outbreeder. To this point, however, no such species has been found. It is of interest to note that wild and weedy types of *F. tataricum* have been found and as the isozyme patterns vary little in Tartary buckwheat this would suggest fairly recent speciation. The chances of finding this putative species then appear to be fairly good.

The perennial species, *F. cymosum,* has rhizomes and differs from Tartary and common buckwheat in its shoots, branching and racemes. From the point of view of isozymes, *F. cymosum* is only distantly related to *F. tataricum* and *F. esculentum* (Ohnishi 1983). Therefore, it is apparent that *F. cymosum* was not the putative ancestor of common and Tartary buckwheat as was previously believed.

Most of the wild *Fagopyrum* species, including two newly discovered species, have a narrow endemic distribution in southern China. *Fagopyrum gracilipes* and *F. cymosum* are exceptions. The tetraploid *F. gracilipes,* a mainly self-fertilizing weedy species, covers almost the whole of China, except Tibet. Diploid *F. cymosum* has only been found in Southern China, however. Tetraploid *F. cymosum* extends its distribution westward to Nepal and Kashmir of India (Ohnishi 1993a).

A clear understanding of the evolution of the genus *Fagopyrum* remains unknown. However, it appears that the heterostylous, diploid, perennial species *F. cymosum, F. statis* and *F. urophyllum* may be prototypes. Polyploidy has occurred twice, in *F. cymosum* and in *F. gracilipes.* The latter species has almost lost its heterostyly (it is still maintained in some populations), has become a selfer, acquired colonizing ability and is now widely dispersed.

Self-pollination without breakdown of heterostyly appears to be occurring in the Sichuan province of China. The species *F. callianthum* is morphologically heterostylous yet is selfing. Another self-fertilizing new species - *F. pleioromosum,* found by Ohnishi - was growing in an adjacent area.

True wild Tartary buckwheat is distributed in the Sichuan province of China, Tibet, Kashmir and northern Pakistan. By isozyme analysis it can be placed into two groups. One is identical with cultivated Tartary and widely distributed. The other, found only in Sichuan, differs at three isozyme loci from cultivated Tartary and is probably an older form (Ohnishi 1991). The first is a wild form with strong colonizing ability, while the second is more probably a true wild form. A weedy form of Tartary buckwheat with the morphology similar to cultivated Tartary buckwheat but having characteristics of wild species including shattering ability and strong dormancy was found in northern Pakistan (Ohnishi 1994). The weedy form may be a hybrid between wild Tartary buckwheat and the cultivated form.

The species *F. statice* has existed as herbarium specimens and was described by Wu *et al.* (1984) as distributed in the central part of Yunnan province in China. This species was recently found in Yunmao and Chenjiang of Yunnan province as expected (Ohnishi, unpublished). Isozyme analyses of *F. esculentum* have revealed that no great allozyme differentiation has occurred among local races in Asia and the centre of genetic diversity in Vavilov's sense is obscure (Ohnishi 1988, 1993b).

Distribution of the species

Although buckwheat is known to have been cultivated in China as early as the 2nd-1st centuries BC (Li and Yang 1992), it is not believed to be very ancient (Hunt 1910). The earliest Chinese records on buckwheat suggest that increased production occurred in China in the 5th and 6th centuries AD (Krotov 1963). Presumably it was cultivated in China for nearly a millennium before it spread to Europe via Russia. It was introduced into Europe in the middle ages, probably from Siberia reaching Germany early in the 15th century (Hughes and Hensen 1934). In Russia apparently it was not grown to any great extent until the 15th century (Krotov 1963). It is not believed that buckwheat was cultivated in Indian ancient times. It was found in India, China and most of Europe in the 17th century. From Europe, buckwheat spread to North America along with immigrants from several countries as it was often used on newly cleared land.

Ohnishi (1988) found that the cultivation of common buckwheat in the Himalayas was limited to approximately 500-2500 m in altitude. Above 2500 m, Tartary buckwheat replaces it in cropping patterns. He found a considerable uniformity of

allelic frequencies of isozyme loci and suggests that the recent cultivation of buckwheat in this area is a possible interpretation. An alternative and maybe more plausible interpretation is that the history of cultivation in this area is quite long, but that the repeated migration from adjacent populations led to a uniform frequency of allozymes. Migration could have taken place along several trade routes through this area from southern China and Tibet. Ohnishi found that the places where differentiation occurred were those where a sufficient genetic source for migration had been lacking, that is the margin of the distribution.

Buckwheat is believed to have been introduced into Japan about 3000 years ago as archeological evidence suggests (Nagatomo 1984). Buckwheat had already been cultivated extensively as a catch crop when it first appeared in records in Japan in the 8th century. Nagatomo (1984) and Murai and Ohnishi (1995) suggest that buckwheat was introduced to Japan via the Korean peninsula from Northern China. According to Tsukada *et al.* (1986), buckwheat cultivation in Japan dates back to as early as 6600 BP in the Early Jomon period (7000-5000 BP).

4 Properties of the species

The composition of buckwheat grains compared with other crops is given in Table 1. The average composition of buckwheat grains and some of its components are given in Table 2.

Table 1. Composition of buckwheat (per 100 g) compared with other food grains

Name of food grain	Food energy (cal.)	Moisture (%)	Protein (g)	Fat (g)	Total carbohy- drates (g)	Calcium (mg)	Iron (mg)	Phosphorus (mg)
Buckheat	355	11.0	12.0	7.4	72.9	114	13.2	282
Amaranth	391	9.3	15.3	7.1	63.1	490	22.4	453
Cornmeal	335	12.0	9.2	3.9	73.7	20	3.5	256
Rye grain	334	11.0	12.1	1.7	73.4	38	5.3	376
Whole wheat flour	333	12.0	13.3	2.0	71.0	41	10.5	372

Source: USDA Composition of Food Agricultural Handbook No. 8.

Table 2. Average composition (%) of buckwheat and its by-products

	Dry matter	Digest protein nutr.	Total digest	Nutr. ratio	Protein	Fat	Fibre	N-free extract	Mineral matter
Grain	90.4	8.9	64.4	6.2	11.9	2.4	10.3	63.8	2.9
Flour	87.5	7.9	86.1	9.9	8.6	1.7	0.7	75.3	1.2
Middlings	88.7	25.8	75.7	1.9	29.7	7.3	7.4	39.4	4.9
Feed	89.1	14.7	59.1	3.0	18.6	5.0	18.3	43.1	4.1
Hulls	90.0	0.1	28.0	27.0	4.3	0.9	44.4	38.3	2.1
Straw	90.1	1.2	32.3	25.9	5.2	1.3	43.0	35.1	5.5
Green fodder	36.6	2.9	21.7	6.5	4.6	0.9	8.0	19.5	3.6

Source: Morrison 1945.

Carbohydrates

Starch is the major component of the buckwheat seed. In whole grain of common buckwheat, the starch content varies from 59 to 70% of the dry matter, but the concentration can vary with the method of extraction and between cultivars. The chemical composition of the starch from buckwheat grains differs from the composition of cereal starches. The amylose content in buckwheat granules varies

from 15 to 52% and its degree of polymerization varies from 12 to 45 glucose units (Mazza 1993). Buckwheat starch granules are irregular in shape with noticeable flat areas due to compact packing in the endosperm. They vary from 4 to 11 nm in size. Buckwheat grains also contain 0.65-0.76% reducing sugars, 0.79-1.16% oligosaccharides and 0.1-0.2% non-starchy polysaccharides. Among the low-molecular weight sugars the major component is sucrose. There is a small amount of arabinose, xylose, glucose and probably the disaccharide melibiose.

Proteins

The protein content in common buckwheat varies from 7 to 21%, depending on the cultivar and environmental factors during growth. Most currently grown cultivars yield seeds with 11-15% protein on a whole seed basis. The major protein fractions are globulins which represent almost one-half of all the proteins and consist of 12 to 13 subunits with molecular weights between 17 000 and 57 000. Other known buckwheat protein fractions include albumins and prolamins. Older reports of gluten or glutelin being present in buckwheat seed have recently been discredited (Mazza 1993). The albumin fraction, with a molecular weight of 7000-8000, consists of at least 12 proteins. Prolamin has been fractionated into at least two peaks by gel filtration and into three major and several minor components by SDS-PAGE.

Buckwheat proteins are particularly rich in lysine (Tables 3 and 4). They contain less glutamic acid and proline and more arginine, aspartic acid and tryptophan than do the cereal proteins. Owing to the high lysine content, buckwheat proteins have a higher biological value than the cereal proteins, such as those of wheat, barley, rye and corn. About 56% of glutamic and aspartic acids were found in the form of amides (Marshall and Pomeranz 1982). They also found that whereas correlations among basic or neutral and acidic amino acids were positive, correlations between basic and acidic or neutral amino acids were negative. Digestibility of buckwheat protein, however, is rather low and this is probably due to the high fibre content (17.8%) in buckwheat, which may be desirable in some parts of the world. Buckwheat fibre is free of phytic acid and is partially soluble. The mineral and vitamin contents of buckwheat are given in Table 5.

Lipids

Seeds of common buckwheat contain 1.5-3.7% total lipids. The highest concentration is in the embryo at 7-14% and the lowest is in the hull at 0.4-0.9%. Groats or dehulled seeds of Mancan, Tokyo and Manor buckwheat contain 2.1-2.6% total lipids, of which 81-85% are neutral lipids, 8-11% are phospholipids and 3-55% are glycolipids. The major fatty acids of common buckwheat are palmitic, oleic, linoleic, stearic, linolenic, arachide,behenic and lignoceric. Of these, the 16 and 18-carbon acids are commonly found in all cereals. The long-chain acids - arachidic, behenic and lignoceric -which represent approximately 8% of the total acids in buckwheat, are only minor components or are not present in cereals.

Table 3. Essential amino acid composition of buckwheat compared with other cereals (as percentage of protein)

Food grain	Lysine	Methionine	Tryptophan	Leucine
Buckwheat	5.9	3.7	1.4	5.8
Amaranth	5.0	4.4	1.4	4.7
Wheat	2.6	3.5	1.2	6.3
Rice	3.8	3.0	1.0	8.2
Maize	1.9	3.2	0.6	13.0
FAO/WHO recommendation	5.5	3.5	1.0	7.0

Source: Proceedings of Second Amaranth Conference, 1979, USA.

Table 4. Protein content and amino acid composition (%) of commercially milled buckwheat

Parameter	Whole buckwheat	Buckwheat groats
Protein (N x 6.25) (%)	13.8	16.4
Lysine	6.0	5.9
Histidine	2.6	2.6
Ammonia	2.1	1.9
Arginine	9.2	10.0
Aspartic acid	11.4	11.4
Threonine	4.0	3.8
Serine	4.9	4.6
Glutamic acid	18.5	19.3
Proline	3.8	3.8
Half cystine	1.6	1.8
Glycine	6.6	6.2
Afanine	4.3	4.4
Valine	5.3	4.9
Methionine	2.3	2.8
Isoleucine	4.0	3.7
Leucine	6.7	6.2
Tyrosine	2.0	2.1
Phenylalanine	4.8	4.8
Sum of Lys. + Tyr. + Met.	12.4	12.4

Source: Marshall and Pomeranz 1982.

Table 5. Average mineral and vitamin contents of buckwheat

Mineral	Content (mg/100 g)	Vitamin	Content (mg/1000 g)
Calcium	110	Thiamine	3.3
Iron	4	Riboflavin	10.6
Magnesium	390	Pantothenic acid	11.0
Phosphorus	330	Choline	440
Potassium	450	Niacin	18.0
Copper	0.95	Pyridoxine	1.5
Manganese	3.37	Tocopherols	40.0
Zinc	0.87		

Source: Marshall and Pomeranz 1982.

Phenolic compounds

The phenolic content of common buckwheat is 0.735% in the hulls and 0.79% in the groat. That of Tartary buckwheat is 1.87% in the hull and 1.525% in the groat. The three major classes of phenolics are flavonoids, phenolic acids and condensed tannins. Flavonoids are compounds that possess the same C_{15} (C_6-C_3-C_6) basic skeleton. Three of the numerous classes of flavonoids are found in buckwheat: flavonols, anthocyanins and C-glucosyl-flavones. Rutin (quercetin-3-rutinoside), a well-known flavonol diglucoside used as a drug for treatment of vascular disorders, occurs in the leaves, stems, flowers and fruit of buckwheat. Other reported flavonols are quercitin (quercetin 3-rhamnoside) and hyperin (quercetin 3-galactoside). At least three red pigments have been found in the hypocotyls of buckwheat seedlings. One of these is cyanidin, the other two are presumed to be glycosides of cyanidin. The C-glycosylflavones present in buckwheat seedling cotyledons are vitexin, isovitexin, orientin and isoorientin. The phenolic acids of buckwheat seed are the hydro benzoic acids, synigic, *p*-hydroxy-benzoic, vanillic and *p*-coumaric acids. Soluble oligomeric condensed tannins are present in common buckwheat seeds, which, along with the phenolic acids, provide astrigency and affect colour and nutritive value of buckwheat products. The effects of phenolic compounds on the nutritive value of buckwheat products have been reported by Eggum *et al.* (1981).

Rutin

There is an increased need to identify and utilize value-added components of buckwheat. This will have the effect of increasing production and thus help increase emphasis on the production of this crop. Rutin was discovered in 1842. Since that time it has been found in at least 34 plant families and 77 plant species. The use of rutin as a medicinal agent for the treatment of vascular disorders characterized by abnormally fragile or permeable capillaries has stimulated interest in this compound.

Correction by rutin of increased capillary fragility results in a decreased incidence of vascular complications such as retinal haemorrhage, apoplexy and coronary occlusion (Naghski *et al.* 1955). Rutin has been identified in *Fagopyrum esculentum, F. tataricum* and *F. cymosum.* It occurs in concentrations of 3-6% of the dry weight, with *F. tataricum* having the highest concentrations. Although Tartary buckwheat was utilized in the 1940s for the extractionof rutin it was supplanted by other sources. There now is a trend back to natural sources and a higher concentration of rutin would make the processing of buckwheat more economically feasible. The occurrences and concentrations are not known for the other species of buckwheat that have now been identified. As some of these species are now being crossed with common buckwheat and the remainder may be utilized as sources of specific traits, this information could be of high practical value.

Kitabayashi *et al.* (1995) evaluated the varietal differences and heritability of rutin content in the seed and leaf in common buckwheat. Twenty-seven cultivars or strains were evaluated and a wide variation in the mean rutin content was found. The seed rutin content of tetraploid cultivars from Japan at 20.0-22.1 mg/100 g DW was higher than that of diploid ones at 14.5-18.9 mg/100 g DW. However, there was no significant differencebetween the ploidy level for leaf rutin content. Also, the varietal differences were significant for rutin content in the seed and the leaf. Highly significant differences in the rutin content of seed were recognized among areas Some lines from Nepal had a higher rutin content in both the seed and leaves, with the seed content being significant. The differences within areas for leaf rutin content were significant for Japanese diploid lines. The heritability of the rutin content in the seed and the leaf was estimated at 0.59 and 0.25, respectively. The results showed that the rutin content in the seed was one of the traits with a relatively high heritability among the main characters in common buckwheat, and that the rutin content in the leaf was a trait comparatively affected by environmental conditions.

As Kitabayashi *et al.* (1995) stated, although a few attempts have been made so far to analyze the varietal differences in rutin content in seeds of common buckwheat, no studies have ever dealt with materials from a wide range of areas in the world. Hurusawa and Harada (1961), who determined the rutin content in seeds of strains collected from various areas of Japan did not observe any differences among the strains. Ohsawa and Tsutsumi (1993) reported that the varietal differences in rutin content in seeds were significant in 12 strains and varieties mainly from Japan. In the Kitabayashi *et al.* (1995) study it was shown that there was a wide variation in the rutin content among strains evaluated. Some of the Nepalese material was considered to be useful breeding material for high rutin content owing to the considerable variation that was found. The estimated heritability for seed rutin content found was higher than that for 1000-seed weight.

Although the rutin content in leaf tissue of common buckwheat has been studied for some time, little is known of varietal differences. McGregor and McKillican (1952) suggested that no significant differences in rutin percentage could be detected in 17 strains tested for a 3-year period. Differences between years, however, were highly

significant. It is possible that leaf rutin content could fluctuate because of environmental conditions. A study conducted by Suzuki *et al.* (1987) indicated that the content of rutin fluctuates with light intensity.

The grain, however, contains one or more dyes which, as a result of fluorescence are photodynamically active. They can produce an irritating skin disorder, on white or light-coloured areas of skin or hide, under conditions of heavy consumption of buckwheat and exposure to sunlight (De Jong 1972).

5 Uses

Buckwheat grain is grown mainly for human consumption and as animal feed, although it can also be used as a vegetable, a green manure crop, as a smother crop to crowd out weeds and as a source of buckwheat honey.

Human consumption

Common buckwheat is consumed in many different preparations in different countries. In Japan it is mainly consumed as a noodle *soba.* In Europe and North America buckwheat flour is generally mixed with wheat flour to prepare pancakes, biscuits, noodles, cereals, and is used as a meat extender. In Russia and Poland the groats and flour are used to make porridge and soup. In Sweden it is used to stuff fish. In Southeast Asia buckwheat is a staple food in many hilly areas. Here the flour is used to make unleavened bread *chapattis.* It is also mixed with water and fried to produce a crisp *pakora.* The flour also can be mixed with potatoes to make *parathas.* It is also used for fasts and for religious celebrations. Buckwheat is used to make alcoholic drinks; the liquor prepared from Tartary buckwheat being ascribed medicinal qualities. In China it has been reported that buckwheat is used for the production of vinegar.

Vegetable crop

Buckwheat is often raised as a leafy vegetable crop in many areas of the Indian subcontinent. The leafy tender shoots of the plants are harvested and dishes prepared from them. This often augments the supply of fresh vegetables that are available at this time of year. The crop is generally dual purpose as the remainder of the crop is harvested for grain and straw.

Honey crop

Common buckwheat has been used as a source of nectar for honey production in many countries. Buckwheat fills a special need for the beekeepers because honey production comes late in the season when other nectar sources are scarce. It is often possible to obtain a crop of buckwheat honey after an earlier flow has been harvested from another crop. Relatively pure buckwheat honey is dark-coloured and has a strong flavour that is relished by some people but is disliked by others. According to Morse (1969) buckwheat was once a major source of nectar for beekeepers in New York State of the USA and the supply did not meet the demand. However, in many areas buckwheat production has declined and buckwheat honey is so uncommon that it demands a premium price.

The nectar flow in buckwheat is most favourable under adequate moisture conditions. Under these conditions, a hectare could support up to 2.5 hives and produce up to 175 kg of honey in a season. It is not uncommon for a strong colony to glean 5 kg/day while foraging for buckwheat (Marshall and Pomeranz 1982). Although buckwheat is a dependable and high-yielding honey plant, it normally yields nectar only during the morning and bees are unable to complete a full day of

nectar collection. As honey bees prefer to work the same crop plant all day, they become agitated and hard to work with. They therefore prefer to work other plants and need to be forced to work the buckwheat plants for maximum honey production.

Green manure and soil conditioner

Buckwheat is useful as a green manure crop for renovation of low-productivity land because it grows well on such land and produces a green manure crop in a short time (Marshall and Pomeranz 1982). As many as 7 t/ha of dry matter have been obtained at an age of 6-8 weeks under conditions in Pennsylvania, USA. When ploughed under, the plant material decays rapidly, making nitrogen and mineral constituents available for the succeeding crop. The resulting humus improves the physical condition and moisture-holding capacity of the soil. When a crop is harvested early in a year a second crop of buckwheat often can be grown and ploughed down as green manure.

Smother crop

Buckwheat has been used as a smother crop, owing to the lack of good herbicides for broad-leaved weed control. Buckwheat is generally a very good competitor as it germinates rapidly and the dense canopy that it produces soon shades the soil. Often growers will increase the seeding rate in areas where they expect more weed competition so that the canopy is developed more quickly. This rapidly smothers out most weeds, especially broadleaved ones. If the weed growth gets above the buckwheat canopy, buckwheat becomes a poor competitor. Buckwheat has been cited as being a useful crop for the control of many weeds including quack grass, Canada thistle, sowthistle, creeping jenny, leafy spurge, Russian knapweed and perennial pepper grass (Jensen and Helgeson 1957).

Feed and cover for wildlife

Sportsmen have long known that buckwheat is useful as a food and cover crop for wildlife. Deer eat buckwheat and will begin foraging as soon as a few seeds have developed. The grain is also eaten by wild turkeys, pheasant, grouse, waterfowl and other birds. The crop is generally planted and not harvested so that the standing plants provide both food and cover for wildlife.

Ethnobotanical anecdotal information

Few ethnobotanical reports exist for common buckwheat. It is popular in Japan as a healthy food because of its rutin content. This is reported to aid in increasing the elasticity of the blood vessels and therefore prevent hardening of the arteries. Tartary buckwheat, on the other hand, is reported to be used as a medicinal plant. According to Hu *et al.* (1992) the leaf of Tartary buckwheat is a drug used in traditional Chinese medicine. They state that according to the *Chinese Materia Medicine Dictionary* the therapeutic function of the leaf and stem includes treating choking, ulcer, haemostasis and for bathing wounds, They also report that the book *Classified Materia*

Medica for Emergency indicates that the leaf can be used as food and may improve the functions of sight and hearing, and keep adverse energy down. The plant is also used to treat hypertension, which is believed to be related to the fact that in rural areas, where the incidence is lower, the leaf of Tartary buckwheat is used as a food. In Nepal the consumption of Tartary buckwheat is reported to aid in stomach disorders. In some areas *jang,* a local beer made from Tartary buckwheat, demands a higher price because of its medicinal effects.

Clinical observations carried out on 75 diabetic patients treated with Tartary buckwheat biscuits showed a decrease in the blood sugar level (Wang *et al.* 1992). Other reports from China indicate that Tartary buckwheat shows a hypoglycemic effect. Tartary buckwheat noodles can be obtained at the present time as a treatment for diabetes.

Tartary buckwheat has been reported to treat peridontitis and gum bleeding. Patients who brushed their teeth and gargled every morning and evening with Tartary buckwheat flour showed a 62% recovery (Song and Zhou 1992). This effect was believed to be due to Tartary buckwheat containing many microelements, vitamins and vitamin B, and being especially rich in quercetin and rutin. They report that these special compositions have the effects of maintaining resistance of blood capillaries, decreasing its fragility and permeability, protecting and recovering its elasticity and diminishing inflammation.

6 Genetic resources

6.1 Characterization and evaluation

Common buckwheat varies a great deal in many characteristics such as seed size and shape, pericarp colour, flower colour, plant height, leaf size and shape and many others. Flower colour is usually white in Europe, North America and Japan but is usually pink in South East Asia and Southern China. Commercialization of this crop has resulted in the exchange of many varieties between many of the areas producing the crop for export and therefore the range of diversity of most characteristics has been blurred or obliterated. This has indeed been hastened in many areas through the introduction and use of varieties from other countries in plant breeding or evaluation programmes. Many cultivars of buckwheat have been developed by many countries during the past several decades. Many of these have not been documented to date except in a few instances, such as by Joshi and Paroda (1991). These authors review some of the known new cultivars that have been developed over the past three decades. These new cultivars contain many economically important traits that have been combined during the breeding process and are therefore very important from a conservation viewpoint.

Although there are many collections of common buckwheat there appears to have been little agreement on important traits to be documented until recently. The preparation of a complete list of Buckwheat Descriptors (IPGRI 1994) was a major step forward in the coordination of passport data and descriptors on this crop. To date, in most evaluations, seed size and density, as well as plant height and lodging ability have been reported. Days to flowering and to maturity also have been recorded on many of the collections. There appears to be little agreement between the breeding programmes worldwide on the most important traits for emphasis in crop improvement, other than yielding ability Perhaps this has in part been due to the outcrossing nature of common buckwheat. Breeding programmes have had to select traits and attempt to stabilize them as in many cases they do not exist or are hard to find in collections. Increasing seed size and therefore increasing groat or flour content has been undertaken in Russia, Ukraine, Canada and Inner Mongolia. This has resulted in a steady increase in seed size of the cultivars being released and utilized in commercial production from these areas. This trend, however, is not evident in collections made in traditional buckwheat-growing areas such as Nepal, India and southern China.

It would appear that the lack of frost resistance by common buckwheat or the frost resistance found in Tartary buckwheat is having an effect on grower preferences in many marginal areas of production. Common buckwheat production is declining while Tartary buckwheat production is staying almost stationary Unfortunately to date there has been no reported finding of frost resistance, a very favourable trait, in common buckwheat. As a result, breeding programmes have been looking at means of introducing this trait from other species. Perhaps a more extensive evaluation of germplasm from very mountainous regions may find variability in this

trait. As evaluations of these kinds of traits are expensive and appear to have limited success, most breeding programmes have concentrated on yield parameters and other agronomic traits such a determinate growth habit for inclusion into new varieties. Although frost tolerance is a very favourable characteristic of Tartary buckwheat there has been little evaluation of this trait and therefore the distribution or variability of this trait is not known.

The development of lower-shattering types of buckwheat has taken place in Russia and Canada. However, there appears to be little evaluation for this trait in present collections. Lodging resistance also has been emphasized in some crop improvement programmes, most notably in Japan; however, it was more readily obtained through the development of tetraploid varieties than from variation in germplasm. The parental material for the production of the tetraploid varieties was usually taken from the highest-yielding and most adapted local landraces available.

The finding of 'rice' buckwheat, a Tartary buckwheat that has a non-adhering hull and therefore dehulls very readily, has been reported in Nepal, Bhutan and southern China. This allows the use of it as a rice replacement in the staple diet in these areas. This trait, however, although reported as desirable, has not resulted in increased production of this type of Tartary buckwheat. Perhaps this has been due to lack of crop improvement efforts that must address yield as well as the ease of dehulling capabilities.

The rutin content of Tartary buckwheat has been found to be higher in lines from Nepal than from lines collected elsewhere (Kitabayashi *et al.* 1995) which should allow selection and improvement of this characteristic. The inheritance of the rutin content in the seeds was found to be much higher than for the content found in the leaf and therefore much faster progress should be possible to increase seed content.

6.2 Range of diversity

India

Joshi and Paroda (1991) reported on 408 collections of buckwheat grown in single-row observation plots during the years 1985 and 1986 at the Regional Station of the National Bureau of Plant Genetic Resources, Phagli Shimla. Data were recorded on three representative randomly selected plants each year and the average of the six plants produced in the catalogue produced. A wide range of variation was found in the germplasm which is given in Table 6. Plant height varied from 60 to 181 cm, number of branches from 1 to 6 and number of internodes from 6 to 28. The number of leaves varied from 10 to 45. Leaf length ranged from 2.8 to 8.0 cm while leaf length ranged from 2.1 to 8.9 cm. A wide range of variation was reported for days to flower (24-78) and days to maturity (75-150), indicating a great deal of variability that could be utilized in the development of lines for different growing periods or for use in double-cropping systems. The 100-seed weight varied from 1.2 to 5.0 g while yield per plant ranged from 2.3 to 20.0 g.

The seed size variation of more than a 4-fold range from smallest to largest could again be utilized in crop improvement programmes. The seed size for many collections has shown that 100-seed weights of over 35 g occur only rarely in most areas that have been collected.

Table 6. Range, mean and coefficient of variation of buckwheat germplasm (n=408) collections evaluated at Phagli Shimla, India

Character	Range	Mean	CV
Plant height (cm)	60-181	120.28	24.64
Number of branches	1-6	3.20	34.59
Number of internodes	6-28	12.82	23.35
Number of leaves	10-45	19.59	34.73
Leaf length (cm)	2.8-8.0	5.05	22.94
Leaf width (cm)	2.1-8.9	4.56	25.29
Days to flower	24-78	43.26	36.92
Days to mature	75-125	97-38	17.21
Number of seeds per cyme	1-7	2.50	24.20
100-seed weight (g)	1.2-5.0	3.00	27.60
Yield per plant (g)	2.3-20.0	9.00	47.28

Source: Joshi and Paroda 1991.

Korea

In the Repulic of Korea, the Crop Experiment Station at Suwon collected and evaluated 100 local landraces and 180 introductions from 15 countries (Choi *et al.* 1995). These were evaluated for flowering, seedset, agronomic traits and grain yield from 1988 through 1993. They state that most landraces of southern Korea are photoperiod-sensitive and belong to fall buckwheat and therefore flower but do not set seeds when planted in the spring. They found that summer-type buckwheat generally produced higher yields when planted in the early spring than fall types planted in the summer. In 95 landraces evaluated in 1989, plant height ranged from 63 to 149 cm, branch number ranged from 5 to 9, the number of flower clusters per plant varied from 5 to 97, and grain yield per plant varied from 0.1 to 4.5 g. When 43 summer types were evaluated in 1990 the stem diameter was found to range from 2.4 to 7.0 mm, stem length varied from 27 to 85 cm, and nodes on the main stem ranged from 3 to 10 with 2 to 9 branches per main stem.

Nepal

A total of 507 buckwheat landraces, out of which 309 were common and 196 were Tartary and 2 were wild types, were evaluated at Kabre (1760 m) (Fig. 4) in 1992 (Baniya *et al.* 1995) for a total of 27 different agro-ecological traits using the IBPGR Buckwheat

Descriptors. The minimum, maximum and mean values with standard errors are presented in Table 7 for common buckwheat and Table 8 for Tartary buckwheat.

In common buckwheat, days to 50% flowering varied from 26 to 45 while days to 95% maturity varied from 67 to 98. This gave a grain-filling period that varied from 33 to 69 days. Plant height ranged from 25 to 116.4 cm, the number of primary branches ranged from 1.4 to 14, number of leaves from 2 to 18.4, number of flower clusters from 1 to 6 and number of seeds per cluster from 7 to 50.2. There was a large variation noted in 1000-grain weight: from 10.2 to 31.8 g. The ratings for disease were from no disease to 100% infection for powdery mildew and from no disease to 60% infection for downy mildew showing a wide variation that could be utilized in crop improvement programmes.

When the plants were considered for 12 morphological traits they again showed a large range of variation: 68% had erect growth habit, 80% had red stem colour, 83% had leaves remaining green at maturity, 57% had red petioles and 99% had green flower stalks. Baniya *et al.* (1995) also reported a wide variation in flower and seed colour. Approximately 42% of common buckwheat landraces had pink flowers, 36% had greenish white and 18% had red flowers. More than half of the common landraces had greyish black seed, 36% had brown seed and the rest had either grey or black seed. Over 92% of the landraces were reported to have a smooth seed coat surface, with 8% having winged seed and one entry having a rough surface similar to Tartary buckwheat.

Fig. 4. Buckwheat being evaluated at Kabre Research Station, Nepal.

Table 7. Minimum, maximum and mean values for agronomic traits of common buckwheat landraces grown at Kabre, Nepal, autumn season, 1992

No. entries	Trait	Minimum	Maximum	Mean	SE of mean
300	Days to 50% flowering	26.0	45.0	28.3	0.16
295	Days to 95% maturity	67.0	98.0	80.0	0.37
295	Grain-filling days	33.0	69.0	51.6	0.37
302	Plant height (cm)	25.0	116.4	7.0	0.96
302	No. of primary branches	1.4	14.0	4.5	0.13
302	No. of leaves on main stem	2.0	18.4	7.9	0.11
302	No. of flower clusters	1.0	6.0	4.2	0.05
300	No. of seeds/cyme	7.0	50.2	19.7	0.40
298	1000-grain weight (g)	10.2	31.8	20.7	0.22
298	Grain yield (g/plot)	1.0	423.0	83.9	2.93
301	No. of plants/plot	2.0	315.0	83.4	3.82
298	Grain yield (g/plant)	0.0	9.3	1.6	0.08
299	Appearance (1=good, 5=poor)	1.0	5.0	3.1	0.04
302	Powdery mildew (0-9)†	0.0	9.0	6.4	0.15
300	Downy mildew (0-9)†	0.0	5.0	0.4	0.05
302	Leaf blade length (cm)	1.0	8.2	5.4	0.05
302	Leaf blade width (cm)	3.0	11.0	4.6	0.05

Source: Baniya *et al.* 1995.
† The scale is 0-9, where 0=no disease, 9=100% disease.

A report on some of the many characteristics of Nepalese buckwheat also was made by Shershand and Ujihara (1995). They reported less variation in days to flowering (27-38) and in the number of branches per plant (2.2-7.0), and a much higher number of flower clusters per plant (10 to 91). Possibly this recorded variation results from different rating systems or to the large variation that is available in the Nepalese landraces, which is caused by the large variation in altitude and agro-ecological conditions under which they have developed.

For approximately 150 Tartary buckwheat landraces, Baniya *et al.* (1995) reported that days to 50% flowering was greater at 29-62 and days to maturity were 59-103 (Table 8), giving grain-filling days of 26-64. Plant height varied dramatically from 5 to 102 cm. The number of primary branches was reported as 2-17, the number of leaves on the main shoot as 3-18, the number of flower clusters per plant as 1-5 and number of seeds per cyme as 1-44. The 1000-grain weight varied similarly to that found in common buckwheat: 10-27.2 g. Powdery mildew infection varied from 0 to 100% and downy mildew from 0 to 70%. Leaf length ranged from 1.2 to 9.3 cm while width ranged from 1.0 to 11.2.

Table 8. Minimum, maximum and mean values for agronomic traits of tartary buckwheat landraces grown at Kabre, Nepal, autumn season, 1992

No. entries	Trait	Minimum	Maximum	Mean	SE of mean
149	Days to 50% flowering	29.0	62.0	41.9	0.61
146	Days to 95% maturity	59.0	103.0	88.3	0.87
146	Grain-filling days	26.0	64.0	45.8	0.94
150	Plant height (cm)	5.0	102.0	49.5	1.90
150	No. of primary branches	2.0	17.0	5.2	0.35
150	No. of leaves on main stem	3.0	18.0	8.6	0.23
150	No. of flower clusters	1.0	5.0	2.6	0.08
146	No. of seeds/cyme	1.0	44.0	15.5	0.78
133	1000-grain weight (g)	10.0	27.2	18.0	0.31
141	Grain yield (g/plot)	0.1	271.3	49.8	4.21
150	No. of plants/plot	1.0	189.0	50.8	4.22
141	Grain yield (g/plant)	0.0	40.0	1.8	0.35
148	Appearance (1=good, 5=poor)	1.0	5.0	3.7	0.10
140	Powdery mildew (0-9)†	0.0	0.9	0.9	0.13
140	Downy mildew (0-9)†	0.0	6.0	0.3	0.09
150	Leaf blade length (cm)	1.2	9.3	5.0	0.13
150	Leaf blade width (cm)	1.0	11.2	4.5	0.14

Source: Baniya *et al.* 1995.
† The scale is 0-9, where 0=no disease, 9=100% disease.

Baniya *et al.* (1995) reported that in Tartary buckwheat 67% of the landraces showed red stem at flowering, 62% had green leaf colour at maturity and 63% of the landraces evaluated had green petioles. Flower stalk colour varied with 43% being green, 38% red and the remaining 19% having pink stalks. More than 95% of the Tartary landraces evaluated had green flowers with the rest having either pink or red flowers. This could possibly be due to a mechanical mix as Tartary buckwheat has only greenish flowers and wild Tartary has white flowers. Variation also was noted in seed colour with 42% having grey, 30% brown, 18% blackish grey and 10% black. Approximately 97% of theentries had a green perianth, 59% had semi-compact cymes and 82% were reported to have intermediate leaf blade shape. The majority of the entries (71%) had a rough seed surface, 27% had winged seeds and 3 entries were reported to have a smooth seed surface. Again Shershand and Ujihara (1995) reported fewer branches per plant (3.6-8.4) and more flower clusters per plant (20-80). A frequency distribution analysis done on the characterization and evaluation of Nepalese landraces (Baniya *et al.* 1992) revealed a bimodal distribution pattern in Tartary buckwheat for most traits examined. This was thought to be due to a subset

of very early and very short landraces. In general, they state that Tartary buckwheat possessed wider variation for yield and yield-related traits than did common buckwheat.

China

The most obvious example of a coordinated approach within a country has taken place in China, where in 1988 a National Coordinated Research Group for Buckwheat Breeding, Cultivation and Utilization was formed. The buckwheat germplasm was collected, multiplied, characterized and documented and compiled into The Catalogue of China's Buckwheat Germplasm (Yang 1995). During 1986-90 over 20 agricultural institutes in China cooperated to evaluate the collections. In addition they attempted to preserve all the germplasm compiled in the catalogue in the National Gene Bank (Zhong 1992). Yang Keli (1992) reports that in China some 2000 accessions had been collected before 1958 but all were lost for some reason They have again collected 2147 accessions from 694 counties. Of these, 1508 have been registered and 1511 have been stored. He reports that they have rescued some genetic resources from extinction and at the same time obtained some rare buckwheat genetic resources.

Few studies have evaluated or reported on the geographical distribution of traits in common buckwheat. Yan *et al.* (1992) compared the geographical distribution and evaluation of red-flowered buckwheat with white-flowered types. They reported that China's common buckwheat resources of 1221 accessions were composed of 434 with red flowers and 787 with white flowers. They found that the red-flowered types were mainly distributed over regions that were over 1000 m above sea level in western China, namely the Loess Plateau, Yunnan, the Guizhou Plateau, Qinghai, the Tibet Plateau in the Tacheng area of Xinjiang and the Shennongjia area of Hubei. The white-flowered types were mainly found in regions below 1000 m in east and south China. These areas are the Northeast Plain, North China Plain, the middle and lower reaches of the Yangtze River, the hilly areas of south China and Northeastern Inner Mongolia. They also state that in the Loess Plateau the red-flowered types are earlier than the white-flowered types with less height and higher 1000 seed weight (2.2-5.4 g). This compares with the Guizhou Plateau and the Tibetan Plain where the red-flowered types are shorter than white-flowered types; however, their 1000-seed weight is 1.3-2.2 g lower than white-flowered types. They feel that the white-flowered types were cultivated at an earlier period and possibly the red-flowered types were introduced from other areas.

When common buckwheat landraces were rated for maturity, Keli (1992) found that 21.2% (204 lines) were less than 70 days, 64.6% (623 lines) were from 70 to 90 days and 14.2% (137 lines) were longer than 90 days. Tartary buckwheat landraces were mainly midseason at 70-90 days (59.6%) while late-maturing types made up 33.7%. Only 6.7% were early maturing types of less than 70 days. When he rated 1000-seed weight he found a large difference between common and Tartary buckwheat. He classified common buckwheat into four sizes: small (<25 g), mid (25.1-30 g), large

(30.1-35 g) and super large (<35 g). He reports that small-seeded types made up 36.8%, midseeded 40.1%, large-seeded 21.7% with only a few being super large or over 35 g/1000 seeds. In Tartary buckwheat the rating system used was small-seeded (<15 g), mid (15.1-20 g), large (20.1-25 g) and super large-seeded (>25 g). They comprised 12.4% small, 59.7% mid, 59.7% large and 0.4% super large-seeded. He also reports that plant height in common buckwheat varied from less than 80 cm to more than 140 cm. The range he found in plant height in Tartary buckwheat was wide, with more than 95% of the short and midrange landraces being found in Guizhou and Sichuan and more than 85% of the super high types (>140 cm) being found in Yunnan and Tibet. He also reports on variation found in branch number, nodes on the main stem, grain weight per plant and flower colour of the collection.

Zhuanhua *et al.* (1995) found that when 100 samples, composed of 48 Tartary and 52 common buckwheat populations were compared by polyacylamide gel electrophoresis there was little within-species variation found for superoxide dismutase (SAD), but a large difference for between-species variation. Esterase bands were similar in common buckwheat except that some lines from Sichuan and Quighai showed a strong E_4 band, while other populations from different regions did not. They speculate that the loss of these alleles probably occurred before and during the spread of buckwheat cultivation.

Keli and Dabiao (1992) studied 1505 accessions for amino acid, vitamin E and P contents. They found that out of 18 amino acids present, glutamic acid was the highest at over 2%, aspartic acid and arginine were intermediate at 1-2% and tryptophan was lowest at 0.12-0.13%. They found little difference between common and Tartary buckwheat on the average. They did find that the Vitamin E content in common buckwheat was 0.4-0.5 mg/100 g higher than in Tartary buckwheat, while the Vitamin P content as 0.31 mg/100 g higher in Tartary buckwheat.

Japan

Ujihara (1983) reports on the evaluation of 217 local buckwheat varieties collected from throughout Japan. Although buckwheat production was over 200 000 ha around 1800 AD it had declined to 25 000 ha by 1970. This decline puts added emphasis on the need to collect these local varieties before further erosion of this important resource takes place. Ujihara (1983) and others in Japan have shown that many Japanese cultivars have a photoperiodic response. This has been classified into three types: summer, autumn and intermediate. The summer type appears to be insensitive to short days while the autumn type is sensitive and can only be grown in the autumn season. Collections from South East Asia exhibit a short day response when grown in North America with common buckwheat exhibiting a stronger response (unpublished data).

Ujihara (1983) selected 26 landraces from different locations in Japan that were different in latitude. These were evaluated for days to flowering, plant height, number of leaves, number of branches, number of flower clusters, number of mature grains, weight of dry matter and weight of grains. He found that the number of days

to flowering became less as the latitude advanced, with a correlation coefficient of -0.69. As latitude increased, plant height, number of leaves and number of branches tended to decrease. Generally, he reports that the later the flowering occurred, the better developed were the vegetative parts. Similar tendencies were found for dry matter. The correlation of latitude to number of flower clusters was highly negative and thought to be closely related to seed yield. Seed yield per plant showed no clear dependency on latitude.

Seko (pers. comm.) reported that when 237 accessions from the Ministry of Agiculture, Forestry and Fisheries Genebank were rated for plant height it was found to vary from 55 to 215 cm. The number of branches ranged from 1 to 21 when 234 accessions were evaluated. The 1000-seed weight exhibited a very wide range (from 3 to 52 g) when 231 accessions were evaluated. The accessions also were rated for plant type, red stem colour, flower colour, winged seeds and hull colour.

Tartary buckwheat

Yoshida *et al.* (1995) reported on 234 strains of Tartary buckwheat collected from the main production areas of the world. The collection areas were divided into three main areas: (1) Chinese strains collected from areas with a wide range of latitude from 23°N to 41°N, (2) Himalayan strains collected in areas with a wide range of altitude from 1000 to 3800 m and with low latitude from 26°N to 30°N, and (3) European strains which were collected from Slovenia, France and Italy, which are countries located at high latitudes. They studied the variation in days from sowing to first flower (DFS). The mean DES was 36.3 while west Nepalese strains varied from 26 to 52 days from the Thak khola area which was the latest of all strains. The DFS of strains from Tibet, Bhutan, east Nepal and central Nepal were relatively short at 28 to 39. Those of mid-west Nepal were long at 35 to 46. In European strains there was generally early flowering, particularly in strains from Slovenia and Italy, with DFS of 26 to 27. They observed that in the Chinese strains the DFS tended to increase with decline in the latitude of their collection area. They note that in north China Tartary buckwheat is cultivated as a spring or summer crop while in south China it is cultivated as an autumn or winter crop and therefore this tendency perhaps reflected a difference to sensitivity to daylength as a result of adaptation to the cropping system. Sensitivity to daylength has been noted for Nepalese Tartary buckwheat grown under summer conditions in Canada (unpublished data).

6.3 Importance of wild relatives as a source of diversity

To the present time the only known species that have been crossed at the diploid level in an attempt to allow transfer of attributes to common buckwheat are *Fagopyrum homotropicum* and *F. tataricum.* These appear to be the most closely related to common buckwheat and therefore should be the most important as a source of further diversity for common buckwheat. The self-pollinating mechanism as well as increased frost resistance appear to be the characteristics of greatest importance at the present time. This aspect is discussed in greater detail in section 7. Breeding.

6.4 Collections

A directory of buckwheat collections has been produced by IPGRI (Zhou and Zhang 1996; Table 9). This was a major undertaking and allows for the dissemination of the information on buckwheat conservation. Although this was a major first step it has also pointed out the future needs in this area. Many collections have taken place and a great deal of total variability that is present in the two main species has been sampled by these collections. There is, however, a lack of basic passport data for many of the collections as well as uniform characterization of the accessions.

Condition of existing collections

The storage conditions on the existing germplasm collections that have been documented (Table 9) reveal the very wide range of methods presently being used. There are some major collections, such as those in India, China and in Russia, that are under medium- and long-term storage conditions. However, many of the collections are being stored at room temperature in paper bags. Some of the collections have been stored at 15°C for up to 10 years and therefore seed viability would be considered to be very low after this interval of time. A detailed evaluation of the material presently in storage would allow for the development of future storage conditions, regeneration of the material if required and a more coordinated approach to storage conditions. Unfortunately, many of the stores of germplasm are limited by the facilities that are present at or near the place of the active collections. This has been addressed recently in Canada with the active collections now being given the mandate of long-term storage as nodes of the National Plant Genetic Resources Program. This allows the researchers who are the most intimately involved with the utilization of the species to direct the evaluation and regeneration of the species as well as the collection of accessions. These nodes, however, must be supported financially or else they will become a direct drain of resources from the crop improvement aspects of the programme.

Availability of data on individual accessions

In most cases data on the availability of individual accessions are obtainable. Approximately one-half of the collections are computerized and therefore lend themselves to easy exchange. The acceptance of the descriptors as developed by IPGRI would be a very large first step, which is required to allow uniform exchange of data between collections. Unfortunately, there is a lack of passport data and data on many of the descriptors for most of the germplasm that now exists in the collections.

Gaps in existing collections

The buckwheat germplasm that has been collected, characterized and stored to date is expected to contain a large proportion of the variability that is present in the local material. However, it is obvious from thelisting of germplasm that has been obtained to date that there has been little coordination of any of the germplasm collections on

Table 9. Institutions holding germplasm collections (> 5 accessions), storage conditions, evaluation of germplasm and details of the collections being stored

Institution†	Storage conditions	Evaluation	Details of collection
Canada			
Agriculture and Agri-Food Canada	medium term	for 11 characteristics	572 accessions of *F. esculentum,* 201 *F. tataricum, 6 F. cymosum; 2 F. tataricum* subsp. *potanini; 2 F. humotropicum;* 1 of each *of F. giganteum, F. leptopodum, F. urophyllum, F. callianthum, F. pleioramosum, F. gracilepes, F. esculentum* subsp. *ancestralis, F. capillatum* and *F. lineare*
Plant Genetic Resources of Canada	long term	no information	321 accessions of *F. esculentum,* 1 *F. tataricum*
Peoples Republic of China‡			
Institute of Crop Germplasm Resources	long term	evaluated for 43 botanical, morphological, quality and other characteristics	1508 accessions of *F. esculentum* and *F. tataricum*
France	no information	no information	20 advanced cultivars and 90 genetic stocks of *F. esculentum;* 80 genetic stocks of *F. tataricum*
Germany			
Institute of Crop Science, Braunschweig	long term	no information	24 advanced cultivars of *F. esculentum* from former Czechoslovakia, Japan, Poland and former USSR; 73 landraces of *F. esculentum* from Bhutan, Canada, Germany, Japan, Mexico, Nepal, former USSR, former Yugoslavia and Zimbabawe; 8 accessions of *F. tataricum*

Institution†	Storage conditions	Evaluation	Details of collection
IPK, Gatersleben	long term	ongoing	84 accessions of *F. esculentum;* 13 *F. tataricum*
India	medium term	402 acc. were evaluated for 31 traits	316 accessions of *F. esculentum,* 60 *F. esculentum* var. *emarginatum,* 197 *F. tataricum, 25 F. tataricum* var. *himalianum;* 3 *F. giganteum;* 5 *F. cymosum*
Japan			
National Institute of Agrobiological Resources, Tsukuba	long term	for 11 characteristics	318 accessions
Resource Crop Breeding Laboratory, Ibaraki	medium term	for yield, botanical characters, downy mildew	50 accessions of *F. esculentum,* 5 *F. tataricum,* 2 *F. cymosum*
Laboratory of Genetics, Research Centre of Plant Germplasm, Kyoto	medium term	for plant height, 100-grain weight and days to flowering	15 wild *Fagopyrum* spp., approx. 120 landraces of *F. esculentum,* approx. 120 landraces of *F. tataricum,* approx. 200 mutants with various kinds of morphological characteristics
Hokkaido National Agricultural Experimental Station	medium term	for yield, botanical characters and downy mildew	50 accessions of *F. esculentum,* 5 *F. tataricum,* 2 *F. cymosum*
Nagano Chushin Agricultural Experimental Station, Nagano	medium term	for 11 characters	50 accessions *F. esculentum,* 10 *F. tataricum,* 1 *F. cymosum*
Shinshu University	medium term	no information	approx. 500 accessions including *F. esculentum, F. tataricum* and *F. cymosum*

Institution[†]	Storage conditions	Evaluation	Details of collection
Democratic Peoples Republic of Korea	medium term	for 6 characters	160 accessions of *F. esculentum,* 8 *F. tataricum*
Republic of Korea	no information	for 6 characters	245 accessions of *F. esculentum*
Latvia	no information	some material has been evaluated using a preliminary list of descriptors	70 accessions of *F. esculentum*
Nepal			
Central Plant Breeding and Biotechnology Division, Kathmandu	no information	for short duration and cold tolerance	80 accessions of *F. esculentum,* 92 *F. tataricum*
National Hill Crops Research Program, Kabre, Dolakha	short-term	for 27 agronomical and morphological characters	318 accessions of *F. esculentum,* 193 *F. tataricum*
Poland	long term	preliminary evaluation for phenological and agronomic traits	41 advanced cultivars and 18 breeding or inbred lines of *F. esculentum*
Russia			
N.I. Vavilov All-Russian Research Institute of Plant Industry	no information	Field and laboratory evaluation using the International COMECON descriptors list	2200 landraces, cultivars, and wild forms of *F. esculentum* and *F. tataricum* subsp. *multholium*
Research Institute of Pulse and Groat Crops	short-term	No information	10 cultivars and mutant forms of *F. esculentum*

Institution[†]	Storage conditions	Evaluation	Details of collection
Slovenia	medium term	no information	361 landraces of *F. esculentum,* 17 accessions of *F. tataricum*
USA			
National Seed Storage Laboratory, Fort Collins	long term	Responsibility of the station holding the active collection	131 accessions of *F. esculentum*
USDA-ARS, Plant Genetic Resources Unit, Cornell University	long term	Responsibility of the station holding the active collection	30 accessions of *F. esculentum,* 31 *F. tataricum*

Source: Frison and Serwinski 1995; Zhou and Zhang 1996.
[†] For full addresses see Appendix I.
[‡] Germplasm is conserved at nine additional institutions (see Appendix I) and duplicated at the institute of Crop Germplasm Resources.

buckwheat to the present time. The collection of the N.I. Vavilov All-Russian Research Institute of Plant Industry is the only large collection that has attempted to obtain representation from many parts of the world.

There also exists several collections that possibly contain duplication as they were collected from the same localities. These include the collections that have been made in Nepal, which are backed up in Canada, one of the few collections that do have a duplicate backup, but are possibly also duplicated with the collections stored in Japan. Collections from Nepal have been made by several researchers from Japan and several were made from similar localities with probably similar ecological conditions. This type of duplication, however, appears to exist very infrequently in present buckwheat germplasm collections.

The collection of Tartary buckwheat has lagged behind that of common buckwheat as can be seen from the listing of buckwheat collections where *F. tataricum* accessions (1006) are far less (approximately one-eighth) than *F. esculentum (7820).* This is in large part because common buckwheat is the most economically important species. However, in many parts of the world, including the mountainous areas where buckwheat originated, Tartary buckwheat is extremely important as a foodstuff for the indigenous population. If the collection of buckwheat germplasm were on a species basis then it is readily apparent that there needs to be a much larger effort in collecting this species, compared with common buckwheat, to effectively sample the existing germplasm. It must be recognized, however, that the areas in which this collection should take place are in the mountainous areas of the Himalayan where it is often difficult to obtain ready access.

The recent effort that has been made in collecting and characterization of the related species of buckwheat deserves due recognition. This has allowed a more complete understanding of the origin of the species and their distribution. It will also undoubtedly lead to further findings in this area. Although there have been a number of reports of evaluation and characterization of related species of *Fagopyrum* from China, there has not yet been any reported collecting of these species. This is urgently required if the origin and distribution of these very important species are to be determined. It also appears that the very important and useful collections that have been made up to the present are seriously lacking in long-term storage of the collections. Although there is a need to have working collections of these species, a long-term conservation programme for them should be developed.

There exists a need to collect and document varieties that have been developed in many countries as well as the locally collected and exotic germplasm that is usually reported. Although in many cases it would be expected that these cultivars actually have been collected and do exist in germplasm collections, there still exists the need to report them as an integral part of the germplasm under storage. The development of many mutant forms of buckwheat has been reported from the former USSR, especially from the Ukraine. These have not yet been reported as stored as have some of the forms found in Japan. It would appear that there is a large need to determine which of these mutants are in storage, their characterization and their availability.

There also would seem to be large areas where either inadequate collecting has taken place to sample the existing germplasm or where collecting has not yet been done. A large area of southern Europe has few, if any collections presently in storage. As an example, four collections from Italy are present in the Ljubljana germplasm storage, while apparently none exist or are known in Italy. Also, to date there are no known collections of the germplasm that exists in South Africa. This concern must be addressed at an early date so that systematic sampling of the existing germplasm that has not yet been collected can take place.

6.5 Conservation techniques and methods used

The cultivation of common buckwheat is widespread, but in many of the countries were it is produced for home use it occurs in small scale only As crop improvement programmes produce more cultivars the result will probably be more or less genetically uniform cultivars replacing many of the local types. This would be expected in areas where common buckwheat is produced as an economic crop but also have effects in neighbouring regions. This has recently been shown on Hoikkaido, Japan where the cultivar botan Soba has been replaced with Kitawasesoba over just a few years in some growing regions (Wagatsuma, pers. comm.). Even in areas of small holdings, rapid change can be expected with the introduction of improved types thus genetic erosion can be expected in these areas as well.

Fig. 5. Isolation cages used for controlled pollination of common buckwheat. These are double-screened to prevent insects transferring pollen from outside the cage.

Ex situ collections of common buckwheat are difficult to maintain because of the incompatibility system of the crop. Therefore seed increases must occur under spatial or screen isolation (Fig. 5). It is imperative that screen enclosures are double-screened to prevent the 'working' of the plants by insects from outside the cages. Large numbers of accessions in some collections put extreme pressures on facilities to accommodate seed increases as plant populations must be large enough to be a true representative sample of the collection and at the same time small enough to be contained in an enclosure.

6.6 Major constraints in conservation

Buckwheat is cultivated in many countries, but in many of these it is cultivated on a small scale or on small holdings. This is especially true of the hilly or mountainous areas of southern China, Nepal, India and Bhutan. Recent studies in Nepal indicate that many of their landraces are under threat, especially for common buckwheat, as the area of production is declining and is being replaced with other crops that are seeing more rapid improvements due to plant breeding. This appears to be also true in China. Crop improvement through plant breeding of buckwheat will probably result in a much faster replacement of the local landraces with more uniform or genetically pure varieties. This has already been documented in Europe where in Slovenia about 100 years ago light pink flowering buckwheat was predominant (Ohnishi 1993c). However, at the end of the last century, the higher-yielding white-flowered buckwheat was imported from a European country and gradually replaced the pink-flowered buckwheat. Ohnishi (1993c) reports that buckwheat from the Himalayan regions has never been introduced into Europe. However, the Himalayan buckwheat has often been influenced by buckwheat coming from China. Therefore a more detailed evaluation of the spread and distribution of buckwheat species should allow the designation of areas that should contain buckwheat having a high prevalence of certain characteristics. When this information is taken together with present-day production trends it should identify areas that are at high risk of erosion as well as areas that are at low risk and thus serve as a guide in future protection of or collecting from these areas

When the known *Fagopyrum* accessions in storage are totalled by storage type, with the storage conditions known in all but a few cases, there appears to be a total of approx. 9070 accessions in storage at the present time (Table 9; this figure excludes active collections of 1835 accessions housed at nine institutions in China, which are duplicated under long-term storage conditions, see Appendix I). Of these, 580 are in active collections under short-term storage conditions. These consist mainly of storage at room temperature in paper bags. For 677 accessions, information on storage conditions is unavailable. There are approximately 3071 accessions in refrigerated medium-term storage and 4742 accessions in long-term frozen storage. There are only two fairly large collections of buckwheat that are under long-term conditions; these are at the Institute of Crop Germplasm Resources, Beijing and at the Vavilov Institute, St. Petersburg. It would appear that there is an urgent need to

place many of the active and medium-term storage collections under conditions of long-term storage.

Possibly the major constraint that exists in the conservation of buckwheat germplasm at the present time is the fact that it is a crop of secondary interest in the agriculture of most countries where it is grown. Therefore, it has been very rare that the type of effort that has been expended on the major crops has been expended on buckwheat as well. This has become increasingly evident under conditions of reduced budgets for agricultural research in many countries. This research effort, or sometimes reduced effort, manifests itself in that the germplasm that has been collected to date is not being utilized effectively in the improvement of the crop. Little between-country cooperation has been developed for duplicate or back-up storage or in collecting efforts. These issues must be addressed and rectified so that the research efforts presently being expended on this crop will produce maximum results from the minimum resources available.

7 Breeding

7.1 Breeding objectives

The major objective in buckwheat breeding programmes worldwide has been the improvement of seed yield. Other objectives that have been stressed in various breeding programmes include:

- increased seed size (1000-seed weight)
- increased seed-shattering resistance
- early maturity
- easier dehulling ability
- determinant flowering
- increased groat percentage
- seed coat colour
- flower colour
- leaf size, both small and large
- lodging resistance.

7.2 Breeding principles

Common buckwheat is a self-incompatible species and this therefore dictates the breeding patterns most used on it. Owing to its outcrossing characteristics, all lines that are being developed must be kept in isolation, either spatial or in cages, from each other (see Figs. 4 and 5). Tartary buckwheat crop improvement programmes can be handled in the same manner as other self-pollinating crops. It is thus much easier to generate and maintain the high numbers of segregating progeny and advanced lines that are required in a plant breeding programme.

The self-incompatibility of buckwheat is of the dimorphic, sporophytic type and thus seed production is dependent on cross-pollination between 'pin' (long pistil, short stamen) and 'thrum' (short pistil, long stamens) flowers. Flower forms with reduced style length have been found and self-fertile homomorphic lines have been developed (Marshall 1969). Certain of the lines that were developed were especially adapted to self-pollination since the flowers have equal pistil and stamen heights. However, the introduction of this character into other buckwheat lines almost always results in severe inbreeding depression. This is probably due to a large number of deleterious recessive genes being carried along with the thrum gene, as this gene never occurs in the homozygous state.

Many breeders have looked to the development of self-pollinating buckwheat as a means of increasing the ease of selection in buckwheat and also as this allows for an extensive search for spontaneous recessive mutations that are normally hidden in the cross-pollinating form. Self-pollinating forms have been reported by Fesenko and Lokhatova (1981) and Marshall (1969). Fesenko also reports that a study done on Zamyatkin's homostylous long-styled buckwheat form showed it to be a facultative cross-pollinator. It was found that the degree of self-pollination under conditions of free cross-pollination of plants of the same type was 54.5 and 58.6%

under field conditions and even higher at 88% when done under greenhouse conditions. This higher seedset under greenhouse conditions may in part be due to the manual pollination that was performed. However, it was shown that the homostylous form was highly self-compatible and capable of self-fertilization not only when individually isolated but when pollen from other plants of the same or heterostylous forms predominated.

Induced mutants have been used to increase the polymorphism of buckwheat (Alekseeva 1979). The basic selection method that she used was the individual-familial type where families characterized by similar traits and properties are combined and then studied as a single strain. Individual mutants isolated during the breeding process on the basis of definite economically valuable traits and properties or complexes of such traits and properties are studied for varietal testing. She also used biologically valuable mutants in hybridization. She reports that most high-yielding mutants have been produced with the aid of irradiation. The frequency with which desirable mutants appear among forms created by chemical mutagensis is significantly lower. The varieties Aelita and Lada were produced through gamma-irradiation in doses of 30 and 40 kR. She also reports that breeding stock obtained through combined treatment of seeds with chemical mutagens and radiation was of particular value. Application of the familial-group selection technique to this stock resulted in creation of the Podolyanka variety.

It is of interest to note that valuable mutants with high contents of protein and of individual amino acids such as lysine, phenylalanine, methionine, proline, arginine and glutamic acid were found in material subjected to chemical mutagens and to combined chemical and radiation mutagenesis (Alekseeva 1979). Forms that have an increased content of rutin have also been found after mutational treatment. This allows the development of individual desirable traits that then can be introduced into high-yielding or lines with other desirable traits through backcrossing.

The improvement of the species *F. tataricum,* although secondary in many breeding programmes, is of major importance in the areas of the world that rely on this crop, these areas being mainly the mountainous regions above 2500 m in altitude that present a danger of frost damage to the crop. Although the species is being evaluated in several breeding programmes for the improvement of common buckwheat, little direct work is taking place on the improvement of this species through crop improvment programmes or by interspecific hybridization. As pointed out by Ohnishi (1995) a putative progenitor species that has a self-incompatible pollination mechanism has still not been found. This would appear to have high priority in future collections of wild buckwheat species. The finding of the closely related wild and weedy Tartary buckwheat species and types has made it so that crosses are now possible between these species and types. It is of interest to note that in any programme for the improvement of common buckwheat that involves interspecific hybridization with Tartary buckwheat, there also exists the possibility of improving Tartary buckwheat with very little extra effort. This opens up a broad new area, with its accompanying challenges, in the collaborative breeding of

buckwheat. Although Tartary buckwheat has several characteristics that are desirable, including frost tolerance and self-pollination, it contains a bitter component that must be removed from any hybrid that utilizes it as a parent. There is a need therefore to determine the bitter component and to develop a screening technique that can be used in identifying it in segregating progeny.

Buckwheat improvement in the Russian Federation has producedmany cultivars for different purposes (Fesenko, pers. comm.). He reports that buckwheat in parts of Russia and Siberia is more photoneutral and earlier maturing than in most countries of the world. They have produced ultra early maturing cultivars that can be used as forecrops for winter cereal production under the conditions of a short Russian summer. They have also produced larger-grained cultivars and cultivars with improved growth habit. These include determinate cultivars, cultivars with limited secondary branching and small-leaved cultivars. Only *F. esculentum* is grown countrywide, with photosensitive types being produced in the far east of the country.

7.3 Interspecific hybridization

Although the genus *Fagopyrum* contains at least 15 species of buckwheat, only two are utilized as food or feed and wild buckwheat *(F. cymosum),* mainly found as tetraploid, is used on a sporadic basis as a green vegetable or as cattle forage. The development of hybrids between two different species of buckwheat has now been demonstrated several times. *Fagopyrum cymosum* and *F. tataricum* hybrids as well as *F. cymosum* by *F. esculentum* hybrids have been produced at the tetraploid level. *Fagopyrum esculentum* by *F. homotropicum* hybrids have proven to be fertile at the diploid level. *Fagopyrum esculentum* by *F. tataricum* hybrids have been developed at the tetraploid level and are presently being developed at the diploid level. This will allow movement of characteristics from one species to another in the development of improved cultivars.

As common buckwheat has many characteristics that are desirable for its use as food many efforts have been made to produce interspecific hybrids by using it and the other two species as parents. Most of these results have not been successful. Conventional breeding techniques have not been successful in crossing common and Tartary buckwheat (Morris 1952; Ruszkowski 1980; Adachi *et al.* 1989). A number of studies on the development of interspecific hybrids have attempted to overcome cross-incompatibility by using embryo or ovule culture systems (Hu and Wang 1986). Successful hybridization of Tartary buckwheat with common buckwheat at the diploid level has been accomplished by Cyrus Samimy and Thomas Bjorkman of Cornell University (pers. corresp.). They used conventional breeding techniques to cross the two species and then grew the resulting ovules on media. The embryos that emerged from the ovules formed calli with buds; leaflets and were subsequently rooted using a different media. These plants grew in the greenhouse but were sterile. Hirose (pers. corresp.) also developed the same and reciprocal crosses of these two species. Takahiro Wagatsuma from the Horokanai Agricultural Research Center, Horokanai, Japan was the first known person to produce a fertile cross between these

two species. He crossed a strain of Chinese Tartary buckwheat with a self-pollinating plant obtained from growing the variety Kitawase under moisture stress conditions. This cross produced fertile F_1 and F_2 plants which produced viable seeds (Nagatsuma, pers. comm.). This cross has now been accomplished at Morden, Manitoba with F_2 embryosbeing obtained to date from F_1 plants with low self-fertility rates (unpublished data).

Many interspecific attempts have been made using *F. cymosum* as one of the parents. A successful interspecific hybrid between *F. tataricum* and *F. cymosum,* in the tetraploid state, was reported by Krotov (1975) and named *F. giganteum.* A successful cross between *F. esculentum* and *F. cymosum* was accomplished by Ujihara *et al.* (1990) and Hirose *et al.* (1993), again at the tetraploid level. This was accomplished using ovule culture; further backcrossing of the hybrids with common buckwheat has resulted in fertilized ovules which had to be rescued, with the resulting plants still being sterile. This hybrid was again produced by Suvorova *et al.* (1994) through the use of ovule rescue. Although the ploidy level was not reported, the hybrids that developed were characterized by complete sterility.

One of the main reasons for the use of *F. tataricum* as a parent in interspecific crosses has been the desire to transfer its desirable traits of higher seedset as percentage of flowers produced, self-pollination ability, frost resistance and overall plant vigour (Fig. 6). These traits, however, are present not only in this species but

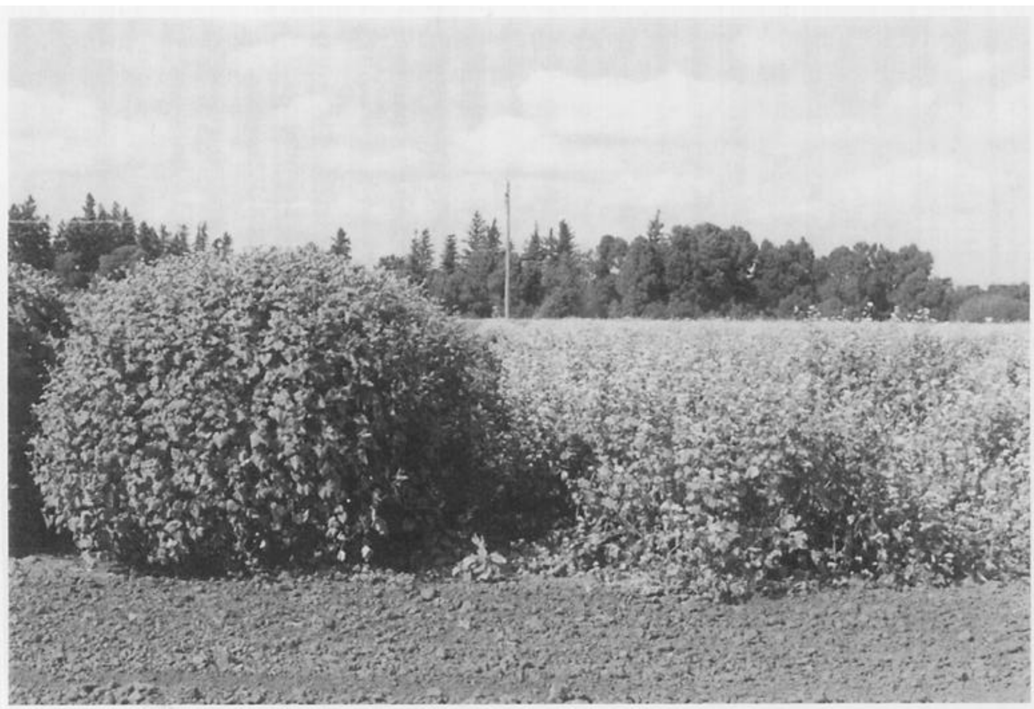

Fig. 6. Biomass production of tartary buckwheat (left) compared with common buckwheat (right), grown at Morden, Manitoba, Canada.

in other species as well. The finding, identification and classification of additional buckwheat species by Ohnishi (1990) has now opened the door to increased interspecific opportunities in buckwheat.

Campbell (1995) reported on the first successful interspecific hybridization by conventional pollination of buckwheat with *F. homotropicum* (both at the diploid level, $2n=16$), in which the progeny are fertile (Fig. 7). The progeny have been backcrossed to *F. esculentum* to transfer the desirable traits of *F. homotropicum* to common buckwheat. As *F. homotropicum* has a self-pollinating system and possesses some frost tolerance, these traits were considered to be the most desirable to transfer into common buckwheat. The *F. homotropicum* parent, unfortunately, has severe seed-shattering due to the development of an abscision layer. This undesirable character must be eliminated after hybridization.

As common buckwheat has a seed abortion problem so severe that often only approximately 12% of the flowers produce mature seeds, the transfer of the self-pollinating mechanism into common buckwheat may allow for increased yield. The interspecific hybrid might also be utilized as a future bridge in further hybridizations with other species.

As Tartary buckwheat has other desirable characteristics which would be of benefit if transferred to common buckwheat, work has now begun on the development of *F. tataricum* by *F. homotropicum* interspecific hybrids. The successful development of these hybrids has now been made at Morden, Manitoba by Kade Research Ltd. (unpublished data). These crosses can now be utilized to transfer traits between all three species. This should not only benefit improvement of common buckwheat but might also benefit Tartary buckwheat improvement. This requires

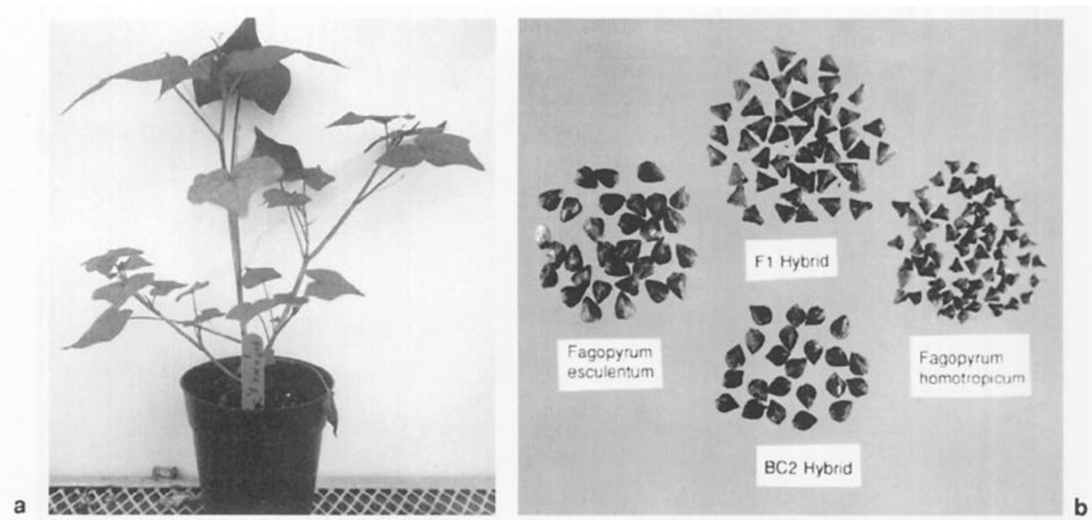

Fig. 7. F_1 plant of the cross *Fagopyrum esculentum* x *F. homotropicum* (a), F_1 seeds of the interspecific cross compared with the parental species (b), the backcross 2 (BC2) seeds were produced by backcrossing to *Fagopyrum esculentum.*

that the bitter component be removed and an easier dehulling type developed for those areas of the world that now rely on the hardiness of this species to supply some of their food requirements. Other characteristics of these species might also be transferred, increasing the quality and value-added components of common buckwheat, which could increase the importance and production of a crop that at present is underutilized.

The creation of interspecific hybrids between buckwheat species has opened up a new area for plant breeders. These crosses can now provide a means of transferring traits, not available within some species, from one species to another and transferring desirable traits into improved germplasm. The selection of specific desirable traits and the elimination of undesirable ones requires a rapid method for the identification of these traits. This would allow for early selection of desirable plants having the specific traits or combinations of traits without having to verify their presence using older and much slower methods. This will thus allow the plant breeder to make much more rapid progress in the improvement of buckwheat and in the development of new cultivars.

The identification of molecular markers linked to individual chromosomes and to specific genes has been demonstrated in many species. This usually utilizes random primers in conjunction with polymerase chain reaction (PCR) technology. Primers can be identified that amplify DNA fragments that are polymorphic between lines having different genes as well as being linked to known markers on different chromosomes. This type of analysis, combined with rapid leaf disc DNA extraction techniques, offers a very effective means of applying the knowledge gained to practical plant breeding.

8 Major and minor production areas

Common buckwheat is mainly produced in The Russian Federation, PR China, Ukraine and Kazakhstan although it is grown to a lesser extent in many other countries. Production and cultivated areas are given in Table 10. In several countries buckwheat is quite an important crop as its cultivation exceeds 3% of the total cropped area. It must be noted that there is no recorded production for many countries such as India, Nepal, Australia and several others. The countries that are involved in international marketing are PR China, Canada and the USA. Tartary buckwheat generally does not enter into international trade but is produced for local consumption. It is mainly grown in PR China, Bhutan, Northern India and Nepal. It is also grown in many other countries as a plough-down crop or for specific markets. Although there is yearly fluctuation in production there does not appear to be any noticeable trend and therefore production appears to be fairly constant.

Table 10. Buckwheat production and cultivated area

Country	Production (tonnes)	Cultivated area (ha)	% of total cropped area
PR China	1270000	1055000	1.18
Russian Federation	875007	1764770	3.06
Ukraine	424356	473333	3.78
Kazakhstan	148000	389667	1.79
Poland	47425	46249	0.55
Brazil	44800	42900	0.21
USA	35150	35550	0.06
Canada	23025	24661	0.12
France	21659	8501	0.09
Japan	19555	23690	0.94
Belarus	10000	26333	1.02
Korea Republic	7486	8111	0.58
Bhutan	6135	7319	7.09
Tajikistan	5733	10833	3.98
Moldova Republic	3604	6427	0.89
Slovenia	567	553	0.47
South Africa	498	1300	0.02
Lithuania	200	600	0.05
Estonia	167	100	0.03
Yugoslavia	152	112	0
Croatia	30	50	0.01
Total	2943549	3926059	

Source: FAOSTAT and for: Bhutan - Statistical yearbook of Bhutan 1991; Japan - The 69th Statistical Yearbook of Ministry of Agriculture Forestry and Fisheries Japan 1988-89; 1992-93; Korea - Statistical Yearbook of Agriculture, Forestry and Fisheries 1991, Korea Statistical Yearbook 1992, 1993; Kazakhstan, Russian Federation and Ukraine - Agricultural Statistics of the Former USSR Republic and the Baltic States.

9 Ecology

Common buckwheat is generally considered a short-day plant. According to Ujihara (1983), Tatebe *et al.* (1933) found that flowering of common buckwheat was stimulated by a short-day treatment. However, their experiments covered only a few varieties and did not deal with agro-ecotype problems. As quoted by Ujihara (1983), Onda and Takeuchi (1942) classified Japanese buckwheat into three agro-ecotypes: summer, autumn and intermediate. This was based on different seeding times and using the number of days required for flowering as the main criterion. They did not, however, give a clear explanation for the features of the ecotypes and thus failed to establish a strict definition of the agro-ecotypes. Matano and Ujihara (1979) classified 300 strains from Japan into summer, autumn and intermediate agro-ecotypes. These were found to have a close relationship to geographical distribution. Matsuoka (1956) in a study on Nepalese strains found that the yield and growing period varied with the altitude. It is considered that the primary agro-ecotype could be the autumn type that adapted to conditions of lower altitude. The summer agro-ecotype could therefore have originated because of cultivation under different conditions as it occurs in Northern China, North Korea and Manchuria and is thought to have diffused there from Southern China.

Buckwheat is a short-duration crop (3-4 months) and requires a moist and cool temperate climate to grow (Joshi and Paroda 1991). Common buckwheat has little tolerance to frost and thus is usually grown at lower altitudes than is Tartary buckwheat. Tartary buckwheat has some frost tolerance and is grown at higher altitudes where risk of frost damage is greater. Gaberscik *et al.* (1986) found that buckwheat had little frost resistance when studied under laboratory conditions and tested in a climatic chamber at optimal humidity of 60-80%.

Buckwheat thrives well on sandy, well-drained soils. When moisture is limiting, buckwheat is very sensitive to high temperature and hot dry winds. This usually results in the loss of flowers, a condition called ‘blasting’. Krotov (1963) reported that flowering at temperatures above 30°C is accompanied by desiccation of the fruit and lowering of yield. Gubbels (1978) found that the yield of common buckwheat increased with high soil moisture although seedset remained essentially the same. This indicated that seed size increased with increased soil moisture content. Adequate soil moisture appears to be essential for good yields. Common buckwheat wilts badly and grows very slowly when affected by low soil moisture. If moisture is received, the plants will often start to grow again but maturity is delayed. This is usually the opposite of cereal crops where low soil moisture often results in earlier maturity. If buckwheat is grown under fertile soil conditions it can lodge badly, especially if subjected to high winds and heavy rains. The buckwheat plant does not have the same ability as cereal plants to recover from lodging. The tips of the plants grow upward but the stem often remains in contact with the soil and often can be subject to disease and rot.

10 Agronomy

Cultural practices

The seed bed for buckwheat is usually prepared to conserve moisture and at the same time to control weeds. As few herbicides can be used with buckwheat, most weed control is cultural. In many countries the soil is cultivated and immediately seeded to take advantage of the fast growth of the buckwheat plants. Seeding rates are generally from 35 to 40 kg/ha. Although buckwheat can compensate for poorer stands by increased branching, the higher seeding rate is generally used to promote a faster canopy and therefore better weed control. Emergence is usually in 4-5 days. Buckwheat plants that produce a good canopy are very good competitors for weeds and generally smother them out. However, if the weeds are more advanced than the buckwheat plants, buckwheat is a poor competitor. Increased seeding rates of up to 80 kg/ha are utilized in some areas to force earlier maturity and are also used when the crop is grown under irrigation (Fig. 8).

Buckwheat usually thrives well on infertile soil and on land that has recently been cleared for cultivation. It has good tolerance to acid soils. It has been estimated that a buckwheat crop removes 47 kg nitrogen, 22 kg phosphorus and 40 kg potassium for each hectare seeded and gives a yield of 1600 kg/ha in Manitoba, Canada (Campbell and Gubbels 1978).

Fig. 8. Buckwheat under irrigation in Mid Hills of Nepal.

Harvesting and threshing

Owing to its indeterminate flowering habit, buckwheat seeds mature over a long period. Therefore flowers, green seeds and mature seeds are present on the plant at the same time. If harvest is delayed, seeds can shatter due to wind. Although buckwheat does not have an abscision layer that causes shattering, the seeds can be broken loose by winds, especially under dry climatic conditions. The crop is usually cut first, either by hand or mechanically windrowed, and is then threshed after the seeds and plants have dried (Fig. 9). The seeds are generally dried to 16% or less moisture content before being stored. If the seeds are artificially dried the drying temperature should not exceed 43°C. The seeds are stored with the hulls on and are dehulled shortly before use to prevent development of rancidity.

Pests and diseases

Although buckwheat is not attacked by many diseases or pests, a number have been reported on the crop. Many of these have been recently reviewed by Joshi and Paroda (1991).

Fig. 9. Buckwheat harvest on Hokkaido Island, Japan.

The major diseases on buckwheat as reported by Joshi and Paroda are:

Sphacelotheca fagopyri - smut
Septoria polygonicola - leaf spot
Phytophthora fagopyri - root and stem rot
Erysiphe polygoni - powdery mildew
Ascochyta italica - brown leaf spot
Puccinia fagopyri - rust
Sclerotinia libertiana - root and collar rot
Botrytis cinereu - stem rot
Fusarium spp. - root rot
Alfernaria alternata - chlorotic leaf spot
Bipolaris sorokiniana - stipple spot disease
Peronospora ducumeti - downy mildew.

In addition they report that several viruses have been reported to cause reduction in plant height and losses in grain yield.

The major pests as reported by Joshi and Paroda are:

Acanthecelids obtectus - bruchids
Cirphis spp. - cutworms
Cephitineu sp. - grain moth
Mycetophagus sp. - storage beetles.

11 Limitations of the crop

One of the major limitations in common buckwheat appears to be the high amount of seed abortion that occurs. The causative factors for the abortion are not fully understood even though this has been an identified problem for over 30 years. There also have been no reports of decreased percentage in accessions from different parts of the world. While this problem does not exist in Tartary buckwheat or in the species *F. homotropicum,* it does not appear that genetic variability in this trait can be readily found. Therefore any improvement in it must come from mutational or interspecific breeding.

Common buckwheat, however, is susceptible to spring and fall frosts and therefore care must be taken to avoid this problem. This lack of frost tolerance is a major restraint in many production areas. Although screening of accessions has shown very little variability to frost damage, this aspect is now being addressed through interspecific hybridization. The frost tolerance found in *F. tataricum* and *F. homotropicum* is being evaluated to determine if it can be transferred between species. If the character can be transferred then a major constraint to the production of this crop could be altered or removed.

12 Prospects

Common buckwheat, although it is an underutilized crop, has many advantages for both the grower and the consumer. It has a very short growing season and is thus often grown in areas with a short frost-free period, or as a second crop. It can also be grown after the first crop fails for environmental or other reasons and will still produce satisfactory yields. It should be noted that if it is grown as a second crop and thus seeded after the normal time of seeding, the yield obtained will often be lower than that obtained from earlier seeding. It does, however, give the grower the alternative to summer fallowing the land. Owing to the wide range of maturity dates now present in buckwheat varieties it is now possible to select from cultivars varying from 60 days to ones requiring 120 days to maturity.

Common buckwheat, with its high level of lysine, is a very desirable crop in areas of production where there is limited access to transportationand to sources of protein. By mixing it with cereal grains that are low in lysine a balanced amino acid profile can be achieved. Although this is a very advantageous feature of the species, few crop improvement efforts have been directed toward improving the lysine or other amino acid contents. Amino acid contents of accessions have been evaluated in some collections but to date no evaluation of the related species has been undertaken. It is probable that a large amount of variability exists and could be utilized in the improvement of the species. This aspect should also be addressed to determine if this feature is common throughout the genus.

Tartary buckwheat, although not utilized in the international trade to the extent of common buckwheat, is an important crop for growers in many areas. Owing to its frost tolerance it is produced in mainly mountainous areas that are subject to frost damage. At these altitudes it frequently outyields common buckwheat. Therefore in some areas of Nepal and China common buckwheat production is declining but Tartary buckwheat is remaining stable or increasing. This increase is taking place even though Tartary buckwheat has a tightly adhering hull that makes it difficult to dehull and contains a bitter component that affects its palatability. Little work has been done on the development of easily dehulling Tartary buckwheat even though types exist in Nepal, Bhutan and China that have a loose hull which is easier to remove. This type is generally referred to as ‘rice’ buckwheat because it can be dehulled and the groat cooked similar to rice grains. The genetics of and the effects of the environment on the bitter component require further research. An evaluation of existing germplasm is required to determine the identity and function of this compound and if it can be eliminated from this very desirable crop.

13 Further research needs and recommended plan of action

Collecting, characterization, evaluation and utilization of buckwheat germplasm to date have taken place, generally in an uncoordinated fashion. No major designated repository has accepted the mandate for this very important task. Although many of the germplasm collections that exist are being adequately utilized there is a need for closer coordination of; first, the data on germplasm in the collections and second, on the distribution of the stored material. The development of a listing of buckwheat germplasm worldwide that was recently undertaken by IPGRI has been a major step forward in meeting some of these needs. Another major step was the development and publication of descriptors for buckwheat.

Although a great deal of information on the origin and distribution of the various species of buckwheat has appeared over the past 10 years, a great deal of effort is still required. The major influence in this area has occurred in Japan through the efforts of Dr Ohnishi, Kyoto University. There also has been a great deal of effort placed in this area by buckwheat researchers in China. It would appear that given the importance of this area of research on buckwheat improvement worldwide there need to be increased efforts in this area. At the present time there are no coordinated efforts in the area of collecting, characterization and utilization of the wild species for crop improvement programmes. Characteristics that are highly desirable in such programmes must be considered both in the collecting of wild species and the sampling of general variability. This must be addressed for the benefit of those who have expended so much effort in the collecting and characterization of these species, and also for the benefit of the plant breeders and others who utilize the material. The long-term storage aspects of these collections urgently need to be addressed.

As the number of researchers working on buckwheat improvement is limited, compared with those working on primary food crops, it is even more important that their efforts be coordinated in some fashion, It is realized that this coordination can only be facilitated through a network or facilitating agency. It will depend on the development of collaborative projects, both small and large, between individual buckwheat programmes that will allow for the maximization of their efforts for the benefit of both. The collaborative projects can vary from formal to informal but will only be successful if both sides desire the results and are prepared to work together to achieve them.

Recommended plan of action

The present and ongoing buckwheat collecting, characterization and storage must be coordinated through a greater effort between the researchers utilizing the collections, the researchers undertaking the collections, and IPGRI.

A collecting system must be developed that will allow for the systematic sampling of the germplasm in areas that have not yet been adequately sampled so that collecting in these areas can be organized. There should be a review of present collections so that areas can be identified that have been adequately sampled to avoid

duplication of effort. This must take into account the present condition of the accessions that are being stored as well as any regeneration of germplasm that is required.

1. Emphasis must be placed on collecting wild and weedy species. This will not only allow these to be utilized in the breeding programmes now and in the future but will allow a clearer understanding of the site of origin and the differentiation that has taken place between buckwheat species. This should also allow for a more systematic approach to be taken in collecting individual characteristics in species that are closely related to the two economically important species presently being cultivated.
2. Mutant forms that have been developed or found in many of the breeding programmes have not been adequately stored on any systematic basis. These are very important in the variation of both morphological characters and also in quality or value-added characteristics of the species.
3. Cultivars that have been produced over the past several decades appear not to be stored according to any coordinated method. Although many of these are probably in working collections or in long-term storage, their status should be determined.
4. An electronic database should be developed that will allow for faster updates and faster dissemination of the data that are available in the present germplasm storages. Although approximately one-half of all accessions are documented on computer, but many of these systems are incompatible. The development of a compatible system and Internet access would allow much better utilization of these data.
5. Germplasm storage sites should be developed or appointed that have the mandate for storing buckwheat and its closely related species.
6. Collaboration must be encouraged and supported between the collection sites and the breeders utilizing these sites. This will often mean between developed and developing countries. This is very important as many buckwheat breeding programmes are decreased in size in many countries because of monetary constraints. This will also make the utilization of the stored germplasm by the breeding programmes more efficient on a global basis. This must include not only not only Government, University and International sites but also private companies.
7. There must be developed a means of having, for the collections now in place and those of the future, standardized evaluations on many of the characteristics that the breeders or those utilizing the germplasm deem to be the most important. As funds decrease for breeding programmes this will become increasingly more important from a global viewpoint. It will also make the entire system more efficient as it will reduce duplication of effort between breeding programmes. This should also allow for faster dissemination of the data obtained.
8. A more coordinated effort should be made in the area of crop improvement through the utilization of stored germplasm. This, although difficult to

implement, would make the utilization of the present germplasm collections, both long-term and working, much more efficient. This could include the initial evaluation of the germplasm, and the early generations of crosses involving specific characters.

9. IPGRI should play a larger role in the International Buckwheat Research Association in the areas that are under its mandate. This could include assistance in evaluation of germplasm collections from a logistics and sometimes from a funding viewpoint. As well there needs to be a more coordinated effort for exchange of materials and information which could be accomplished as part of the Association.

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Appendix I. Centres of crop research, breeding and plant genetic resources of buckwheat

Address	No. of accessions
Canada	
Agri-food Diversification Research Centre Agriculture and Agri-food Canada Research Station Unit 100-101 Route 100 Morden, MB R6M lY5	572 *F. esculentum* 201 *F. tataricum* 19 *Fagopyrum spp.*
Plant Genetic Resources of Canada Central Experimental Farm Building 99 Ottawa, ON K1A 0C6	321 *F. esculentum* 1 F. *tataricum*
Peoples Republic of China	
Institute of Crop Germplasm Resources Chinese Academy of Agricultural Sciences 30 Bai Shi Road Beijing 100081	1508 *F. esculentum* and *F. tataricum*
Gansu Pingliang Prefecture Agricultural Institute Pingliang, Gansu 744000	83 *F. esculentum* 55 *F. tataricum*
Potato and Minor Crops Institute Inner Mongolia Academy of Agricultural Sciences Southern Suburb Huhhot 010030	289 *F. esculentum* 8 *F. tataricum*
Ningxia Guyuan Prefecture Agricultural Institute Guyuan County Ningxia 75600	16 *F. esculentum* 9 *F. tataricum*
Agricultural Experimental Station of Jilin Agricultural University Donghuan Nanlu Changhuan, Jilin 130118	149 *F. esculentum*

Lab. of Crop Germplasm Resources Qinghai Academy of Agricultural Sciences 39 Ningzang Road Xining, Qinghai 810016	49 *F. esculentum* 24 *F. tataricum*
Institute of Crop Germplasm Resources Shanxi Academy of Agricultural Sciences 6 Nongkebei Road Taiyuan, Shanxi 030031	460 *F. esculentum* 143 *F. tataricum*
Yulin Prefecture Agricultural Institute Shangjun Nanlu Yulin, Shaanxi 71900	180 *F. esculentum* 91 *F. tataricum*
Liangshan Zhaojoe Agricultural Institute Zhaojue County Liangshan, Sichuan 616150	30 *F. esculentum* 133 *F. tataricum*
Yongsheng Institute of Agricultural Sciences Anion Province Yongsheng, Anion 674200	116 *F. esculentum* and *F. tataricum*
France	
Station d'Amélioration des Plantes Institut National de la Recherche Agronomique Domaine de la Motte BP 29 35650 Le Rheu	110 *F. esculentum* 80 *F. tataricum*
Germany	
Institute of Crop Science Federal Research Centre for Agriculture Bundesalle 50 38116 Braunschweig	97 *F. esculentum* 8 *F. tataricum*
Institute for Plant Genetics and Crop Plant Research Genebank Corrensstr. 3 06466 Gatersleben	84 *F. esculentum* 13 *F. tataricum*

India	
National Bureau of Plant Genetic Resources Regional Station Phagli, Shimla 171004	376 *F. esculentum* 222 *F. tataricum* 8 *Fagopyrum* spp.
Japan	
National Institute of Agrobiological Resources 2-l-2 Kannondai, Tsukuba 305	318 *F. esculentum*
Resource Crop Breeding Laboratory National Agriculture Research Centre Kan-nondai, Tsukuba, Ibaraki 305	50 *F. esculentum* 5 *F. tataricum* 2 *F. cymosum*
Laboratory of Genetics Research Centre of Plant Germplasm Faculty of Agriculture Kyoto University 1, Nakajo, Mozume, Mukoh-shi Kyoto	120 *F. esculentum* 120 *F. tataricum* 15 wild *F.* spp. 200 mutants
Hokkaido National Agricultural Experimental Station Engaru, Monbetsv 099-04	50 *F. esculentum* 5 *F. tataricum* 2 *F. cymosum*
Nagano Chushin Agricultural Experimental Station 1066-1, Tokoo, Souga Shiojiri-city, 399-64 Nagano	50 *F. esculentum* 10 *F. tataricum* 1 *F. cymosum*
Department of Plant Breeding Faculty of Agriculture Shinshu University 399-45 Minamiminowa Kaminagun, Naganoken	500 *F. esculentum,* *F. tataricum* and *F. cymosum*
Democratic Peoples Republic of Korea	
Pyongyang Crop Genetic Resources Institute Durudong, Sadong District Pyongyang	160 *F. esculentum* 8 *F. tataricum*

Republic of Korea	
Crop Experimental Station of RDA Suwon 441-100	245 *F. esculentum*
Latvia	
State Agricultural Research Institute 5126 Skriveri, Aizkrakule District	70 *F. esculentum*
Nepal	
Central Plant Breeding and Biotechnology Division Kumaltar, Lalitpur Kathmandu	80 *F. esculentum* 92 *F. tataricum*
National Hill Crops Research Program Kabre, Dolakha	318 *F. esculentum* 193 *F. tataricum*
Poland	
Plant Breeding and Acclimatization Institute 05-870 Blonie, Radzików near Warsaw	59 *F. esculentum*
Russia	
N.I. Vavilov All-Russian Research Institute of Plant Industry (VIR) Bolshaya Morskaja Str. 42-44 St. Petersburg 190000	2200 *F. esculentum* and *F. tataricum*
The N.K. Voltzov Institute of Development Biology Vavilov Street 26 117808 Moscow	2 lines of *F. esculentum*
All-Russia Scientific Research Institute on Legumes and Groat Crops 303112 Orel p/b Streletskoye	10 cvs. and mutant forms of *F. esculentum*
Slovenia	
Centre for Plant Biotechnology and Breeding Agronomy Department Biotechnical Faculty Jamnikarjeva 101 Ljublijana 61111	316 *F. esculentum* 17 *F. tataricum*

Sweden	
Nordic Genebank Smedjevagen 2 B PO Box 41 23053 Alnarp	4 *F. esculentum*
USA	
National Seed Storage Laboratory US Department of Agriculture Agricultural Research Service 1111 S. Masoh St. Fort Collins, CO 80521-4500	131 *F. esculentum*
USDA-ARS, Plant Genetic Resources Unit Cornell University Geneva, NY 14456-0462	30 *F. esculentum* 31 *F. tataricum*

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Roger Orr Department of Primary Industry and Fisheries Mt Pleasant Laboratories PO Box 46 Kings Meadows Launceston, Tasmania 7249 Fax: +61-3-63365410 Email: rorr@dpi.tas.gov.au	Evaluation
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Hiroshi Obinata Food Technology Research Institute of Nagano Prefecture 205-1 Kurita, Nagano-city Nagano 380 Fax: +81-262-27-3131 Email: sho@nagano-it.go.jp	Food processing
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Chloroplast genome

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Model of buckwheat efficiency, mineral nutrition of buckwheat, quality of buckwheat yield

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Genetic transformation

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