

Photo by RL Pendleton

ABSTRACT

This article summarizes information on the taxonomy of 'Appar', a perennial blue flax cultivar (*Linum perenne* L. [Linaceae]), and characteristics that distinguish it from native Lewis flax (*Linum lewisii* Pursh [Linaceae]). 'Appar' apparently originated as a European flax that escaped from garden cultivation. Randomly amplified polymorphic DNA (RAPD) analysis places 'Appar' with other collections of European *Linum perenne* and separates it from native North American collections of Lewis flax. Morphologically, 'Appar' differs from Lewis flax in having an intense blue petal color, shorter internodes, leaves that point upward along the stem, and multiple slender stems suffused with red near the base. The heterostylous reproductive system, which it shares with its European cousins, keeps 'Appar' reproductively isolated from native populations of Lewis flax. All available data indicate that 'Appar' is not invasive and does not pose a threat to native flax populations. Ease of establishment, seed production, and showiness of the abundant flowers recommend 'Appar' for use in xeriscape plantings. Alternatively, the recent germplasm release of Lewis flax, 'Maple Grove', also establishes readily from seed and can be effectively used when objectives dictate the exclusive use of native germplasms.

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NOMENCLATURE

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The 'Appar' Flax Release

ORIGIN, DISTINGUISHING CHARACTERISTICS,
AND USE; AND A NATIVE ALTERNATIVE

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Forbs are important components of plant communities. They contribute to biodiversity, often accounting for the majority of plant species richness (Pokorny and others 2004). They resist the expansion of functionally similar herbaceous weed populations and provide critical habitat needs for native wildlife (Shaw and others 2005). Despite the importance of forbs to ecosystem stability and habitat, few native forbs have been developed for commercial release (McArthur 1988; Shaw and others 2005).

In 1980, the Soil Conservation Service released the 'Appar' cultivar for commercial production of seed to be used in restoration plantings (Howard and Jorgensen 1980). At the time of release, the germplasm was believed to be a selection of the North American Lewis flax (*Linum lewisii* Pursh [Linaceae]). Lewis flax is a relatively short-lived perennial forb with showy blue flowers borne in open cymose clus-

ters. It occurs across a range of habitats, from semiarid desert shrubland to montane forest and meadows, throughout the western half of North America. Lewis flax provides spring forage for deer, offers seeds for birds and small mammals in fall and winter (Howard and Jorgensen 1980; Stevens and Monsen 2004), and contributes to the aesthetics and biodiversity of plant communities. The 'Appar' cultivar possesses many characteristics that make it useful for ornamental plantings, roadside stabilization, wildlife habitat improvement, and in wildland restoration plantings (Howard and Jorgensen 1980; Kitchen 2002). 'Appar' has good seedling vigor, establishes easily, produces abundant seeds, and is widely adapted. The deep blue color of the petals and the plants' drought tolerance make it attractive as an ornamental for xeriscaped gardens (McArthur 1988; Figure 1).

In 1989, we observed that 'Appar' plants growing outside the Shrub Sciences Laboratory were heterostylous

(Figure 2). Heterostyly is a plant reproductive system, thought to promote outcrossing, in which populations consist of 2 (distyly) or 3 (tristyly) plant morphs that differ in the relative heights of their stigmas and anthers (Barrett 1990). Successful seed production requires deposition of pollen from an alternate plant morph. Taxonomic descriptions of Lewis flax, however, characterize it as homostylous, having only long-styled plants. Furthermore, homostyly is the key characteristic distinguishing Lewis flax from *Linum perenne* L. (Linaceae), a blue-flowered perennial flax found throughout Europe.

The observation that the 'Appar' cultivar is heterostylous posed numerous questions regarding the origin and use of the 'Appar' germplasm. Did 'Appar' represent a reproductive variant of native Lewis flax, or was it a nonnative flax? Is Lewis flax a valid species? Taxonomists disagreed on placement of Lewis flax within the *Linum perenne* complex;



Figure 1. 'Appar' Lewis flax plants growing in front of the Shrub Sciences Laboratory in Provo, Utah. Photo by RL Pendleton

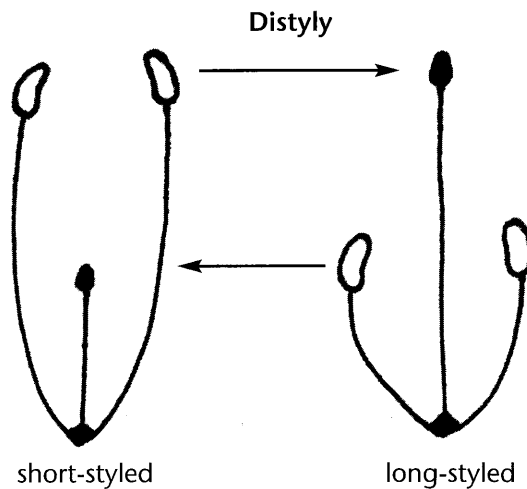


Figure 2. Diagram depicting reciprocal anther and stigma heights of distylous *Linum perenne*. Successful seed production requires pollen transfer between alternate plant morphotypes (arrows).

some regarded Lewis flax as a separate species (for example, Kearney and Peebles 1969; Martin and Hutchins 1980; Cronquist and others 1997), while others considered Lewis flax as a subspecies of *Linum perenne* (for example, Munz 1968; McGregor and others 1986; Welsh and others 1993; Kartesz and Meacham 1999). Concerns were also raised regarding possible expansion of 'Appar' plantings into native communities and subsequent introgression of 'Appar' genes into naturally occurring populations of Lewis flax (Kitchen 2002).

WHERE DOES 'APPAR' FIT TAXONOMICALLY?

In a recent report (Pendleton and others 2008), we present results from morphometric, genetic, and pollination studies using seed collections of known North American, European, and 'Appar' sources. In this study, we grew plants of 9 European, 9 North American, and 3 'Appar' seed sources. European accessions were obtained from botanical gardens in Europe and represented collections of both wild and cultivated plants from Austria, Belgium, Finland, Germany, Poland, Hungary, and the Czech Republic. Eight of the collections were of *Linum perenne* and one was of *Linum austriacum*, a close relative within the *L. perenne* complex. North American collections made by S Kitchen came from populations of diverse topography and elevation located in South Dakota, Washington, Colorado, Nevada, and Utah. 'Appar' sources were grown from certified 'Appar' seed and from 2 maintained seed lines. The Black Hills seed line is the putative source for 'Appar'. The Montana seed line is virtually identical, causing some uncertainty as to which gave rise to 'Appar'. We measured 18 morphological variables on 10 plants grown from each seed collection and examined genetic relatedness of the different collections using randomly

amplified polymorphic DNA (RAPD) analysis. We also performed self- and cross-pollinations within and among seed source groups. We concluded that Lewis flax fulfills most definitions of a unique species, separate from other European members of the perennial blue flax (*Linum perenne*) complex. Lewis flax accessions were reproductively isolated and distinct both morphologically and genetically from perennial blue flax collections. 'Appar' plants were morphologically similar to smaller-statured European collections and fully interfertile with them. Cross-pollinations between 'Appar' and North American sources yielded only 2 potentially viable seeds (seeds were not germinated) from a possible 920 (0.2%). UPGM clustering of RAPD data (Figure 3) shows a distinct separation of the North American and European sources, with 'Appar' plants clustering amid European sources. These data demonstrate that the 'Appar' release is of European ori-

gin and likely escaped from garden cultivation somewhere in the northern plains states near South Dakota.

DISTINGUISHING 'APPAR' FROM LEWIS FLAX


When in flower, 'Appar' plants can readily be distinguished by the reproductive system. 'Appar' plants are of 2 types, designated long-styled and short-styled. Long-styled plants have style lengths of about 7.5 mm (0.3 in) and stamen lengths of 4.5 mm (0.18 in). Short-styled plants have the opposite configuration, with average style lengths of 4.8 mm (0.19 in) and stamen lengths of 7.1 mm (0.28 in; Figure 4A, B). Also, the shape of the stigmatic surface in 'Appar' plants is rounded or capitate. Lewis flax plants are all long-styled (longer even than long-styled 'Appar' plants), with an average style length of 10.9 mm (0.43 in) and

an average stamen length of 7.1 mm (0.28 in). At higher elevations and latitudes, however, the distance between stigmas and anthers may be less than is reported above (Mosquin 1971). Stigmas in Lewis flax are linear in shape (Figure 4C). Additionally, the petal color of 'Appar' plants is consistently of a deep blue, whereas flower color in Lewis flax varies considerably, ranging from near white through lavender to blue (Figure 5). In our study, 2 of 9 native flax collections were blue (Larimer County, Colorado, and Sanpete County, Utah), whereas one from Clark County, Nevada, was nearly white. The other 6 collections were predominantly lavender. Experience indicates that dry-site collections of Lewis flax tend to be lightest in color, while those from higher elevations and latitudes have deeper color.

Heterostyly is most often associated with genetic self-incompatibility (Barrett 1990). Homostylous North Ameri-

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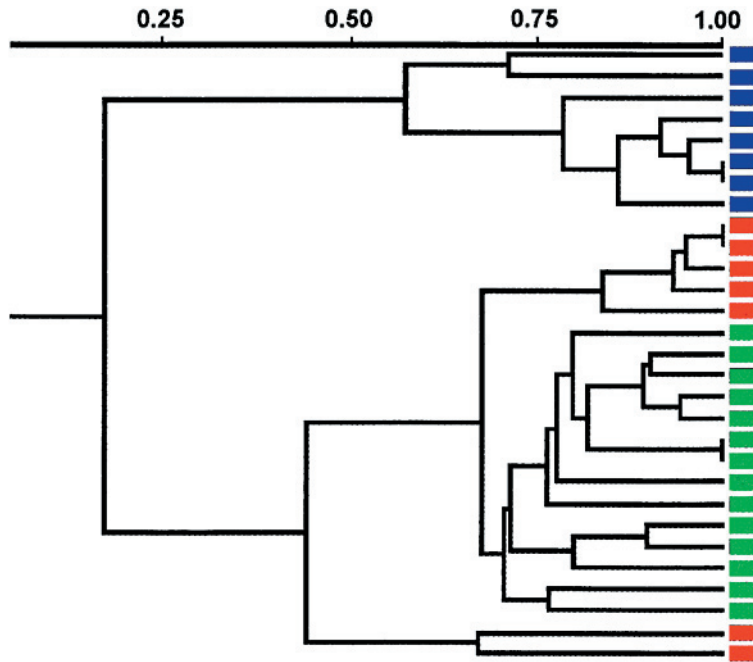


Figure 3. Phenogram produced using UPGMA clustering analysis (NTSYS-pc, Rohlf 1993) for 29 bulked or individual tissue samples of flax. Bulked North American population samples are depicted in blue, bulked European population samples are in red, and individual plants of putative 'Appar' sources are in green.

can Lewis flax is self-fertile, in our study producing an average of 8 seeds per fruit out of a possible 10. In contrast, hand-pollinations of 'Appar' flowers using self pollen produced no viable seeds.

'Appar' plants tend to be shorter than most native collections, having shorter internodes, upright leaves, and multiple stems that are suffused with red near the base. Lewis flax plants have longer internodes, reflexed leaves, and fewer, thicker stems. A classification program using 11 morphological variables (Breiman and others 1984; Therneau and Atkinson 1997) selected petal color as the most important distinguishing character, followed by leaf angle. Petal color alone correctly classified 93 (88% of the 106-plant total) of the 30 'Appar' and 76 Lewis flax plants. Leaf angle correctly classified 92% of the plants. Five of the Lewis flax plants that were incorrectly classified using leaf angle were from a collection taken from Elk Knoll, Sanpete County, Utah. Most of the plants from this collection appeared to be in poor health, a fact that may have affected leaf position.

Seeds of 'Appar' can be distinguished from native Lewis flax seeds by both size and weight, being smaller and lighter in weight. In the above-mentioned study, we determined that mean seed length ($n = 30$) for 'Appar' was 3.3 mm (0.13 in) and mean seed width was 1.9 mm (0.07 in). Seed sizes for Lewis flax varied with population, with mean lengths ranging from 3.5 to 4.6 mm (0.14 to 0.18 in; $n = 10$ per population), and mean widths ranging from 1.9 to 2.4 mm (0.07 to 0.09 in). Seed weights for 'Appar' accessions ranged from 29 to 36 mg for 25 seeds (690 000 to 860 000 seeds/kg [1900 000 to 1520 000 seeds/lb]), whereas North American accessions ranged from 39 to 67 mg for 25 seeds (640 000 to 373 000 seeds/kg [1 410 000 to 825 000 seeds/lb]). 'Appar' seeds also have a pronounced "hook" at the radicle end that may or may not be present in seed collections of Lewis flax (Figure 6).

CONSIDERATIONS FOR USE OF THE 'APPAR' GERMPLASM

Appropriate use of any flax seed requires that the seed source be properly identified. Seeds of 'Appar' origin have been used in native plant gardens and in research studies in the belief they were native Lewis flax. A few companies continue to market 'Appar' as "native" Lewis flax. Consequently, care must be taken regarding the true source of seeds currently labeled as Lewis flax (*L. lewisii* or *L. perenne* ssp. *lewisii*). Seed producers should designate seeds from the 'Appar' source as perennial blue flax (*Linum perenne*). Source-identified native flax seeds should be designated as Lewis flax (*Linum lewisii*). A new Lewis flax germplasm release, 'Maple Grove', is now available for situations where the use of native plant material is desired (Kitchen 2006). 'Maple Grove' was selected from a series of 19 North American Lewis flax accessions for its seedling vigor, drought tolerance, plant longevity, rust resistance, and seed production (Kitchen 1995, 2006). It is considered comparable to 'Appar' in establishment success and plant vigor but produces fewer flowers and seeds per plant. Consequently, 'Appar' may continue to have a place in revegetation of areas where color, diversity, and ecosystem stabilization are primary considerations, and the exclusive use of native seeds is not mandated.

The discovery of a heterostylous reproductive system in 'Appar' plants and subsequent determination of a European origin raised concerns over the possible unintended spread of 'Appar' into native communities and the subsequent introgression of 'Appar' genes into native flax populations. These concerns prompted members of the Colorado Weed Management Association (CWMA) to consider listing 'Appar' as a noxious weed (Kitchen 2002). A workshop organized by the CWMA in 2000 resolved many concerns resulting in the near-unanimous con-

clusion that 'Appar' was not invasive and should be removed from the CWMA handbook. Some concern over introgression still remained, however. Our data from cross-pollination experiments demonstrate almost total reproductive isolation between 'Appar' and native Lewis flax, with only 2 potentially viable seeds produced from a possible 920. A further investigation of possible gene exchange examined linear-simple-sequence repeat DNA markers (ISSRs) and morphological characteristics of sympatric indigenous Lewis flax and seeded 'Appar' (Johnson and others 2006). This recently completed field study found no evidence of hybridization. Therefore, we conclude that established plantings of 'Appar' should not pose a threat to the genetic integrity of native flax populations.

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Figure 4. Flowers of native North American Lewis flax and the 'Appar' blue flax release showing relative positions of anthers and stigmas. Long-styled 'Appar' plant (A). Short-styled 'Appar' plant (B). Long-styled North American plant (C). Note differences in the shapes of the stigmatic surface (arrows). Photos by RL Pendleton



Figure 5. Lewis flax populations show variation in the color of their petals. Photo by RL Pendleton



Figure 6. Seeds of 'Appar' (left 2 seeds) compared with seeds from the new 'Maple Grove' Lewis flax release (right 2 seeds). Photo by Anne Joria

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