First evidence for the presence of invasive Solidago altissima (Asteraceae) in Europe

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First evidence for the presence of invasive Solidago altissima (Asteraceae) in Europe

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Abstract: The North American invasive species Solidago altissima L. (Asteraceae) is reliably recorded from a single locality in Belgium (Beveren, Waaslandhaven, Verrebroekse Plassen). Nuclear genome size, as measured by flow cytometry, showed this population to be distinct from the closely similar and widespread S. canadensis L. Plants were shown to be hexaploids, with an estimated chromosome number of 2n = 54, while only diploids (2n = 18) of S. canadensis are known from Europe. These findings were further supported by morphological traits. Solidago altissima has repeatedly been claimed from Europe but all these records may be referable to S. canadensis var. canadensis and, more likely, S. canadensis var. hargeri Fernald. To the best of our knowledge, the recently detected population in Belgium represents the first unequivocal record of S. altissima in Europe.

Key words: Asteraceae, Compositae, Solidago, Solidago altissima, Solidago canadensis, genome size, flow cytometry, Europe, Belgium, invasive

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Introduction

Solidago L. (Asteraceae) is a predominantly American genus. Of the c. 120 currently accepted species, only six to ten are native to Eurasia (Semple & Cook 2006; Semple 2016). Recent molecular phylogenetic studies considerably helped to resolve relationships within the genus, as well as to other genera within the tribe Astereae. For instance, the grass-leaved goldenrods [Euthamia (Nutt.) Cass.], traditionally included in Solidago, proved to be distinct. Oligoneuron Small, in turn, was shown to be part of Solidago (e.g. Beck & al. 2004; Schilling & al. 2008). Although goldenrod, as a genus, is readily recognized, identification to the species level is often difficult (Semple & al. 1999). This particularly holds true for S. subsect. Triplinerviae (Torr. & A. Gray) G. L. Nesom, also known as the S. canadensis complex. This group is reputed for being one of the most taxonomically challenging species assemblages in North America (Melville & Morton 1982; Semple & Cook 2006). It includes several species that are widely grown as garden ornamentals (e.g. S. canadensis L. and S. gigantea Aiton; Yeo 2000). These species are vigorous perennial herbs with strong rhizomes. Wherever recorded in the wild (as escapes, from discarded garden waste or from transported rhizomes), they are readily considered noxious environmental weeds, also in Europe (e.g. Voser-Huber 1983; Guzikowa & Maycock 1986; Schlaepfer & al. 2010; etc.).

In Belgium, two species from this complex are more or less widely naturalized: Solidago canadensis and S. gigantea (Verloove 2016). The latter is by far the most frequent, although it long remained overlooked due to

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confusion with the former (Lawalrée & Vanden Berghe 1946). At present, however, both are rather easily separated based on characters such as stem indumentum (present or absent), involucre size and ray floret length (Lambinon & Verloove 2012). A third species from the complex, *S. altissima* L., has been claimed from other parts of Europe, although McNeill (1976) concluded that all claims appear to be referable to *S. canadensis* s.str. Further, he stated that *S. altissima* is cultivated and may also be naturalized. Yet, some authors disagree. Sell & Murrell (2006) suggested that the latter [as *S. canadensis* subsp. *altissima* (L.) O. Bolòs & Vigo] is the “common race” in the British Isles, and Weber (1997, 2000) even ascribed all European populations to *S. altissima*.

*Solidago canadensis* and *S. altissima* were both described by Linnaeus (1753). They were considered similar species in the British Isles, and Weber (1997, 2000) even suggested that the latter is cultivated and may also be naturalized. Yet, some authors disagree. Sell & Murrell (2006) suggested that the latter [as *S. canadensis* subsp. *altissima* (L.) O. Bolòs & Vigo] is the “common race” in the British Isles, and Weber (1997, 2000) even ascribed all European populations to *S. altissima*.

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In July 2016 a small population of an odd-looking species of *Solidago* was discovered in a sand-raised site in the nature area Verrebroekse Plassen in the Waasland port area in Beveren (Belgium, province of East Flanders). Morphologically, these plants were clearly more similar to *S. canadensis* than to *S. gigantea*, especially with regard to the short-hairy stems. However, compared with *S. canadensis*, these plants were unusually tall (c. 200 cm), with stiff stems, and leaves that were markedly scabrous and hairy throughout. Moreover, flowering started very late in the season (late October to early November), several weeks after *S. canadensis*. These traits are characteristic of *S. altissima*. In order to confirm this identification based on morphological grounds, genome size was measured and compared with that of *S. canadensis*. Genome size as well as chromosome number demonstrated that this population indeed belongs to *S. altissima* (var. *altissima*).

In this paper the distinguishing features of *Solidago altissima* and *S. canadensis* are discussed and the former is illustrated.

Material and methods

**Plant material**

Leaf material of *Solidago canadensis* and *S. gigantea* was obtained from living plants cultivated at Leiden, the Netherlands, and that of the putative *S. altissima* from Verrebroekse Plassen in the Waasland port area in Beveren, Belgium, with voucher material deposited in the herbarium of the Botanic Garden of Meise (F. Verloove 12620, BR).

Flow-cytometric measurement of nuclear DNA content

For the isolation of nuclei, c. 0.5 cm² of a young leaf was chopped together with a piece of *Agave americana* 'Aureomarginata' as an internal standard (Galbraith & al. 1983). The nuclear DNA content (2C-value) of *A. americana* was measured as 15.9 picograms (pg) per nucleus with human leukocytes (2C = 7 pg; Tiersch & al. 1989) as the standard. Based on published male human genome size of 6.294 × 10⁹ base pairs, the nucleus was calculated to contain 6.436 pg (Doležel & al. 2003). However, this is based on a human sequence for which the size of the very large repeat sequences could not be accurately
Table 1. Main distinguishing features of Solidago altissima var. altissima and S. canadensis var. canadensis in W Europe; S. canadensis var. hargeri differs from the latter only in stem indumentum characters (see text).

<table>
<thead>
<tr>
<th>Feature</th>
<th>Solidago altissima var. altissima</th>
<th>Solidago canadensis var. canadensis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem height</td>
<td>up to 200 cm</td>
<td>rarely exceeding 150 cm</td>
</tr>
<tr>
<td>Stem indumentum</td>
<td>short-hairy throughout</td>
<td>glabrous in proximal half</td>
</tr>
<tr>
<td>Start of flowering</td>
<td>end of October to early November</td>
<td>end of August to early September</td>
</tr>
<tr>
<td>Leaf margin (leaves on distal half of stem)</td>
<td>nearly entire (finely and remotely serrate)</td>
<td>usually sharply serrate or serrulate</td>
</tr>
<tr>
<td>Leaf texture</td>
<td>thick, ± leathery</td>
<td>thin, not leathery</td>
</tr>
<tr>
<td>Involucre length</td>
<td>3–4 mm</td>
<td>1.7–2.5(–3) mm</td>
</tr>
<tr>
<td>Chromosome number</td>
<td>2n = 54</td>
<td>2n = 18</td>
</tr>
</tbody>
</table>

Table 2. Genome size, number of measurements and origin of Solidago species.

<table>
<thead>
<tr>
<th>Solidago species</th>
<th>2C-value (pg per nucleus)</th>
<th>Number of measurements</th>
<th>Origin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solidago altissima</td>
<td>5.61</td>
<td>2</td>
<td>Belgium: Waasland port area</td>
</tr>
<tr>
<td>Solidago canadensis</td>
<td>2.14</td>
<td>4</td>
<td>Netherlands: Leiden Schubertlaan</td>
</tr>
<tr>
<td>Solidago gigantea</td>
<td>3.81</td>
<td>6</td>
<td>Netherlands: Leiden Schubertlaan</td>
</tr>
</tbody>
</table>

Results and Discussion

A small population recently discovered in Belgium exhibits morphological features that fully correspond with Solidago altissima. Plants were unusually tall with stems up to 200 cm long (“verge d’or haute”) and short-hairy throughout. Their leaves were nearly entire, more or less leathery and stiff in texture, and rough and large up into the inflorescence (typical for S. altissima var. altissima). Flowering commenced very late in the season (end of October to early November; “late goldenrod”). Moreover, involucres were markedly longer than in S. canadensis. The main distinguishing features of both species are summarized in Table 1 and illustrated in Fig. 1–4. A detailed description of S. altissima var. altissima is presented below in order to prevent further confusion with S. canadensis var. hargeri in Europe.


The following description refers to Solidago altissima var. altissima; values given in boldface are means.

Plants up to 200 cm tall; rhizome short- to long-creeping. Stems 1–40+, short-hairy throughout. Leaves all cauline, sessile or subpetiolate, tapering to bases, proximal leaves withering by flowering; leaf blade oblanceolate, 95–150 × 16–20 mm, relatively thick and firm, strongly 3-nerved, abaxial surface finely striigose, more so along nerves, adaxial surface ± scabrous, margin (nearly) entire, apex acute to acuminate; middle to distal cauline blades oblanceolate (proximally) to lanceolate (distally), middle blades (30–)45–74–120(–170) × (5–)6–11–16(–25) mm, much reduced on distal blades [20–46–83 × 3–7.3–13(–17) mm], abaxial surface moderately striigillose, densely villous-striigillose along nerves, sometimes minutely stipitate-glandular on distal blades, adaxial surface ± scabrous, margin finely serrate on middle blades (teeth 0–6–8) per side), usually becoming entire or remotely serrulate on distal blades. Inflorescence not flowering before September (later in Europe), a secund, conical, paniculiform array, 5–30 × 2–25 cm, with (15–)100–1200+ second capitula; branches divergent and recurved, sometimes ascending-divergent, inflorescence sometimes merely club-shaped thyrsiform in small plants. Peduncles 1–3.5 mm, moderately densely shortly hispidulous-striigillose; bracteoles

Macro-morphological identification

All relevant taxonomic literature on Solidago subsect. Triplinerviae was investigated (e.g. Semple & al. 1999, 2013, 2015; Semple & Cook 2006; etc.). Identification was based on macro-morphological characters of the available herbarium specimens.
Fig. 1. *Solidago altissima* in Verrebroekse Plassen nature area in Beveren, Belgium, photographed on 9 October 2016. The tall and stiff habit of the plants is very characteristic.

Fig. 2. *Solidago altissima*, emerging inflorescence. Note the leafy inflorescence and the late flowering time. – Belgium, Beveren, Verrebroekse Plassen nature area, 9 October 2016.

Fig. 3. *Solidago altissima*, cauline leaves. Leaves are thick and stiff and only remotely serrate. – Belgium, Beveren, Verrebroekse Plassen nature area, 9 October 2016.
The stem is short-hairy throughout. – Scale bar = 1 mm. – Fig. 4.

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