PERSPECTIVE

Canada Goldenrod (*Solidago canadensis* L.): An Aggressive Colonizer or a Useful Resource?

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Abstract

Canada goldenrod (*Solidago canadensis* L.) is a controversial and misunderstood plant species. It is an example of both a maligned weed, even in its native lands, and a problematic colonizer at locations where it has become established. In both native and introduced environments, it tends to become a dominant species of high-density growth. In places where it is a native plant, goldenrod is tolerated to a limited extent as it is non-toxic to humans and, in general, not detrimental to fauna. Goldenrod has historically been used as a source of herbal medicine, especially by indigenous North Americans.

However, goldenrod is also an aggressive colonizing species characterized by prolific growth that crowds out other species, and this aspect is of concern at locations where it can invade and expand its territory of occupation rapidly. Regardless, in both native and non-native (invasive) environments, Canada goldenrod is often dealt with by pulling or digging out plants and either burning them or leaving them to rot. However, as a potential source of biomass, it is also a resource to be utilized.

Canada goldenrod has seen limited utilization, mainly as a source of natural compounds and extracts for medicinal or nutritional uses. The present report is an overview and perspective of Canada goldenrod in terms of its properties, characteristics, growth and habitat, as well as its positive and negative aspects. In our view, the utilization options of Canada goldenrod as a viable biological resource are real although broader opportunities for applications may require further development.

Keywords: *Solidago canadensis; goldenrod;* colonizing; biomass utilization; renewability; sustainability

Introduction

Many weedy species, including both long-established species ('natives') and newly arrived species, which can spread widely ('invasive') are treated by most people with disdain regardless of their inherent characteristics. As all weedy species are 'pioneering species' or 'colonizing plants', some of these viewpoints are controversial. The issue of how best to deal with them is a perpetual and often divisive subject. Considerable effort is often made to eradicate or at least control the proliferation of weeds in situations where they might be problematic. These efforts can be both costly and harmful to the environment. Elimination of weeds may in some cases disrupt the ecology of local ecosystems on both macroscopic and microscopic levels.

The debates about what is 'native' still rage on in ecology and must surely be related to how long a species has existed in an environment or a continent with or without human interference or introductions. *Are all such colonizing species undesirable? Do they not have redeeming values?* These are contentious issues (Chandrasena, 2023).

Certain 'native' weedy species have become established in local or larger ecosystems where they thrive and even proliferate. As colonizing plants, it is in their inherent nature to reproduce as prolifically as possible and perpetuate their species (genes). Such species may largely be ignored and taken for granted by the local human population if they do not interfere much with human endeavours.

On the other hand, 'likes' or 'dislikes', depending on how we perceive species, can lead to attempts to get rid of those considered problematic, often at great environmental costs. The latter is especially true where certain species have become aggressive colonizers of habitat, which can, at least temporarily, disrupt local ecosystems and, in some cases, have detrimental effects on the local economy or human activities (Chandrasena, 2023).

An example of such a weed species as described above, which is controversial for several reasons in its 'native' habitat and has become a problematic colonizing plant in areas outside its native range, is Canada goldenrod (*Solidago canadensis* L.). It is a species that has been in the North American continent for millennia. Therefore, it should be considered a 'native'. However, in many habitats and environments, goldenrod is considered a problematic 'weed' and is often reviled for several reasons.

It is an aggressive, fast-growing species, which can easily spread into new areas. It has spread from eastern North America to other parts of the world, becoming a problem species as it established quickly and begins to dominate in 'new' areas. While various attempts have been made to manage the spread of Canada goldenrod, the plant has proved difficult to control and even to manage to a reasonable extent. In some cases, the colonization has been so successful that it is now considered a 'naturalized' species on several continents (Foster, 2023).

Canada goldenrod is, in many ways, a unique weed. It is reviled by many people and desired by others, especially for its characteristic golden yellow flowers which can add colour to gardens or cultivated meadows. A large stand of flowering goldenrod plants, with their rich golden yellow blooms, can be pleasing to the eye. The blooming plants also attract pollinating insects, including bees and butterflies and may be welcomed in certain gardens or other habitats for those reasons (Eisenstein, 2019).

Canada goldenrod can pose problems in both urban and rural areas. In the latter, large, unchecked stands of growth may have a detrimental effect on the growth of certain field crops or on cultivated soils, as well as on animals that may forage on grasses in infested fields. While the species, in general, is not problematic to humans in terms of toxicity, its profuse flowering has been long associated with allergenic properties, which causes many to think of Canada goldenrod only with negative connotations (Pavek, 2012). Despite the reputation as a nuisance that may be justified by some of its inherent characteristics, the species is misunderstood from other points of view and needs to be re-evaluated.

An alternative to the elimination or aggressive management of weedy species, such as goldenrod, is to utilize them in ways that are not harmful to the environment and can provide some economic advantage on the local or broader level. Research over at least two decades has shown that whole plants of *Solidago canadensis* or certain parts may be utilized to make a variety of products, making it a valuable plant resource. Plants, which are composed of lignocellulosic biomass, contain many components which can be used directly or converted into useful end products (Ayoub and Lucia, 2018).

In a previous publication, Duns (2020) presented the case of smooth cordgrass (*Spartina alterniflora*) which has become a problematic colonizer in Asia and other parts of the world, but one that can be an invaluable resource. Smooth cordgrass is an example of the possibilities of successful utilization of its colonizing abilities for human benefit.

The article described how cellulose fibres from smooth cordgrass stems can be used to make a variety of moulded pulp products in China with economic benefits. Utilization allowed managers to avoid the harmful burning of the infestations and the potential environmental damage such aggressive control may bring about on China's eastern coastline. This example demonstrated what can be done with large biomasses from weedy taxa if proper efforts are undertaken with understanding, along with support from the local government, industry or population.

In addition to traditional sources of lignocellulosic biomass, from agriculture, forestry and fisheries and their wastes, other potential sources are the large numbers of colonizing plants that exist on any continent. Utilization of such species represents a vast pool of available lignocellulosic biomass and can be an environmentally advantageous alternative to the use of fossil fuels as a resource. For the most part, they are a vast untapped and unrealized pool of available biomass (Sharma and Pant, 2018).

The issue of some of these taxa becoming 'invasive species' is a common theme world-wide. There is a general perception that some colonizing taxa can crowd out desirable, native species both on land and in waterways and coastal areas. They may also have detrimental effects on local environments and economies. These plants are commonly removed and then buried or burned, which creates an additional environmental disturbance (Duns, 2020). Utilization of these problematic species would accordingly be a way to not only reduce pollution but to help local economies as well by providing raw materials to produce energy or other products (Sharma and Pant, 2018; Chandrasena, 2023).

The purpose of this perspective is to highlight the present status of Canada goldenrod as both a native and colonizing species and to indicate its potential as a useful resource that is either neglected or eradicated. is not to review in detail the various applications of goldenrod; An overview of the species, its taxonomy, colonizing abilities, negative and positive aspects and public perceptions is given, together with methods of management, and finally, utilization of the plant as a resource.

Taxonomy

Solidago canadensis L., a member of the Asteraceae, was named by Carl Linnaeus in his *Species Plantarum* (1773). Its taxonomy has long been a source of controversy and some confusion because it is morphologically a highly variable species (Werner et al., 1980; Popay and Parker (2014). One former taxon, *S. canadensis* spp. *altissima* (previously known as *S. canadensis* var. *scabra*) is now treated as a separate species, with the accepted name: *S. altissima* L., which is common in Europe. The morphologies of the two species are remarkably similar, except for the presence of short hairs on *S. altissima* leaves and the absence of hairs in *S. canadensis* (Zhao et al., 2014).

While there are many similarities in appearance and other characteristics between various *Solidago* species, differences do exist in terms of plant morphology (Pavek, 2012). There are also major differences in the phytochemical profiles and bioactivities of Canadian goldenrod populations (Kołodziej et al. 2011; Vrabiˇc-Brodnjak and Možina, 2022), as well as some differences in its preferred habitats (Eisenstein, 2019).

General characteristics

Canada goldenrod is an erect, perennial, terrestrial plant, reproducing by both rhizomes and by seed. The species is hermaphroditic, self-fertile and is also pollinated by insects. Its characteristics include strong fecundity, fast spreading, clustered growth, and a high degree of stalk lignification at the maturity period. Importantly, the plant is a major source of nectar and habitat for insects including pollinators (Ford, 2020). Individual plants have a tendency to grow large, with normal growth achieving dimensions of up to 1.8-2.0 m. It tends to grow in clusters. It is noted for attracting wildlife.

The stems branch only in the upper part, hairless near the base, but very finely pubescent toward the top. The stems are strong and are a useful source of fibre. The plant has numerous narrow leaves that are stalkless, and often crowded. They are generally 1-15 cm long and 1-22 mm wide, lanceolate, and widest in the middle, tapering to both ends.

Leaf margins vary from nearly entire to usually having fine or sometimes coarse, widely-spaced teeth. Most leaves have one prominent mid-vein on the undersurface and two distinct lateral veins that branch from it and parallel it nearly to the tip of the leaf. The lower and middle stem leaves of plants in thick patches of growth are often seen dying and falling off by the time flowering begins (Figure 1)

Figure 1 (a) *Solidago canadensis* L. *growth* (Top) Young Canada goldenrod plants in spring, with no blooms. Upon close examination, the teeth or serrated edges of the leaves many be observed. (b) Plants in bloom in an urban area in late summer

The inflorescence is a broad or occasionally narrow pyramidal panicle 5-40 cm in length and nearly as wide, with several to many horizontal branches. The upper sides of the branches carry numerous, densely-crowded small heads of golden yellow flowers, thus giving the plant its name. Each individual flower head is about 3 mm long and wide. In northern climates, the species flowers from mid-July to October in its native habitats, with the seeds ripening from September to October (Figure 2).

Figure 2 (a) The characteristic bright golden yellow florets of newly-blooming Canada goldenrod plants. (b) clusters of Canada goldenrods in urban fields and backyards near houses (author's collection)

Apart from profuse flowering, Canada goldenrod can reproduce from vegetative shoots that arise just below the root surface (Figure 3). Clonal growth and reproduction, from underground stem parts add considerably to the reproductive strengths of the species and also make its populations extremely difficult to control (Tang et al., 2013).

There are notable similarities between many goldenrod species, with some subtle differences. For example, *Solidago canadensis* can be distinguished from *Solidago missouriensis* Nutt. by its taller stature and its larger, more branched, open flower panicles. The Canadian goldenrod can also be distinguished from *Solidago gigantea* Ait. by its hairs on the stems and yellow bracts. (Pavek, 2012)

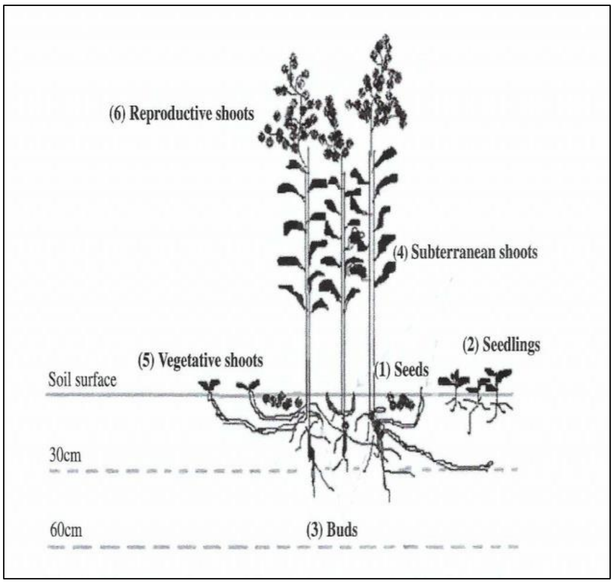

Figure 3 Canada goldenrod growth and reproduction - a depiction from Tang et al. 2013

Habitats and Biogeographical Distribution

Canada goldenrod generally grows easily and in abundance, as a robust plant. Growth will occur in any moderately fertile moist soil and in sunny conditions or semi-shade. The species is generally found growing naturally in many environments and locations, including in moist or moderately dry fields and meadows, edges of forests, swamps, clearings, orchards and compost piles, as well as along roadsides, streams, fencerows and shorelines, and as a weed in cultivated fields.

The fact that it grows well in diverse types of soil, especially in heavy or clay soils indicates its adaptability. In terms of soil pH, it can grow in mildly acid, neutral and basic (mildly alkaline) soils, while it avoids overly acidic soils. It can grow in semi-shade (light woodland) or no shade. Recently, Eckberg et al. (2023) demonstrated the dominance of Canada goldenrod in its local environment and found that it negatively correlated with the richness and combined biomass of all other plant species in that community. They attributed this dominance to the taller goldenrod plants reducing light availability for other types of plant growth. However, in the wild, goldenrods are often found mixed with other taller weedy species, such as milkweeds (*Asclepias* L. spp.), thistles (*Cirsium* Mill. spp.) and wild carrot (*Daucus carota* L.), and generally thrive in such situations.

In many rural areas of Canada and the USA, Canada goldenrod inhabits old or abandoned farm fields, pastures, and prairie lands, as well as undeveloped areas (Werner et al., 1980). In such localities, it is an early successional species. However, in well-managed prairies, pastures and cropland, Canada goldenrod typically consists of <5% of canopy cover (Smart et al., 2013). It is also important to note that goldenrods are a component of tall-grass prairies in provinces, such as Ontario in Canada. Unlike the grasses, introduced to Canada by farmers, such as Timothy (*Phleum pratense* L.) or bluegrass (*Poa pratensis* L.), native grasses have evolved to coexist with goldenrod (Ford, 2020).

Native range

Canada goldenrod is originally native to Eastern North America, from 26°N to 45°N, while it now extends to 65°N in the territory of Alaska. It primarily ranges from Newfoundland in the east to Ontario in the west and south to Virginia. This native range and main growth area encompasses much of the Great Lakes region, primarily in Ontario and Quebec in Canada and several northeastern United States where it undergoes a seasonal growth cycle.

Additionally, Canada goldenrod has spread to and now thrives in all US states except Alabama, Florida, Georgia, Hawaii, Louisiana and South Carolina. The species has also now extended its range to all Canadian provinces except for Nunavut in the far north (Pavek, 2012; Canadensis, 2020).

World-wide Spread

Canada goldenrod has now spread to various parts of the world and has been called an 'invasive species' of significant concern. Its abundant seeds, rapid vegetative reproduction ability, and allelopathy to other plants are the main reasons for its successful invasion. (Tang et al., 2013; Zhu et al., 2022).

Canada goldenrod was introduced to Britain and Europe from North America as an ornamental plant in the 17th to 18th centuries. It then spread from gardens to the surrounding natural environments in Central and Eastern Europe expanding at a rate of 741 km^2 per year in Europe. The species then spread to become naturalized in many countries, including Australia, Brazil, China, India, New Zealand and Japan (Zhang and Wan, 2017).

Canada goldenrod was introduced to China in 1935 as an ornamental plant for the gardens of Shanghai (Liu et al., 2005). Since then, it has become a significant and problematic colonizing plant widely distributed in China, especially along the southeast coast and the Yangtze River Basin (Dong et al., 2006; Yang et al., 2011).

In China, Canada goldenrod proliferated to the extent that it accounted for around 35% of the total weed infestations affecting China. It is now extensively distributed in most provinces of China and is listed as one of the most destructive and widespread weeds in China, having negative impacts on native environments (Zhao et al., 2014).

Dong et al. (2006) concluded that a lack of natural enemies in the invaded ecosystems made Canada goldenrod highly invasive and that abiotic factors, such as niche opportunities created by habitat disturbances, human activities, and nitrogen deposition, promoted its establishment and spread through seed dispersal and vegetative structures. In a recent review of Canada goldenrod (Lin et al., 2023), the 'invasion' success of the species in China was attributed to the combination of human activities and its inherently competitive nature.

A detailed study by Zhao et al. (2014) of the genetic diversity among native and invasive populations of Canada goldenrod in China, using AFLP markers, concluded that populations originated from multiple introductions and then spread through long-distance dispersal associated with human activities. They also noted that high genetic variability in the species in the invaded range has favoured its establishment and spread, factors that may well provide a challenge for its successful control. They also suggested that North American populations were possibly of a single genetic group.

Allelopathy

The allelopathic properties of Canada goldenrod have been studied for more than four decades (Zhu et al., 2022). Allelopathic polyacetylenes and diterpenes have previously been isolated from the plant's roots. In some early studies, Fisher et al. (1977) showed that Canada goldenrod reduced the germination and growth of sugar maple (*Acer saccharum* Marshall) in the absence of competing vegetation. In a recent review of allelochemicals of two *Solidago* species Kato-Noguchi and Kato (2022) reported that the extracts, root exudates, essential oil and rhizosphere soils of Canada goldenrod suppressed the germination, growth, and establishment of several native plant species.

Allelochemicals, such as fatty acids, terpenes, flavonoids, polyphenols and their related compounds have been identified in the extracts and essential oils of *Solidago canadensis.* The concentrations of total phenolics, total flavonoids and total saponins in the rhizosphere soil of *S. canadensis* obtained from the invaded ranges were also greater than those from the native areas and ranges, which the species occupied. Kato-Noguchi and Kato (2022) and Zhu et al. (2022) concluded that the strong allelopathic activity of both species supports their 'invasiveness' and the formation of thick monospecific stands.

Abhilasha et al. (2008) found that the Canada goldenrod root exudates inhibited the growth of mouse ear-cress [*Arabidopsis thaliana* (L.) Heynh.]. The magnitude of the inhibition increased with the concentrations of the extract. In their analysis of 40 different root extracts, Abhilasha et al. (2008) found four main secondary compounds with allelopathic properties and different molecular masses that were consistently present in the samples. The levels of the four allelochemicals were lower in *Solidago* populations from newly invaded ranges than in populations of the same ploidy level in their native range. This prompted the authors to suggest that the production of these secondary compounds by the colonizer, invading a new area was lower, possibly because of the higher susceptibility of other plants in such habitats to these substances.

Environmental Effects

Positive Effects

As Eisenstein (2019) recently discussed, several benefits of Canada goldenrod justify growing it in various local environments without trying to control it. This is mainly because the species is known to attract a variety of pollinator insects and other wildlife, including birds that may feed on the insects or seeds. From this point of view, the plant is considered an asset even by farmers who appreciate its ability to attract pollinators who will then pollinate the crops. Together with its distinct golden yellow flowers, goldenrods are also a colourful and desirable species in garden beds, parks or natural settings.

Just like many other high biomass-yielding and fast-growing plants, goldenrods, with their tall and dense stands, can be a good agent for carbon sequestration by absorbing atmospheric CO_2. Removal of large goldenrod stands on a large scale could therefore be detrimental to the environment from the point of view of greenhouse gas reduction, in addition to habitat disruption. While not primarily a wetlands plant, Canada goldenrod can establish itself on the periphery of wet and moist areas. As a consequence, the goal of preserving wetlands may also be adversely disrupted by excessive attempts at removing dense stands of Canada goldenrod.

Negative Effects

While there are positive aspects to Canada goldenrod, it certainly has negative effects on both its native habitats and in newly invaded environments. Its prolific and dense growth can cause moisture and nutrient deficits to other neighbours, which may decline in abundance. This may cause a reduction in local biodiversity and economic losses to agriculture in both crop and livestock farming (Canadensis (2020). If not controlled, dense stands and clusters of Canada goldenrod can reduce grasses or hay on pastureland (Figure 4).

Figure 4. A Photo showing the impact of late summer/fall mowing on Canada goldenrod. The headland of this field (to the right) was mowed for hay in June of the previous year. The area to the left was knocked down in late August, encouraging goldenrod to break dormancy and produce stalks (dark green clumps) (Ford, R., 2020)

Broadly, as a known producer of a variety of terpenoids, phenolics, flavonoids and a large number of essential oils, goldenrod could also affect soil properties and soil microorganisms (Zhu et al., 2022). Some people, especially those with urinary tract or heart disorders may be allergic to various goldenrods; upon touching the plant, some may experience a skin reaction (allergic contact dermatitis) (Macleod, 2013).

Public Perceptions

Given the aforementioned positive and negative effects of Canada goldenrod, it is not surprising that the public perceives it as a controversial species (Canadensis, 2020). In the public mind, the negative aspects of its growth may outweigh the positive aspects. Where it has largely co-existed with humans for a considerable time, if not exactly welcomed every spring, people have come to tolerate the species to a certain extent in many gardens.

A main reason that Canada goldenrod is despised by the public is that it has not been known to live harmoniously with many other plants, particularly in recreational areas, such as public parks and home gardens. Since it can reproduce vegetatively by rhizomes and also by seed, the species can easily take over areas that are otherwise agriculturally productive (Eisenstein, 2019).

One major stigma that goldenrod has long been associated with is that it has been accused of being the cause of allergies or hay fever. However, this accusation is largely unproven. Goldenrod is insect-pollinated and its heavy and slightly sticky pollen does not blow on the wind. Rather, it is common ragweed (*Ambrosia artemisiifolia* L.) that is the usual culprit (Eisenstein, 2019; Canadensis, 2020).

Management of Canadian Goldenrod

Canada goldenrod can be a difficult plant to manage due to its inherent tendencies of rapid, dominant growth. As is the case with many weedy species, several different control methods have been used for its control with varying degrees of success.

Mechanical control

The traditional method of mechanical control is unsurprisingly widely used to deal with Canada goldenrod infestations. Mechanical control includes pulling, digging or hoeing out plants and then disposing of them by various means. This tedious method is suitable for small clusters of plants and is practised by homeowners who wish to eliminate the plants from their properties. However, Canada goldenrod can withstand heavy cutting and will regrow if cutting is done during the growing season. Thus, complete removal of the plants is preferred. To prevent seed dispersal, flower heads also need to be removed before seed ripening (Pavek, 2012).

Large stands of Canada goldenrod may also be dealt with by the removal and burning of the plants. The resulting ashes or char residue can be used as a fertilizer or soil amendment if the land is to be used for growing purposes. This physical control method is widely practised in China, normally after the stems have died (**Figure 5**). This burning represents the wastage of a vast amount of potentially useful biomass, and the smoke from the burning of large stands of plants can be a source of air pollution presenting a significant health risk to those with respiratory problems.

Figure 5 Canadian goldenrods removed by hand from a stand of growth in an area in eastern China (upper) and being burned (lower) (courtesy J. S. Chen).

Chemical control

Several selective, broad-leaf herbicides are available to control Canada goldenrod. However, it is a 'hard-to-kill' species without harming other broad-leaf vegetation. In addition, herbicides are not very practical for Canada goldenrod infestations that can cover large areas. Goldenrods can be killed with the selective herbicide triclopyr, which has a relatively short half-life in soil (Foster, 2023). At heights of 10-15 cm, glyphosate and other selective herbicides, such as 2,4-D and picloram can also be used to control several *Solidago* species.

A mixture of fluroxypyr and metsulfuron has proven selective in wheat, while Canada goldenrod growth on waste land can be effectively treated with other selective broadleaf herbicides, such as sulfometuron, imazapyr, flazasulsufuron and chlorsulfuron. In some cases, selective treatments could be followed by glyphosate and fluroxypyr to increase the effectiveness of control and recovery (Popay and Parker, 2014). In general, multiple herbicide applications are required to treat infestations because they are inherently difficult to control (Foster, 2023).

Biological control

Canada goldenrod is susceptible to many pathogens and insect pests, which reduce biomass production as well as seed production. Thus, biological control presents an alternative to managing the species. In Europe, herbivore pressure is generally low. Snails and small rodents rarely feed on goldenrod stems and leaves. In Switzerland, 18 phytophagous insects feeding on *S. canadensis* are known (Popay and Parker, 2014).

Tang et al. (2013) investigated various non-chemical methods for controlling Canada goldenrod in heterogeneous environments. These included cutting and hoeing and the inoculation with an indigenous pathogen, the fungus *Sclerotium rolfsii* SC64, which was isolated from *S. canadensis* and applied as a solid formulation. The research found that *S. rolfsii* SC64 caused 70% of plant mortality of *S. canadensis* under 150 cm growth stage.

The efficacy of control increased to 80% when the above-ground material was removed. Individually, the methods of cutting, hoeing or treating with *S. rolfsii* SC64, did not provide sufficient control of *S. canadensis*. However, a combination of cutting, hoeing and treating with isolate SC64 during the growing season in May, July and September was able to kill more than 90% of the ramets.

The combinations not only eliminated the plant's sexual reproduction but also killed the underground stems, preventing regrowth. Tang et al. (2013) concluded that such an integrated approach may provide an optimal strategy for the control of *S. canadensis.* These findings support those of Dong et al. (2006) and Lin et al. (2023) who also concluded that combined control methods, and minimizing seed production seem to be critical for effectively controlling Canada goldenrod and these control measures need to be taken before flowing.

Utilization of Canada Goldenrod

Instead of attempting to eradicate or control large infestations of a species, such as Canada goldenrod, an alternative is to take advantage of them as a freely available resource to be utilized (Ciesielczuk et al., 2016; Duns, 2020; Chandrasena, 2023) for a variety of applications. As with other large biomass-producing colonizing species, Canada goldenrod has been utilized for some traditional applications over the years. However, there are various other possible utilization opportunities also, which are under investigation. Some applications utilize the entire above-ground biomass of the plants, while others make use of only specific parts or even specific chemicals extracted from the plant (Figure 6).

In this brief review, the intention is to give the reader a sense of which applications have the greatest value and what could be done in the future. In the utilization of Canada goldenrod, the whole biomass may be utilized, such as burning it for heat or fuel in its most simplistic form, or only one or a few components may be utilized, e.g., carbohydrates for bioethanol. Some applications involve the conversion of biomass into its various constituent components (e.g., cellulose, hemicellulose, and lignin), which can then be further converted into other products by chemical, mechanical (pressure, agitation, grinding) and/or biological processes (enzymes, microbes) to produce many possible products.

The products that can be derived from fast-growing and large biomass-producing colonizing species include biofuels, such as bioethanol, biomethanol, biodiesel and biogas, cellulose fibres for pulp and paper, lignin, carbohydrates and proteins, as well as smaller chemical building blocks to synthesize other larger chemicals that would otherwise be obtained from petroleum refining (Ayoub and Lucia, 2018; Chandrasena 2023).

Zihare and Blumberga's review (2017) of Canada goldenrod utilization was a quantitative study of the number of publications related to this objective. Their hypothesis was that such weedy species could be a valid resource for high-value-added products and instead of eliminating them, great benefit could be obtained from their use. A breakdown of the major areas of utilization of Canada goldenrod that they determined is shown in the pie chart of Figure 6.

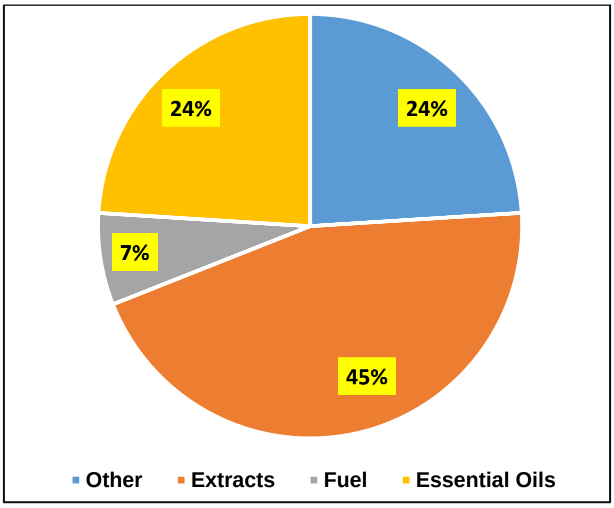

Figure 6. Proportions of studies reported on different utilization modes of Canadian goldenrod (Source: Zihare and Blumberga 2017).

It is to be noted that extracts make up 45% of the total utilization modes, with essential oils and the “Other” category making up 24% each, and fuel (biofuel) applications at 7%. The “Other” category is composed of assorted uses such as cellulose, compost, animal litter, honey production, isolated compounds, pest control, and rubber incorporation, in approximately equal proportions of 3.4% each of the total 7% of this category.

Figure 7 below provides an overview of different Canada goldenrod plant parts that can be utilized beneficially. ‘Extracts’ obtained from the plant are the most dominant utilization category for various practical applications, although this aspect also appears to have immense potential for further development. Some of the more historical and significant practical uses of Canada goldenrod, and other uses, which are at the developmental research stages, are discussed below.

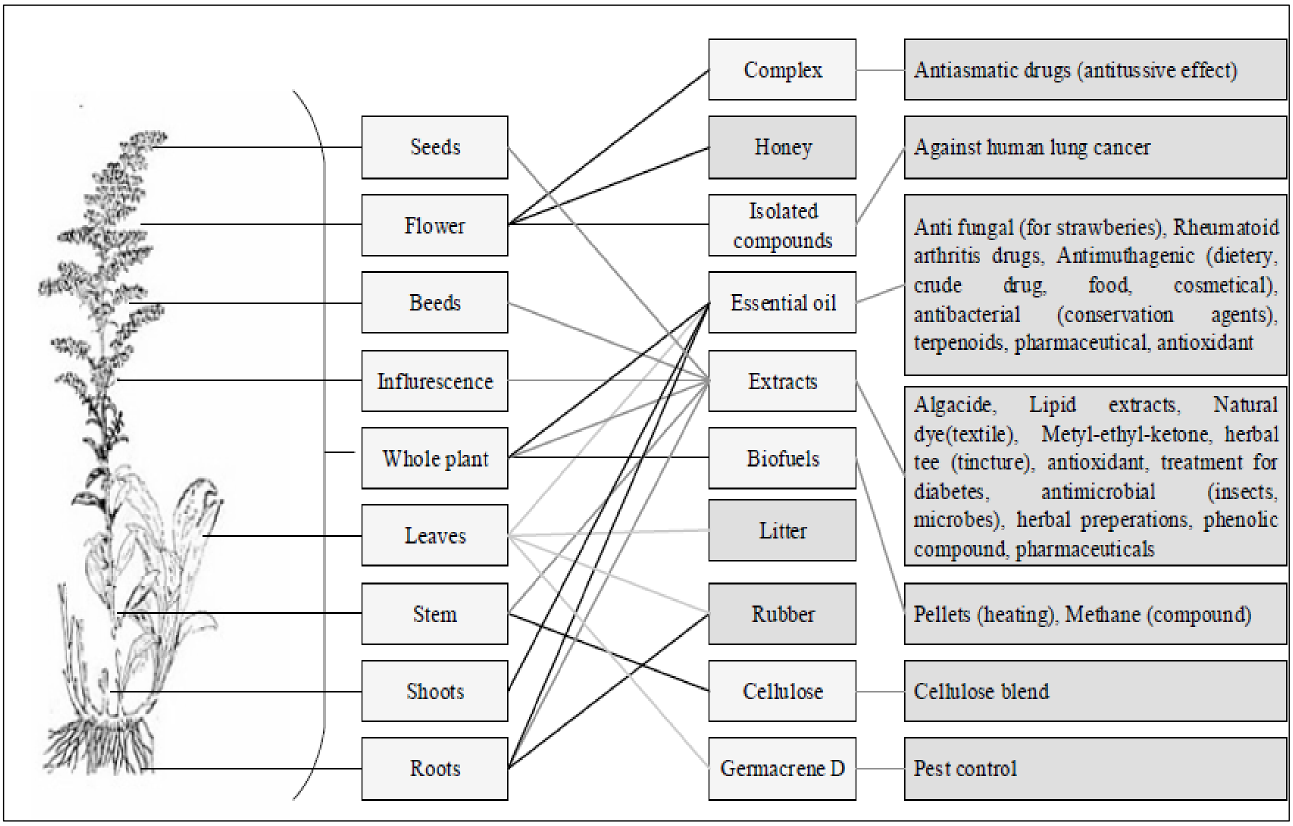

Figure 7. Classification of *Solidago canadensis* plant parts used as resources for various applications and products (reproduced from Zihare and Blumberga, 2017)

Medicinal and Nutritional uses

The best-known traditional use of Canada goldenrod is in the area of herbal medicine. Parts of the whole plant or extracts have been used to cure various ailments for centuries. The origin of the Latin name also reflects the plant’s many traditional medicinal uses; the genus name *Solidago* comes from the Latin *solidus* meaning “whole” and *ago* meaning “to make”. In effect, *Solidago* means “to make whole or cure” (Macleod, 2013).

Canadian goldenrod has been used by North American First Nations peoples for millennia for its medicinal and nutraceutical benefits. Its flowers and roots have traditionally been used to treat a wide range of ailments or symptoms, such as burns, fever, snake bites and sore throats (Wetzel et al., 2006).

Other traditional medicinal benefits of the species include asthma prevention, treatment for fever, fungal infection and inflammation of the mouth. (Canadensis, 2020). The plant extracts have also been used for urological, antiphlogistic and analgesic applications, gastro-intestinal and liver treatments, as well as for treatment of burns and ulcers. Infusions from goldenrod were used to relieve intestinal cramps and headaches. Broadly, Canada goldenrod extracts exhibit a spectrum of activities, including diuretic, anti-microbial, cytotoxic and antioxidant properties and also stimulate the immune system.

The nutritional or food uses of Canada goldenrod are linked with its medicinal usage. Flowers and leaves are edible and can be considered a modest source of nutrition (or nutraceuticals) (Wetzel et al., 2006). The plant has been brewed as a tea for centuries and the seeds can be used for thickening soup (Canadensis, 2020). Canada goldenrod is also an important source of the plant flavonol and antioxidant quercetin (3,3′,4′,5,7-pentahydroxy flavone. These chemicals are currently being studied and promoted by nutritionists and natural health practitioners to help combat chronic malnutrition and diabetes (Macleod, 2013).

Essential Oils

Many of the medicinal effects of Canada goldenrod and other goldenrods have been attributed to its essential oils and other components. Earlier studies on the plant have led to the isolation of a wide range of flavonoids, phenolic acids, saponins, alkaloids, polyacetylenes, mono- and di-terpenes and sterols (Lu et al., 1993; Bakia et al., 2019; Shelepova et al., 2019).

An extract of the flowers of a European goldenrod (*Solidago virgaurea* L.) was recently launched commercially in the Egyptian market under the trade name Cystinol® at a dose of 400 mg. It is used for the treatment of urolithiasis by promoting the excretion of water more than the electrolytes and increasing renal blood flow. This facilitates the washing out of bacteria from the urinary tract and prevents crystal formation, and hence kidney stones (Bakia et al., 2019).

In their review, Zihare and Blumberga (2017) determined that approximately 70% of the research on Canada goldenrod relates to the extraction of essential oils from the plant. The essential oils have both cytotoxic and anti-microbial activities. Zhu et al. (2009) compared the antimicrobial activities of volatile, essential oils from *Solidago decurrens,* a traditional wild medicinal plant and *S. canadensis* from east China. The most abundant component of the volatile oil from the leaves of *S. canadensis* was germacrene D (44.24%), while the most abundant component of the volatile oil from the leaves of *S. decurrens* was δ-elemene (21.73%). Overall, the antibacterial activity of the oil from *S. canadensis* was lower than that from *S. decurrens*.

El-Sherei et al. (2014) examined the effect of seasonal variations on the composition of the hydro-distilled essential oils of fresh flowers and green aerial parts of *Solidago canadensis* cultivated in Egypt over the four seasons of the year. The major compounds detected in the oil samples of all seasons were: germacrene D (9.9-29.5 %, (in agreement with Zhu et. al., 2009), α-pinene (3.4-29.2 %), γ-cadinene (0.4-20.4 %), myrcene (3.0-13.7%) and limonene (4.8-11.5 %). In addition to these dominant terpenes, reports indicate significant amounts of 6-epi-β-cubebene, a taste-generating sesquiterpene also in Canada goldenrod essential oils (Wang et al., 2006).

El-Sherei et al. (2014) reported a seasonal variation effect with the summer samples containing the highest amounts of monoterpene hydrocarbons, while the winter samples yielded the highest amounts of sesquiterpene hydrocarbons. While all oil samples showed considerable potential cytotoxic activity against human liver, breast and cervix carcinomas (Hepg2, MCF7 and Hela, respectively), the winter samples showed relatively higher cytotoxic activity compared to the summer samples. Thus, essential oils and other chemicals extracted from Canadian goldenrod have the potential to be developed further for obtaining beneficial health effects.

Anti-Oxidant Activity

The leaf and bark of Canada goldenrod contain a wide range of bioactive compounds (Wang et al., 2006; Deng et al., 2015; Shelepova et al., 2019), which show antioxidant, antimicrobial, antifungal and anti-inflammatory properties. However, this review finds that the properties of these molecules and/or their mixtures are yet to be fully understood and explored for beneficial, practical applications.

Deng et al. (2015) investigated the total phenolics, tannins and flavonoids and the antioxidant and antimicrobial activities of ethanolic extracts from the leaves and bark of Canada goldenrod at three ripening stages - vegetative growth only; full bloom; and mature after flowering. Extractions were made with either high-pressure (HP) or ultra-sonication.

The antioxidant activities, as well as the phenolic, tannin and flavonoid contents varied with ripeness stage, tissue type and extraction method. Overall, the ultra-sound extracted leaves of the full bloom stage exhibited the highest phenolic content (3.8. mg GAE g dry matter^{-1}), 2,2-diphenyl-1-picrylhydrazyl (DPPH) scavenging capacity (0.547. mg AAE g dry matter^{-1}), and oxygen radical absorbing capacity (ORAC) value (57.86. mmol TE g dry matter^{-1}). The high-pressure extracts of mature plant samples had the highest flavonoid content (2.45. mg RE/g DM and reducing power - 3.38) as well as the highest tannin content (4.17. g/100. g DM) (Deng et al., 2015).

All leaf extracts exhibited antimicrobial activity against *Listeria monocytogenes* and *Staphylococcus aureus*, but only the HPE extracts of the VG samples showed activity against *Salmonella* spp. (Deng et al., 2015). The UE leaf extracts at the MF stage demonstrated the maximum inhibitory potency against *Escherichia coli*, *L. monocytogenes* and *S. aureus*. These results highlight the potential of using Canada goldenrod extracts as natural antimicrobial and antioxidant substances for food applications.

As part of a study examining the anaerobic degradation of Canada goldenrod by sulphate-reducing and methane-producing bacteria, Havryliuk et al. (2023) analysed the plant's phenols, flavonoids and total carbohydrates in 70% ethanol extracts and whole plant samples. The results (Table 1) showed that goldenrod extracts contained an exceptionally large amount of carbohydrates (4.54 mg mL^{-1} of extract or 511.5 mg g^{-1} of dry matter). The concentration of phenolic compounds was also high (4.3 mg mL^{-1} of GAE, gallic acid equivalents or 485.6 mg of GAE g^{-1} of extract). Flavonoids were 3.4 mg mL^{-1} or 385.7 mg g^{-1} of extract. The authors also showed that antioxidant activity was also high in the Canada goldenrod extracts, reaching a value of 86.3%. Overall, they demonstrated that goldenrod plants contain a large concentration of organic compounds, and, in particular, carbohydrates, vitamins and flavonoids. The study concluded that Canada goldenrod was a valuable substrate for the growth of anaerobic microorganisms and biogas synthesis with major applications in the production of biofertilizers, bio-ethanol and biofuels.

Table 1. Total phenols, flavonoids and carbohydrates contents in plant extracts and plant biomass of *Solidago canadensis L.* (from Havryliuk et al., 2023)

Type of Analysis	Value mg/mL of Extract	Value mg/g of Extract	Value mg/g of Plant
Phenols (GAE)	4.3 ± 0.3	485.6 ± 28.4	105.7 ± 6.2
Flavonoids (RUE)	3.4 ± 0.1	385.7 ± 16.4	84.0 ± 3.6
Total Carbohydrates	4.5 ± 0.2	511.5 ± 23.1	111.4 ± 5.0
DOC	8.5 ± 0.5	956.8 ± 45.5	208.3 ± 17.7
Anti-oxidant activity %	86.3 ± 4.2	-	-

Kołodziej et al. (2011) had already reported significant antibacterial and antimutagenic activity of hexane and ethanolic extracts of three *Solidago* species (*Solidago virgaurea*, *Solidago canadensis*. and *Solidago gigantea*). They observed that both extracts of all three species were antibacterial. However, the extracts were stronger in inhibiting Gram-positive bacteria (i.e., *Staphylococcus aureus*, *Staphylococcus faecalis* and *Bacillus subtilis*) than Gram-negative bacteria (i.e., *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*).

Hexane (lipophilic) extracts of Canada goldenrod were the strongest against Gram-positive bacteria, while the other extracts were weaker. However, ethanolic extracts of *S. gigantea* and *S. canadensis* showed relatively strong activity against Gram-positive bacteria. In general, alcohol extracts were stronger in antibacterial activity compared with hexane extracts. Nevertheless, hexane extracts of the three goldenrods exhibited antimutagenic activity at a concentration of 2.5 mg mL^{-1} whereas ethanolic extracts, in the range of concentrations tested, did not show antimutagenic activity (Kołodziej et al., 2011).

Biofuels and Bioenergy

The most significant non-food application of biomass-based materials has undoubtedly been in the area of biofuels and bioenergy, as the search for environmentally benign, non-toxic, renewable and sustainable alternatives to fossil fuels widens. The large biomasses of several fast-growing colonizing species are ideal for this purpose (Young et al. 2011; Sharma and Pant, 2018; Chandrasena, 2023).

However, Zihare and Blumberga (2017) noted that unlike some other weeds and other organic waste materials, Canada goldenrod biomass has yet to be subjected to adequate investigations and applications as a source of bioenergy or biofuels. Only 7% of studies on different application modes of goldenrod have been in the fuels area (Figure 6).

The study of Ciesielczuk et al. (2016) who examined the possibility of using Canadian goldenrod, wormwood (*Artemisia absinthium* L.) and common tansy (*Tanacetum vulgare* L.) as sources of biofuels is an important contribution. The authors studied field harvested yields, density of growth, dry matter contents of the harvest, bulk density, ash content and calorific values obtained from the species. Their results revealed that all species, with their capacity for fast growth, could be great energy sources due to their favourable characteristics, such as high calorific value (over 16 MJ kg^{-1}), low moisture, low costs and abundant availability.

Canadian goldenrod, in particular, was found to be especially promising as a fuel source since it is capable of covering large areas of land and could be efficiently harvested and burned without much heating system changes (Ciesielczuk et al., 2016).

Yao et al. (2014) had earlier observed that the methane production of Canadian goldenrod digested with cattle slurry was highly stable and efficient. Their results are supported by Havryliuk et al. (2023), who examined methane production, as well as copper immobilization through the degradation of Canada goldenrod plants by methane-producing and sulphate-reducing bacteria. Recording highly efficient methane production and copper detoxification in the degradation of goldenrod biomass by methanogenic bacteria, the study recommended that harvested biomass be easily fermented for biogas without the use of additional fermentation co-substrates.

Another application in the biofuels area is the bio-conversion of plant biomass to ethanol (bio-ethanol). While bio-ethanol has become a major commodity in the "green" fuels sector, the need for non-food sources of sugars to ferment to ethanol is required to avoid land use conflicts with food crops, such as corn and sorghum. Consequently, organic waste materials, such as crop residues, food waste, brewers' dregs and other materials have been examined to produce "second generation" bio-ethanol. Weedy species, a source of lignocellulosic biomass, are thus an appropriate potential source of bio-ethanol (Chandrasena, 2023, p. 273-277).

In a recent study, Wiatrowska et al. (2022) examined the energy production potential of several weedy species in Poland. The species were: Asian knotweed (*Reynoutria japonica* Houtt.), *Reynoutria sachalinensis* (F. Schmidt) Nakai and a hybrid *Reynoutria* × *bohemica* Chrtek & Chrtkova; Canada goldenrod, *Solidago gigantea*, and steeplebush (*Spiraea tomentosa* L.). The higher heating value (HHV) and lower heating value (LHV) of the plants were calculated. *Solidago canadensis* and *S. gigantea* had high heating values of 19.9 MJ·kg−1 and 19.4 MJ·$kg^{-1,}$ respectively. The observed heating values ranged from 18.5 MJ·kg^{-1} for *R. japonica* to 19.9 MJ·kg^{-1} for *R. sachalinensis.* For the remaining species, heating values were also approximately 19.0 MJ·kg^{-1}; indicating the possibility of using the biomass of such species for energy purposes, via combustion. The authors also noted that these high heating values were comparable with the values obtained for some common, energy-yielding species, such as willow (*Salix* L.) species (19.4–19.6 MJ·kg^{-1}) and the grass -*Miscanthus* (17-20 MJ·kg^{-1}).

Wiatrowska et al. (2022) also investigated the above species as sources for obtaining bio-ethanol using an alkaline pretreatment with 1% sodium hydroxide, followed by simultaneous saccharification and fermentation. While the highest bio-ethanol yield was obtained at 2.6 m^3 ·ha^{-1} for the *Reynoutria* × *bohemica* biomass, the remaining species, including the two *Solidago* species, also gave ethanol yields around 2 m^3 ha^{-1}, proving that the studied weedy species could be an inexpensive, potential raw material for the production of bio-ethanol.

Pulp and Paper

A significant application of biomass from various large-sized weedy species is their use as a source of cellulose fibres for paper pulp and other related products (Zihare and Blumberga, 2017; Duns, 2020; Vrabiˇc-Brodnjak and Možina, 2022). Colonizing species, including Canadian goldenrod, are a readily available source of lignocellulosic biomass. They are eminently suitable as renewable alternatives to traditional wood sources of cellulose fibres that can be used in the manufacture of paper and paper products, such as personal hygiene products and packaging materials.

In the area of papermaking. Li et al (2006; 2007) determined the chemical composition and fibre morphology of Canada goldenrod plants in China. Their results showed that the chemical composition included - ash content (2.92%), lignin (18.78%), holo-cellulose (80.28%), and pentosan (19.34%). The ash content was much lower than that of wheat straw (*Triticum* L. spp.), and close to that of common reed [*Phragmites australis* (Cav.) Trin. ex Steud.]. The lignin content was similar to that of wheat straw, while its holocellulose content was equivalent to that of poplar (*Populus* L. spp.).

Goldenrod fibres were on average, 9.8 mm long, with a length-width ratio of 0.86. The fibrous cell wall thickness was 3.03 µm, and the ratio of cell wall thickness to lumen of 0.36. These measurements indicated that the Canada goldenrod fibres were suitable for pulping and papermaking. Studying the effectiveness of bleaching for the production of chemical pulp from Canada goldenrod fibres, Li et al. (2007) reported that standard alkaline-anthraquinone bleaching was sufficient and suitable for producing the bleached chemical pulps from those fibres.

Despite the suitability for producing chemical pulps from its cellulose fibres, this particular utilization of Canada goldenrod has yet to see full commercialization to any extent, unlike *Spartina alterniflora* (smooth cordgrass). As discussed by Duns (2020), an industrial facility was successfully established and operates in China (WHERE?? xxxx) to produce moulded pulp products from smooth cordgrass, taking advantage of extensive and large stands. The possibility exists to extend a similar technology to the harvested stands of Canada goldenrod without letting the biomass go to waste.

Wood-Polymer Composites

Another significant and growing application of biomass from colonizing species is in wood-polymer composites, or specifically, those that are designated wood-plastic composites (WPCs). In effect, they are mixtures of wood fibres and thermoplastic resins, such as polypropylene (PP), polyethene (PE), or polyvinyl chloride (PVC). The composites are thermoplastics, reinforced with filler consisting of natural plant fibres and prepared under controlled temperature and pressure, and mixing. The cellulose fibres from plant sources partially replace the synthetic polymer in the composite material.

WPCs have many excellent properties, such as high durability, wear resistance, and specific strength and stiffness and can also attain a texture similar to that of solid wood. In many cases, the cellulose fibres impart improved mechanical and chemical properties in the composite compared to the original polymer matrix, such as improved tensile strength, density, weight reduction and moisture absorption. The main application of WPCs was initially in the manufacture of exterior decking and fencing. However, WPC applications have greatly expanded to other industries, such as the automobile, aerospace and electronics sectors, and advanced building construction materials (Ayoub and Lucia, 2018).

WPCs have also been fabricated from other environmentally friendly materials, such as wood waste, waste paper, agricultural residues, such as wheat straw, other unused natural resources including various plant species, and recycled thermoplastic resins. Fibres from diverse sources of biomass, including colonizing plants, have accordingly been investigated for use in composites.

The average individual fibre properties are an important requisite for the use of a particular type of fibre in composites. The characteristics of the particular filler used for manufacturing WPCs influence the physical and mechanical properties of the obtained composite. Filler materials include wood-based filler, other natural fibres, and recycled materials

In an important, first-ever report from China, Liu et. al. (2017) provided details of the chemical composition and fibre characteristics of Canada goldenrod (Table 2). They also investigated the potential of goldenrod fibres as a filler to produce high-density polyethylene (HDPE) composites. The filler consisted of goldenrod stem fibres pulverized into powder and chemically modified by the addition of a silane coupling agent to render the polar fibres more non-polar to be compatible with the non-polar HDPE. The treated fibres were mixed with HDPE in various proportions to prepare composites.

When the composites were prepared, scanning electron microscopy (SEM) analysis revealed good contact and interaction between the fibre-matrix interfaces, forming a three-dimensional network structure, a property which is essential for good composite construction. The resulting mechanical properties of the composites showed that a maximum tensile strength could be obtained at a loading of 30% Canada goldenrod biomass replacing the HDPE.

Table 2. Chemical composition and fibre morphology of Canadian goldenrod (from Liu et al., 2016)

Chemical composition	
Cellulose (%)	36.69
Pentosan (%)	18.68
Lignin (%)	16.37
Ash (%)	2.35
Extractives (%) *	4.58
Fibre Morphology	
Length (um)	720.72
Width (um)	212.24
Aspect Ratio	3.397

* Ethanol-Toluene extractives

The study by Liu et. al. (2017) has proved how useful the biomass content, chemical/physical characteristics and fibre properties of Canada goldenrod can be. The strength and other properties of the HPDE composites that can be made with Canada goldenrod fibres also show the potential for expanded utilization of the species as a natural material for filler for composites.

Biochar Applications

Biochar is a carbonaceous material, a type of charcoal with high carbon content, which can be made from biomass via pyrolysis under low oxygen or anaerobic conditions. Due to its large specific surface area, and well-developed pore structure, biochar is an excellent adsorbent material. When added to soil, biochar can improve the soil porosity, air content, water holding capacity and fertilizer efficiency of soil (Cha et al., 2016).

The carbon in biochar is stable and no longer participates directly in the carbon cycle, so this is a significant approach to carbon sequestration, which has the potential to help mitigate climate change and reduce the greenhouse effect via carbon sequestration (Panwar et al., 2019). Biochar is also relatively cheap to produce on a large scale and has become increasingly popular for various environmentally-friendly applications.

The use of biomass from weedy species, such as Canada goldenrod and many others, as a source of biochar has been under investigation for more than two decades. In a recent study, Zhang et al. (2018) prepared biochar from Canada goldenrod and showed its effective use for alleviating the inhibition of tomato seed germination by allelochemicals in soil. The biochar-amended soils also promoted the germination and growth of tomatoes compared with soils, which were not amended.

Phytoremediation Potential

Canada goldenrod plant biomass may also serve in environmental applications as a biofilter medium or phytoremediation agent for removing heavy metals from contaminated soils or water. This was proved in a study in Poland by Bielecka and Królak (2019) who analysed Pb and Zn contents of above-ground and below-ground parts of Canada goldenrod from an agricultural and previously mined, industrial area. Lead contamination in the agricultural area was low (median of 22 g kg^{-1}), while the industrial area was heavily contaminated (median of 201 mg kg^{-1} but up to 1626 g kg^{-1}) of Pb in soil. In addition, Zn levels in the contaminated soils were: in the agriculture area – 42 mg kg^{-1} and in the industrial 350 mg kg^{-1}.

The results showed that Canada goldenrod tolerated and bio-accumulated both metals. Pb accumulation was mainly in the roots and rhizomes (estimated to be up to 540 g Pb ha^{-1}) whereas above-ground parts had 70 g ha^{-1} of Pb. Concerning Zn, in the heavily contaminated industrial soils, both above and below-ground parts of plants accumulated similar amounts (ca. 450 g Zn ha^{-1}). However, in the agricultural area, with a natural Zn content in the soil, goldenrods bio-accumulated Zn in larger amounts (ca. 250 and 110 g ha^{-1}) in the above-ground and under-ground parts, respectively.

This result prompted Bielecka and Królak (2019) to suggest that Canada goldenrods could be used to phyto-extract Zn from the soil. In discussing their results, the authors also recommended that Canada goldenrod be used as a phytostabilizer of Pb and Zn in soils heavily contaminated with these elements.

Dyes for Various uses

One of the earliest non-food applications of plants has been as a source of dyes, which are naturally occurring colouring materials. A wide range of natural plant dyes gives rise to a spectrum of colours ranging from yellow to black. These dyes arise from various organic and inorganic molecules in the plant, which absorb light in the visible region of 400-800 nm. Based on archaeological evidence, nontoxic and renewable natural dyes and pigments have been used for colouring food substances, leather, wood, natural fibres and fabrics from the dawn of human existence (Chandrasena, 2023a,).

These colour-producing compounds commonly include a vast array of flavones and flavonoids, quinones, polyenes (carotenoids), and nitrogen-containing organics, such as pyrroles, pyrimidines and alkaloids. Dyes have traditionally been used to impart specific colours or mixtures of colours to various textiles, such as silk and cotton, leather and yarn, including jute, while non-toxic dyes are used in the food and cosmetic industries (Choudhury and Chandrasena, 2022; Chandrasena, 2023b, p. 297).

Many colonizing species have been the most important sources of plant dyes for millennia and some species have more value in this regard than others (Choudhury and Chandrasena, 2022). Canada goldenrod has traditionally been used as a source of natural dye, mainly yellow dye from the carotenoids present in the flowers (Chandrasena, 2023b, p. 297).

Canada goldenrod has also been used as a model plant for investigating and standardising industrial dye production methods and properties of plant dyes. For example, Bechtold et al. (2007) studied aqueous solutions containing flavonoid dyes extracted from goldenrods employing absorbance measurements by photometry after the addition of FeCl2, analysis of total phenolics (TPH) in the extracts and the depth of dyeing of wool yarn. In this study, TPH calculated as gallic acid equivalents ranged from 62-97 g kg^{-1} of plant material with one sample exceeding this range with a value for TPH of 142 g kg^{-1}.

Correlation among TPH, photometry in the presence of FeCl2 and lightness of the dyeing have been used to characterise plant sources for dyes.

However, the study found a poor correlation between the photometric results and the colour depth of the final dyeing of yarn Bechtold et al., 2007).

Leitner et al. (2012) used Canadian goldenrod as a representative case to study the production of a concentrated solid plant dye as opposed to the direct use of more dilute natural plant extracts for dyes. The authors concluded that using such a concentrated naturally produced dye offers novel approaches concerning the standardisation of dyestuff quality, handling and applicable dyeing techniques.

Natural growth elicitor/pesticide

The large variety of chemicals produced as secondary metabolites by Canada goldenrod may also serve as growth elicitors or a natural pesticide that can be put to practical use. One of the best-documented examples is the algicidal activity reported by Huang et al. (2013; 2014). In their studies, concentrated ethanol extracts of Canada goldenrod controlled the toxigenic cyanobacterial blooms of *Microcystis aeruginosa* in a natural water column (pond). Extracts of 0.3-0.5 g L^{-1} inhibited *Microcystis* biomass by more than 70% after 5 days after treatment (DAT) and more than 80% after 25 DAT, without any long-lasting negative effects on water quality parameters. Moreover, the extracts had lower toxicity to *Daphnia magna* and zebrafish than to *Microcystis aeruginosa*. With hardly any adverse effects on the aquatic ecosystem, the study suggested that it was feasible to use Canada goldenrod extract as an algicide to control *Microcystis* blooms in static bodies of water.

Adding to these findings, Liu et al. (2017) investigated the anti-fungal properties of Canada goldenrod essential oil against the highly virulent, pathogenic fungus ‘grey mould’ (*Botrytis cinerea*) in a range of in vitro studies. The practical application investigated was to determine whether the vapour from the oils could be used to prevent the post-harvest decay of strawberry (*Fragaria* × *ananassa* Duchesne) fruits, caused by the grey mould. The essential oils from the leaves of Canada goldenrod plants exhibited a highly potent and dose-dependent, antifungal activity against *B. cinerea*. Compounds in the vapour profoundly altered the pathogen’s mycelial morphology, cellular structure, and membrane permeability. The study suggested that Canada goldenrod oils could be developed further for the control of post-harvest fungal diseases while maintaining taste and other qualities in strawberries.

Animal husbandry

As well as being a natural food source for many insects such as butterflies, the prolific growth of Canada goldenrod in rural fields and pasture lands suggests that it could be an asset for farmers. It may serve as a cheap and readily available source of food, bedding or litter for farmers and others who raise animals, as well as for certain wild animals.

Zihare and Blumberga (2017) noted that Canada goldenrod leaves have been used as a source of animal litter as well as fodder. The plant is grazed by animals such as cattle, sheep, horses and whitetail deer (Pavek, 2012). However, many farmers, especially in North America dislike Canada goldenrods because of the potential detrimental effects of unchecked infestations on pasturelands and competition with traditional forage crops (Ford, 2020). In such cases, farmers would do well to avoid dense stands from forming. To avoid such conflicts with other fodder crops, Pavek (2012) recommended seeding Canada goldenrod at low densities or planting in small, manageable areas. However, despite the potential, the species is not popular as fodder for animals, especially in North America.

Landscaping and Gardening

Canadian goldenrod is tolerated and even welcomed by some people in their gardens, primarily due to its attractive, golden yellow flowers that can attract butterflies and moths. The plant also attracts other beneficial insects, such as ladybirds, lacewings and hoverflies, which are known to help control insect pests in home gardens. The species, therefore, has landscape uses, including as a perennial for urban and woodland gardens. It is also suitable for cut or dried flowers and has also been used along roadsides for soil containment, and along seashores and riverbanks to mitigate erosion.

Canada goldenrod can also be used for rangeland revegetation of disturbed areas, mine spoil reclamation, and soil stabilization (Pavek, 2012). Utilized in this manner, Canada golden plays a modest ecological role with some environmental benefits. Although it is not typically favoured by horticulturists and gardeners for landscaped settings, due to its rapidly spreading growth, some consider it a worthwhile addition to beautifying gardens. Managing the species in garden settings may require controlling seed dispersal by removing flower heads before seed ripening (Pavek, 2012).

Conclusions and Outlook

As discussed above, with both negative and positive aspects, Canada goldenrod has become a somewhat controversial species. As an extraordinarily successful colonizer, capable of prolific and unbridled growth, the species can quickly become dominant in different habitats and soil types.

As such, it has botanical traits, which make it a nuisance, especially in rural areas where it may compete in agricultural lands in which primary agricultural crops could be grown. Canada goldenrod has been wrongfully accused of being a source of allergies and hay fever and has also been maligned by the public for this reason. The species has spread from North America rather readily to various distant parts of the world, including Europe and China, where it is often considered a significant problem.

Where it is a problem, mechanical control of Canada goldenrod, or indeed many other similar weed species, is likely to be the least harmful to the environment. In the case of relatively small infestations, mechanical or manual control is the most practical, provided the residues are not simply burned but used for other purposes.

Mechanical methods are especially suitable for small stands, or in places where labour is inexpensive and plentifully available (such as in parts of China). Spot treatments with herbicides are also effective in controlling small to medium stands of goldenrods, in cases where the threat of expansion poses a risk to landscapes. However, it should be noted that in many locations I North America, where Canada goldenrod is native, the stands are now largely left alone and, as a result, have proliferated in both urban and rural areas.

Canada goldenrod plants are a rich source of chemicals, which are its secondary metabolites. While some of these chemicals may contribute to its inherent allelopathy and dominance in its local environment, several chemicals clearly have therapeutic values that can be exploited.

While there are many negative aspects to Canada goldenrod, on the positive side, the stands of Canada goldenrod are an enormous source of lignocellulosic biomass that can also be beneficially exploited. Based on analysis of the fundamental chemical and physical properties, this biomass can be a natural raw material for applications, such as wood fibre-polymer composites. Research is certainly moving in the direction of proving that the species could be converted into a new bioresource, which can be of excellent value for industrial applications.

The question as to whether or not a particular colonizing species should or could be purposefully cultivated to serve as a source of biomass is contentious. The traditional solution to weedy species by relentless control is a mindset that is difficult to change. In this situation, controlled cultivation on land less suitable for food crops may serve the two-fold purpose of supporting a local economy while at the same time managing any adverse effects pioneering species may have on local environments. If treated as valuable bioresources, they will not be left to rot and waste away or disposed of by burning, becoming a source of pollution or environmental contamination.

As Chandrasena (2023a, b) has discussed with examples, some countries and jurisdictions have already begun to '*see*' colonizing species as bioresources and not as enemies. Many countries and regions appear ready to use selected species judiciously in many eco-friendly applications and as invaluable raw materials for industries. However, in advanced economies, especially in North America, including the USA and Canada, the UK, Australia and New Zealand, the bioresource potential of colonizing species is largely ignored because of inadequate 'eco-literacy and 'weed-literacy'. It is abundantly clear that the prevailing discourses on weedy species are largely skewed towards '*seeing*' them only as problems (Chandrasena, 2023 a).

Rather than attempting to eradicate colonizing species with costly and environmentally hazardous control methods and tools**,** *is it time to look at other available choices*? Humans can learn to live in concert with many species, simply by learning to utilize the strengths of most species.

The choices are certainly not unique to Canada goldenrod, but this species can certainly serve as an example of what can be done. Based on the scientific evidence available, '*re-thinking'* should allow societies to reach a common consensus, if not a strategy, towards utilization as a management tool for many of the species that are perceived as 'problematic' on a global basis and not just locally.

Utilization, as bioresources, should be a viable option for many colonizing species, such as Canada goldenrod. Their attributes of rapid growth, high biomass production and proliferation together with strong characteristics of root and stem growth render them a reliable source of lignocellulosic biomass. While this particular source of biomass has seen some utilization as a source of raw material to produce energy and a variety of industrial products, it largely remains yet to be exploited to its full potential.

The advantages of using weeds as raw materials are not just related to their robust and fast growth and tolerance of a range of ecological conditions, but also to their resilience. These species are amenable to repeated harvesting, leaving behind sufficient rootstock that may regrow for continual, sustainable harvesting. Ease of harvesting is a key factor in the utilization of weedy species for practical applications (Vrabiˇc-Brodnjak and Možina, 2022).

The utilization of Canada goldenrod is, however, not the complete solution to the problems it may cause in some situations. There could be situations where utilization is not possible, or the populations of the species may have grown out of control on a scale that causes concern to both farmers and the public.

Sufficient knowledge, tools and techniques are available for deployment in these instances, where control is needed. *Control where needed is not in conflict with utilization, where there is potential. Control methods selected should only be the ones that are the most ecologically and environmentally-sound for the specific landscape or situation*.

An integrated management strategy would be ideal in many circumstances. This would consist of judicious management, combined with responsible and environmentally-friendly harvesting techniques and utilization. Large quantities of plant biomass generated by the growth of Canada goldenrod and similar weedy species should not be wasted.

With the increased need for biomass as an alternative to petroleum as a feedstock for energy, chemicals and other products, the outlook for Canada goldenrod to fill at least a part of this need is promising. Increased awareness on the part of the general public, as well as industry, and promotion of the utilization of weedy species, will help to solve the age-old question of how to deal effectively and practically with weeds. There should be a common consensus, if not a strategy, towards utilization on a global basis and not just left as an issue to deal with by local governments or civic organizations.

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