

## Review

# Invasive Alien Plant Species for Use in Paper and Packaging Materials

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**Abstract:** Invasive plant species can impede the establishment and growth of native plants and affect several ecosystem properties. These properties include soil cover, nutrient cycling, fire regimes, and hydrology. Controlling invasive plants is therefore a necessary, but usually expensive, step in restoring an ecosystem. The sustainability of materials with an emphasis on the use of local resources plays an important role in the circular economy. The use of alternative fibers from invasive plants promotes local production in smaller paper mills that offer the protection of local species and the reduction of waste and invasive plants. A synthesis of the literature is needed to understand the various impacts of invasive plants and their practical control in the context of papermaking applications and to identify associated knowledge gaps. To improve our understanding of the practical application of invasive species in the paper industry, we reviewed the existing literature on invasive plant species in the area of fiber production, printability, coating solution production, dyes, and extracts, and collected information on the major invasive plant species in Europe and the methods used for various applications.

**Keywords:** fibers from invasive plant species; Knotweed; Goldenrod; Black Locust; Europe; paper production; pulp; material analysis; applications



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## 1. Introduction

Industry is developing rapidly; population density is increasing and people have more and more needs due to the increasingly stressful and fast pace of life. The above-mentioned factors have a strong impact on the balance and processes in nature, as they greatly deplete the natural resources and raw materials needed to satisfy our diverse needs. We are penetrating deeper and deeper into geographical areas that were untouched in the past and are extremely important for the regulation of biological and climatic balance of the planet. Thus, we feel the consequences of our behavior in environmental problems such as the greenhouse effect, the depletion of the ozone layer, acid rain, smog, heavy metal emissions, soil and water pollution, and the depletion of renewable resources. In addition to all these industrial impacts, transportation, agriculture, energy production, and the consumer society that produces huge amounts of solid waste, including packaging, also contribute to pollution. For all these reasons, it is very important for sustainable development that the economic, social, and environmental sectors harmonize. As a result, a circular economy has evolved that works in the spirit of sustainable development. It is a new concept that aims to maximize the use of raw materials in the production and consumption cycle. Through the process of recycling, repair, and reuse, it aims to create a new “zero waste” lifestyle. We intelligently plan and design products from the beginning and can select or predict the production processes and resources used in advance. In this way, we can effectively manage waste while creating new business opportunities.

According to most scientific evidence related to biodiversity conservation, global warming and climate change can have significant impacts on human health and the environment. In order to improve the well-being and living conditions of present and future

generations, it is important that the negative impacts of human and industrial activities be seriously considered at all stages of planning new developments.

The pulp and paper industry is one of the largest industries in the world with high capital investment. As shown in the preliminary CEPI report for 2021, the production of paper and paperboard in member countries increased by 5.8% compared to 2020. Global paper and board production increased by about 3%. Production of packaging grades is estimated to have increased by 7.1% compared to 2020. Within packaging grades, cardboard materials, which are mainly used for transport packaging and corrugated cardboard boxes, are positively influenced by the current e-commerce boom and recorded an increase of 7.8% [1].

In the paper industry, biomass, such as wood and other species, is undergoing constant change due to countries' efforts to decarbonize, the rise of bio-based materials, and so on. The recent shortage of paper for various media, due to the shift from fiber to packaging applications, opens the space for alternative solutions. Recently, interest in the use of agricultural residues has increased.

Invasive alien plant species (IAPS) are harmful to the environment on a larger scale where they occur. According to the European Union definition, IAPS are species that have been displaced from their natural ecological range by human activities and species whose introduction and spread outside their natural ecological range pose a real threat to biodiversity and the economy [2]. It is reported that there are estimated to be over 12,000 alien species in Europe, of which about 10–15% are invasive. All EU Member States have relatively major problems with IAS on their territory.

The impact of invasive plants has been the subject of many studies, and many researchers have presented solutions for their removal and reuse. These species pose a major challenge to European ecosystems, especially because they destroy agricultural land and displace local vegetation. Their spread disturbs the balance of natural ecosystems in many ways. By competing with each other, transmitting diseases, altering soil and light conditions, and reshaping the functioning of the entire ecosystem, they pose a major threat to native species richness and habitat biodiversity. They displace native vegetation, destroy agricultural land, and cause billions of dollars of damage to the European economy each year. Therefore, they are considered a nuisance species with negative impacts on native species and ecosystems [3].

Nearly two-thirds of the plant species established in Europe were intentionally introduced for ornamental, horticultural, or agricultural purposes. The remaining species were introduced unintentionally, mostly in association with transport vectors or as contaminants of seeds and other commodities [3,4]. Of the invasive plant species that escaped human cultivation, some were intentional releases (i.e., planted in the wild to “beautify” the landscape), some were contaminants or stowaways, and few arrived unassisted [3–6]. Much less is known about the introduction and spread of non-native lower plants and fungi, and about changes in the number of non-native species in Europe over time. It is known that these taxa can have enormous impacts, with perhaps the most damaging examples being diseases of crops and livestock. Therefore, Europe is solving these problems with various projects that address the spread of invasive plant species, their impact on the environment, the consequences, and the controls to measure the impact.

As the paper presents the European invasive plants in paper production, the spread, measurement and control of the spread of these plants is regulated by the European Commission Regulation 1143/2014 on invasive alien species [2]. Namely, the provisions of IAPS EU include prevention, early detection and rapid eradication, and management to prevent the spread of the species and minimize the damage it can cause.

Species that have been investigated by many researchers are *Acacia melanoxylon* [4], *Alternanthera philoxeroides* (weed) [5], *Arundo donax* (cane) [6], *Bromus tectorum* (cheatgrass) [7], *Eichhornia crassipes* (common water hyacinth) [8,9], *Fallopia* spp. [10,11], *Hedychium coronarium* (white ginger lily) [12], *Miscanthus sinensis* [13–16], *Pittosporum undulatum* [17], *Solidago canadensis* (Canadian goldenrod) [18], *Spartina alterniflora* (cordgrass) [19], *Triadica*

*sebifera* (Chinese tallow) [20], *Ulex europaeus* (gorse) [21]. Regarding the use of invasive alien plants, studies on the production of paper and packaging materials have been conducted with Japanese Knotweed, Goldenrod, and Black Locust [22–30]. Feedstocks from different biomasses such as crops and invasive alien plants are therefore gaining increasing interest.

In this review, IAPS solutions employed in Europe for the use of the mentioned plant species in the production and recyclability of paper and packaging materials are presented. It also highlights the limitations and future perspectives of the mentioned solutions.

## 2. Overview of the Various IAPS in Europe for Paper Production

Classical paper substrates are usually made of mechanical or chemical pulp, using different proportions of hardwood and/or softwood fibers with additives such as retention agents, fillers, binders, etc. [31]. In addition to hardwood and softwood fibers, invasive plants can also be used as a fiber source for paper production.

Isolated cellulose fibers from invasive plant biomass have been used in films and fiberboards [29]. Much research has also been conducted on the application of cellulose fibers derived from invasive plant biomass for conventional paper products and their finishing [26–28,30,32].

The IAPS presented, such as Knotweed, Goldenrod, and Black Locust, are the most invasive plant species in Europe used in paper production and are therefore presented in more detail in the following subsections.

### 2.1. Knotweed

The Knotweed family (*Polygonaceae*) comprises about 40 genera [28]. As Lavoie points out in his review, invasive Knotweed has significant negative impacts on native plants, while the abundant litter produced and deep rhizome system alters soil chemistry to the invaders' advantage. The most invasive plants from this plant family in Europe are *Fallopia japonica*, *Fallopia sachalinensis*, *Fallopia x bohemica*, and hybrids between *Fallopia japonica* and *Fallopia sachalinensis*. All the above species also differ in the type of leaves and flowers they possess (Figure 1).



**Figure 1.** Japanese Knotweed with leaves and flowers.

In East Asia, Japan, China, etc., *Fallopia japonica* is native and was introduced into the Dutch botanical garden in 1823 as an interesting plant [4]. Later these plants were cultivated in various places in Europe as ornamental and bee pasture plants with autumn flowers. Over the years, the plants spread throughout Europe and now pose a threat to



the natural ecosystem and biodiversity. Nevertheless, Knotweed is an edible plant that contains many medicinal compounds that have been isolated and identified by many researchers [28,33–36]. It is a rich source of resveratrol, an antioxidant with antibacterial properties. The extracts have been used to dye textiles and improve antimicrobial activity [37–39].

## 2.2. Goldenrod

Goldenrods (i.e., Canadian goldenrod—*Solidago canadensis*—and Giant goldenrod—*Solidago gigantea*) originated in the North of America and can also be found in Europe and Asia. The aforementioned plants are also invasive and can spread locally via rhizomes with large wind-borne seeds [40].

The aforementioned species have a similar habit and grow from 30 to almost 300 cm tall. The stems are unbranched, except in the inflorescence. The leaves are stalkless and three-veined (Figure 2). The inflorescences form broad pyramidal panicles with recurved branches and a central axis. The ray florets are yellow, female, and fertile, while the disk florets are bisexual and fertile. Both species occur in the same habitat types, such as disturbed areas, railroad and road sides, riverbanks, urban and peri-urban areas, agricultural areas, plantations and orchards, forests, and meadows [28].



**Figure 2.** Goldenrod with leaves and flowers.

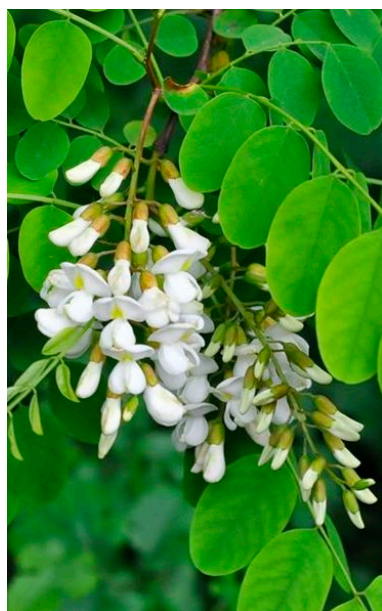
There are differences in plant morphology, phytochemical profiles, and bioactivity between the European native species *Solidago virgaurea* and the invasive alien species *Solidago canadensis* and *Solidago gigantea*. The main differences are in the number of chemical compounds antimicrobial, antimutagenic, and antioxidant properties [41]. While the generally accepted trends and strategies regarding invasive plant species are to limit or eliminate the invaders, some research groups following bioeconomy principles are investigating potential uses of invasive *Solidago* species and attempting to convert wastes into valuable products.

Following Radušienė's research on the importance of goldenrod to the environment, a new approach has recently been developed to use invasive species as a potential source of value-added products, rather than eliminating them using labor-intensive and environmentally damaging methods. The high biomass produced by exotic goldenrod is a promising source of renewable energy that can be used in rural households as an alternative to expensive firewood and that does not compete with food or feed crops [42].

According to the research of Patel et al., *canadensis* contains interesting components in all parts of the plant: essential oils with antimicrobial and antioxidant properties, natural dyes for dyeing textiles, extracted substances with algicidal, antimicrobial and antioxidant properties, stems for cellulose blends, and plant residues for the production of heating pellets and biofuel [43,44].

### 2.3. Black Locust

Black Locust, or *Robinia pseudoacacia* L., is considered controversial in Europe because it was deliberately planted in this region (Figure 3). It was introduced to Europe from North America in the early 17th century. It was introduced to Europe from North America in the 17th century. It was planted as an ornamental tree in parks and gardens, but was also used to produce firewood, as a leaf food for animals, as a nectar source for bees, to produce waterproof wood, and to control soil erosion [45,46]. Nowadays, this plant covers more than 2.3 million ha with an area of at least 100,000 ha in Bulgaria, the Czech Republic, France, Hungary, Italy, Poland, Romania, Slovenia, Serbia, and Ukraine [33–36,47–50].



**Figure 3.** Black Locust with leaves and flowers.

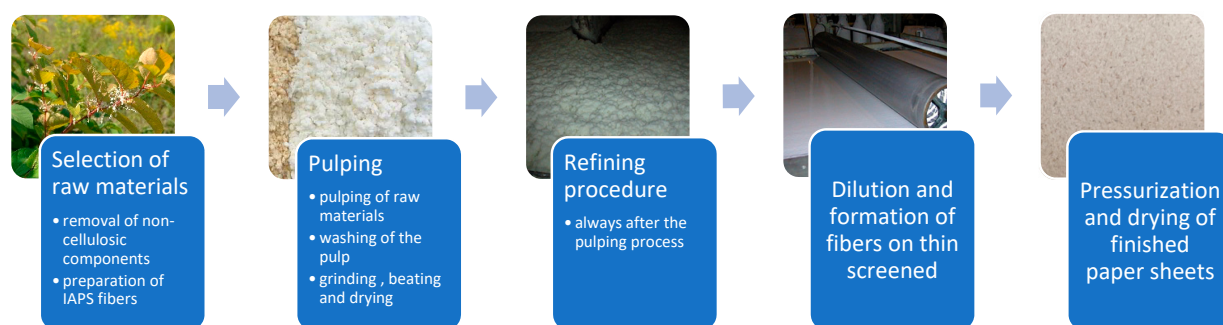
Research and studies have shown that the flowers contain flavonoids, condensed tannins, polysaccharides, and essential oil, which have antimicrobial activity against foodborne pathogens [51–53].

## 3. The Preparation and Process Production of IAPS Fibers for Papermaking Industry

Paper making involves several steps and it is important to select suitable raw materials, the criteria being [54]:

- (a) The supply should be abundant and uninterrupted;
- (b) Fibers should meet certain size requirements;
- (c) Pulp yield should be high;
- (d) Fibers should not deteriorate and lose strength rapidly during storage;
- (e) The insulation of the fibers should be technically and economically feasible;
- (f) Collection, transport, and storage should be economical;
- (g) There should be few competing uses for the selected material.

The process of papermaking includes the selection of raw materials, removal of non-cellulosic components, pulping of raw materials (mechanical, biological, or chemical pulping), washing of pulp, screening and grinding, and beating and drying (Figure 4).



**Figure 4.** The process of paper making from invasive plant species.

The process of fiber preparation begins with the harvesting of the plants, where the leaves and flowers are separated from the stems in the La-boratorium IAPS.

As Kapun et al. pointed out, the samples are chopped into 50–100 mm-long pieces and dried at room temperature and humidity [29]. The biomass is reduced into small pieces with a diameter of about <0.5 mm by grinding. The process included degreasing and comminution. The process involved delignification and shredding. The results showed that all the IAPS studied, including *Fallopia japonica* and *Solidago canadensis*, had relatively high polysaccharide content, remarkable hemicellulose and ash content, and suitable morphology for sustainable papermaking. Kim et al. presented the process for producing cellulose nanofibres from Goldenrod, using alkali oxides, bleaching, and electron beam irradiation [55]. On the other hand, Evdiokimova et al. also presented the production of cellulose nanofibres from invasive plants such as *Agave americana* L. and *Ricinus communis* L. using alkaline or acid hydrolysis [56]. Almeida et al. also produced nano-cellulose gels from invasive Acacia and Ailanthus woods [57].

The results showed improved mechanical properties of the paper sheets. A few pulping processes have been proposed, also presented by Baptista et al. and Ferreira et al., as shown in Table 1 [58,59].

**Table 1.** Preparation of IAPS fibers for paper production.

Type of Fibers	IAPS Source	Production Process	Properties of Final Product	Reference
Cellulose nanofibers	Goldenrod	Alkali cooking and bleaching; electron beam irradiation for pulp preparation.	Higher char yield, increased tensile properties	[55]
Cellulose nanofibers	<i>Agave americana</i> L. and <i>Ricinus communis</i> L.	Alkaline and acid hydrolysis for nanofiber preparation.	High crystallinity index; highly crystalline cellulose-based cytocompatible nanomaterials for biomedical applications	[56]
Nanocellulose	<i>Acacia dealbata</i> and <i>Ailanthus altissima</i>	Kraft pulp of invasive plant pre-treated with NaClO, NaBr, and TEMPO (2,2,6,6-tetramethylpiperidine-1-oxyl radical)	Improved tensile properties, similar to eucalyptus; modest water vapor permeability.	[57]
Fibers	Knotweed, Goldenrod, Black Locust	Delignification and disintegration of biomass for pulp preparation.	High porosity of produced paper sheets, (darker) changes in optical parameters, changes of mechanical and chemical properties are influenced regarding the pulp preparation.	[29]
Fibers	<i>Ailanthus altissima</i>	Kraft cooking and bleaching for pulp preparation.	All properties were closed to eucalyptus source paper. The young wood exhibited a pulping behavior close to eucalypts and lower tensile strength. The mature wood showed a lower pulp yield.	[58,59]
Fibers	<i>Arundo donax</i> L. (Poaceae)	Maceration in glacial acid and hydrogen peroxide of culm for fiber analysis.	High length-to-width ratio, which potentially favors the tensile strength and reduces pulp beating costs. The high wall fraction and the presence of narrow lumens can result in a paper of lower quality with greater resistance to bending.	[60,61]

### Properties of IAPS Fibers and Paper Materials

In this review, the three most frequently analyzed and used IAPS were systematically analyzed on a larger scale based on the literature review.

In particular, Knotweed, Goldenrod, and Black Locust represent a potentially significant source of biomass characterized by their transformability. The properties analyzed were fiber length, width, and orientation, as well as chemical analysis of the IAPS (ethanol, cellulose, hemicellulose, and lignin content), as shown in Table 2.

**Table 2.** Fiber properties of IAPS used for paper production [3–5].

Properties	Knotweeds	Goldenrods	Black Locust	Reference
Fiber length [mm]	0.775	0.452	0.963	[25]
Fiber width [ $\mu\text{m}$ ]	18.66	13.85	13.77	
Fiber orientation in paper sheets [°]	−30 to +30	−10 to +10	−30 to +30	
Chemical analysis of IAPS				
Ethanol Extractives [%]	1.10	1.60	4.70	[28]
Cellulose [%]	35.0	37.0	41.0	
Hemicellulose [%]	36.6	36.0	35.0	
Lignin [%]	27.0	19.0	22.0	

As shown in Table 2, all three IAPS contain a similar amount of hemicellulose but differ in the content of cellulose, ethanol extracts, and lignin. Knotweed contains more lignin and less cellulose and ethanol, compared to Black Locust, which has the highest amount (almost 5%) of ethanol extracts. The same applies to the cellulose content, which is 41% for Black Locust. Since non-wood materials are slow to dehydrate, problems can arise during paper production. Therefore, paper machines cannot run at high speed and the cost of producing paper from non-wood fibers is high. Nevertheless, recently there are more and more pulp mills for non-wood fibers, which are part of biorefineries.

In addition, some of the important properties of IAPS papers make them an attractive candidate for applications due to their biodegradability and environmental aspects. The global demand for recycled paper has increased in recent years, which has also led to poorer quality of waste paper in terms of mechanical properties [62]. Obtaining paper-based products from wood-free and low-grade fiber resources such as IAPS would be a great step towards protecting forest resources.

The unique physical and mechanical properties of IAPS (summarized in Table 3; Table 4), that have led to its use in a variety of applications, exhibit a higher degree of anisotropy and lower elasticity, suggesting that the cross-linking of the structure is poorer. However, compared to commercially available papers made from wood cellulose fibers, cellulose fibers made from IAPS exhibit similar basic structural properties. The reported thickness and grammage of the papers were used because they are important for real paper production and the limits were 0.002–0.004 mm (Table 3). Paper made from IAPS is more voluminous than paper made from conventional cellulose fibers. Therefore, inhomogeneities in the form of weak stability are to be expected. The ash content in graphic papers can be as high as 30 or even 40%, in contrast to IAPS papers where a maximum of 4% has been analyzed [28]. In fact, commercial papers contain inorganic fillers, which have a positive effect on the printing properties and opacity, but a negative effect on the physical–mechanical properties, which is also reflected in the reduction of the possibility of fiber bonding and interlacing.

The tensile properties of the presented papers in Table 4 show that the Goldenrod has the weakest physical–mechanical properties and high anisotropy. Since the papers made from IAPS have shorter fibers, they are stiffer and show the results of bending stiffness, which is the response to external deformation and is important for use in packaging. Studies indicate that the relaxation temperature of paper depends mainly on the structural mobility of hemicellulose and lignin under the influence of heat and moisture [28,63]. As



Placet et.al. have pointed out, a lower relaxation temperature could be the result of the relaxation of hemicellulose, while at higher temperatures it is caused by lignin [64]. From the presented work, it appears that the viscoelastic behavior of IAPS papers is influenced by moisture. Goldenrod cellulosic fibers are closest to tree fibers in terms of basic and physical–mechanical properties and could be more integrated into paper production as a good alternative for reducing wood species to cellulosic fibers.

**Table 3.** Comparison of basic properties of different kinds of papers, produced from IAPS.

Properties	Knotweeds	Goldenrods	Black Locust	Reference
Grammage [g/m <sup>2</sup> ]	97–110	92–105	120	[25,28]
Thickness [mm]	0.123–0.154	0.166–0.178	0.208–0.250	
Density [kg/m <sup>3</sup> ]	630–640	556–582	571–593	
Specific volume [cm <sup>3</sup> /g]	1.588–1.620	1.799–1.834	1.753–1.847	
Ash content [%]	1.90–2.42	3.68–4.05	2.82–3.11	

**Table 4.** Comparison of mechanical and chemical properties of different kinds of papers, produced from IAPS.

Properties	Paper Direction	Knotweeds	Goldenrods	Black Locust	Reference
Tensile strength [MPa]	MD	35.49	21.25	21.75	[28]
	CD	15.22	9.32	10.84	
Elongation [%]	MD	2.18	1.22	1.22	
	CD	4.32	2.64	3.56	
Bending stiffness [km/s]	MD	2.03	1.92	3.97	[25,28]
	CD	0.86	0.71	1.54	
Moisture content [%]		5.70	5.50	5.60	
Roughness Bendsen [mL/min]		5.84	6.57	6.10	[25,27]
Surface free energy [mJ/m <sup>2</sup> ]		62	78	100	
Relaxation temperature T <sub>r</sub> [°]		22.69	32.08	24.41	[28]
Storage modulus E' [GPa]		1.970	2.521	1.425	

#### 4. Different Applications on Papers from IAPS

IAPS could be an important factor in the paper industry by developing new value-added products to improve the durability, added value, or printing properties of paper (Table 5). It is very important to point out that the runnability (adhesion and friction process) in papermaking should be adapted to the requirements of the particular IAPS.

Paper made from IAPS has a textured and robust surface, that affects the printing properties. Many studies have been conducted using digital, screen, and flexographic printing techniques to analyze the possibilities and use of the mentioned papers in practice [26].

The study by Karlovits et.al. showed that papers made from invasive plant species, including Canadian Goldenrod, Black Locust with the addition of hardwood and softwood, have excellent electrographic digital printing quality in uncoated papers. From the study by authors Karlovits and Kavčič, it is clear that a large number of scientific studies have been published on paper properties that affect flexographic printability [25]. The study showed that flexographic printing technology and results related to printing properties prove that the alternative cellulose fibers from *Fallopia japonica*, Canadian goldenrod, and Black Locust can be widely used for packaging applications and printing. With the right smoothness, surface energy, and liquid absorption and optimization, IAPS fibers can achieve good printability and processability in fiber-based packaging products and materials.

On the other hand, printed electronics, an extremely valuable and growing field, allows electronics to be printed on various materials. Sensors, displays, RFID tags, and various electrodes are printed in layers with different inks and used in many fields (medical,



retail, biochemical solutions, etc.) [65–67]. There are also applications of printing electrodes on *Fallopia japonica* and Giant and Canadian goldenrod [25]. One of the most important characteristics for printed electronics is the roughness of the surface, porosity, and pre- and post-treatment of the working electrodes. Research has shown that invasive vegetable papers are suitable for printed electronics using the screen printing technique.

**Table 5.** Applications of IAPS in the papermaking industry.

Applications	The Source of IAPS	Substrate/Solution (Extract, Dye) from IAPS	Reference
Digital, electrographic printability	<i>Canadian goldenrod, Black Locust</i>	Paper	[27]
Flexographic printability	<i>Fallopia japonica, Canadian goldenrod, Black Locust</i>	Paper	[25]
Screen printed electrodes	<i>Fallopia japonica, Canadian goldenrod</i>	Paper	[22,27,29]
Lignin from Knotweed for paper coating	<i>Japanese Knotweed (Reynoutria japonica)</i>	Coating solution	[68]
Extracts and dyes from IAPS for screen printing	<i>Fallopia japonica, Impatiens glandulifera Royle</i>	Extract, Dye	[39,69]

IAPS have been produced and analyzed not only as paper products, but also as coating solutions for packaging papers, which was presented by Lavrič et al., [68]. The researchers isolated lignin from various natural sources, including Japanese Knotweed (*Reynoutria japonica*). The novel coating materials showed promising paper products with barrier properties, such as a reduction in water vapor permeability and a lower contact angle. There were also no significant differences in tensile properties between the uncoated and coated samples. Overall, the results show promising capabilities of such components, which can be applied to the surface of paper substrates to improve their physico-chemical properties and create a sustainable and water/oil resistant coating.

Klančnik produced and analyzed extracts from the rhizome of Japanese Knotweed (*Fallopia japonica*) and from *Impatiens glandulifera* Royle, which were successfully used as dyes for screen printing on paper and textile substrates [39,69].

## 5. Perspectives

Invasive alien plant species have far-reaching impacts on ecosystems, as has been pointed out many times in this report and in many previous studies. Ecologists and scientists are trying to find solutions in many areas. The purpose of this section is to look into the future of IAPS by addressing some remaining challenges. Since the challenges for each feedstock are often the same in different applications, the advantages and disadvantages are presented in general terms in Table 6. The main advantages of the species mentioned are their use in the paper industry in combination with wood or waste fibers, sustainability, biodegradability, and ecological impact when the plants are removed. On the other hand, there are also disadvantages such as the high amount of time and energy required for production, expensive production, and the lack of certain printing properties that are important for the end user (opacity, whiteness, etc.) [70–74].

It is important to emphasize that harvesting IAPS biomass must lead to depletion of plant reserves, as control or eradication of these species must remain the primary goal. The use of biomass from invasive alien species in already invasive areas for resource extraction could also lead to dangerous practices such as intentional planting of these species. A regulatory framework for the use of current invasive species as a source of bioenergy and raw materials could provide a solution [75]. To fully assess the risk of invasion, further research is needed to investigate the potential and different biomass supply chain for papermaking [76–78].

**Table 6.** Overview of the advantages and disadvantages of IAPS discussed in this review.

Advantage	Disadvantage
Potential for highlighting local awareness and business	Time consuming when collecting IAPS
Paper sheets can be used for advertising, eco packaging, art papers etc.	More time and energy required for paper production
Environmental solution regarding removal of the IAPS	Expensive to produce paper sheets
Lower human toxicity	Lack of whiteness of the paper
Sustainable design	
Higher biodegradability	

## 6. Conclusions

Overall, our review revealed some general patterns. First, most invasive plant species in Europe were found to be based on perennial Knotweed, Goldenrod, and Black Dogwood. Second, most of the research reviewed indicated that innovation in invasive plant species is urgently needed to advance paper product manufacturing projects, as these species negatively impact the success and cost of restoration. Third, given the uneven distribution of studies evaluated in Europe, we need to know what developing countries have done to deal with biological invasions related to restoration and application of IAPS such as handmade paper production, small business applications, etc.

Recently, promising results have been obtained in the application of IAPS in combination with other raw materials. Overall, invasive plants have advantages when we consider them as raw materials. They are applicable in many ways. These include papermaking, cooking, textile production, etc.

Finally, there is a gap between scientific and practical knowledge when it comes to finding the best methods to control invasive plant species [70]. This gap can be narrowed by raising awareness of exotic species and involving local communities in invasive species management [70,75].

The decision of which control method to use depends heavily on the growth forms of invasive plant species, the local economic situation at restoration sites, and the resources available for control. There is also a lack of collection sites and landfills where printed and converted paper products produced by IAPS could be deposited.

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