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Creation of Value Chains for the Sustainability of Control and Eradication Actions on *Ailanthus altissima* (Mill.) Swingle

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Abstract: Actions to control and eradicate *Ailanthus altissima* (Mill.) Swingle are essential to the prevention of uncontrolled growth and expansion of this species and its competition with native species. This competition leads to biodiversity and productivity losses in forests. The present study evaluated the potential to create value chains to maintain the sustainability of control actions through the energy recovery of collected *A. altissima* biomass. Other possibilities were also discussed, such as the extraction of allelopathic compounds. For this purpose, and to assess the potential for energy recovery, samples of *A. altissima* were collected and analyzed in the laboratory to discuss the potential of using extracted compounds in nature-based applications, and a literature review was carried out. It was found that, although there is potential for the use of these biomasses for energy production, the high levels of chlorine and heavy metals pose some obstacles to their large-scale use, mainly due to their corrosive potential. On the other hand, the extraction of allelopathic compounds was shown to be potentially interesting for use in the control of other invasive species. Used in this application, it may be possible to create value chains to sustain, control, and eradicate the actions of this invasive species.

Keywords: *Ailanthus altissima* (Mill.) Swingle; biological invasions; biomass recovery; biomass energy; energy recovery; green chemicals

Citation: Nunes, L.J.R. Creation of Value Chains for the Sustainability of Control and Eradication Actions on *Ailanthus altissima* (Mill.) Swingle. *Environments* **2022**, *9*, 64. https://doi.org/10.3390/environments9050064

Academic Editor: Giannantonio Petruzzelli

Received: 26 April 2022
Accepted: 20 May 2022
Published: 23 May 2022

1. Introduction

The *Ailanthus altissima* (Mill.) Swingle is a species of Asian origin and which in the 18th century was extensively planted in urban gardens all over the world, enabling its naturalization [1–4]. *A. altissima* can be found in different types of places and soils, ranging from forest areas to abandoned agricultural areas [5–8]. Its reproductive capacity in impoverished soils and in altered and disturbed environments results from their capacity to sprout from the roots and to the high capacity to produce seeds that they have developed [9–11]. *A. altissima* appears with explosive growths, for example, after soil disturbance caused by harvests, which leads to accelerated growth and dispersion processes, which contributes to the dispersion of the species [12–14].

As it is a species with a wide distribution, *A. altissima* grows in a wide variety of climatic conditions, ranging from temperate to subtropical, and from humid to arid climates [8,15–17]. Exposure to extreme cold situations can cause some mortality, but resprouting is also frequent and has been reported in the literature [2,18,19]. *A. altissima* grows preferentially and best in moisty soils but tolerates a wide range of variations [20–22]. Regarding its relationship with humidity, it is drought-hardy, and does not tolerate flooding [23–26]. Figure 1 shows the worldwide distribution of *A. altissima*.

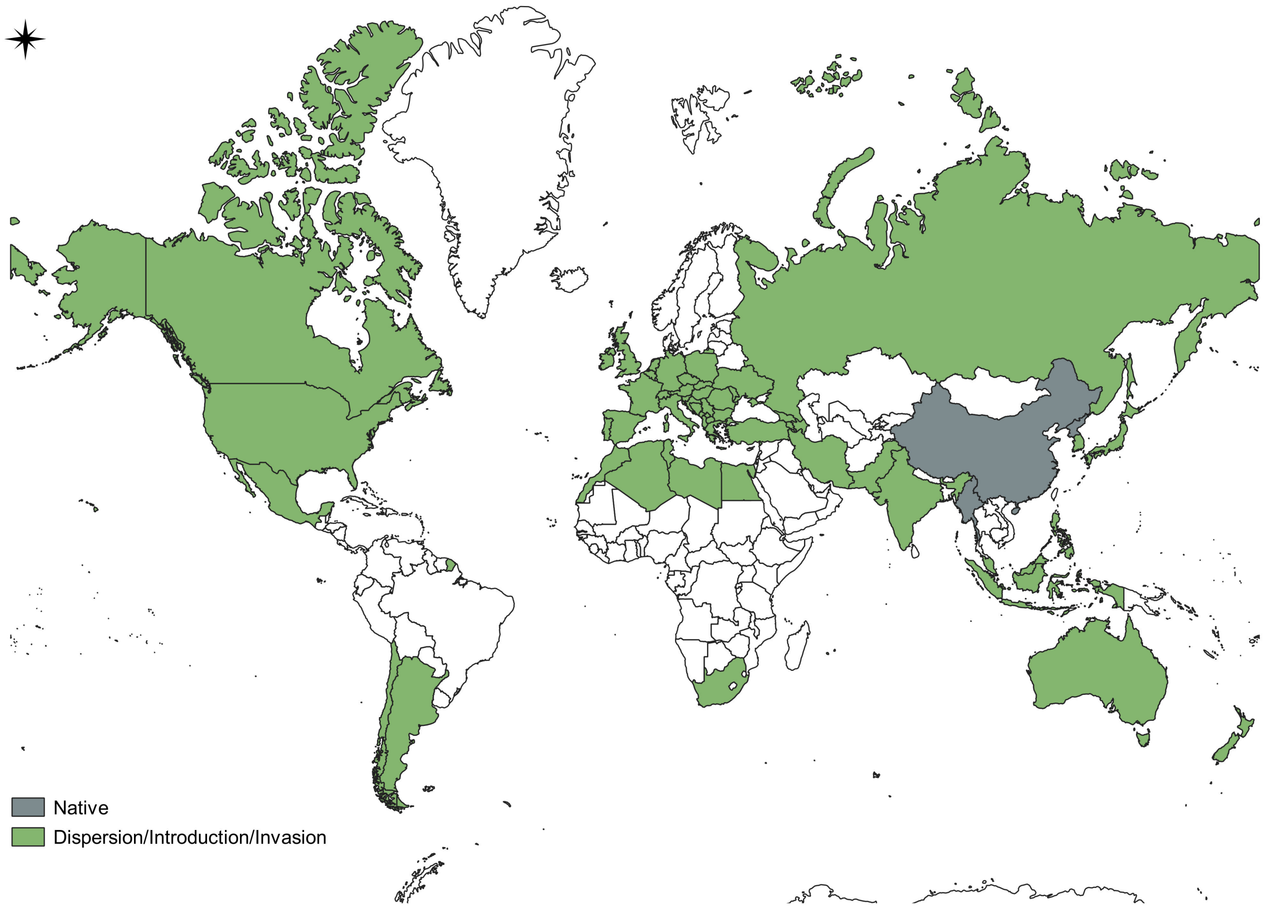

Figure 1. Countries where *A. altissima* has been reported as an introduced, naturalized, and invasive species (adapted from [27–33]).

The success of some invasive species can be attributed and justified, in part, by their high fecundity [34,35]. If invasive species can produce more seeds annually than the native species they compete with, then they will be able to disperse across the landscape, settling, and establishing a solid base from which to start the path to the occupation of the space [36,37]. In the case of *A. altissima*, the seed production capacity can reach such a dimension, once established in a certain place, by the permanent germination of the seed bank stored in the soil. Wickert et al. studied the seed production, viability, and reproductive limits of *A. altissima* in invaded environments, and concluded that the total amount of seeds produced by a single tree can range between 10 and 52 million seeds during its lifetime, demonstrating the high reproductive potential of this tree species [38].

With such high reproduction rates, *A. altissima* manages to invade open and disturbed sites [24,39,40]. However, as presented by Knapp & Canham, it is a recognized shade-intolerant species, and for this reason, it is not normally identified as a species with invasive potential in forests [41]. Due to its reproductive capacity and the seed dispersal capacity, it is a species that manages to occupy areas that for some reason have been deprived of its vegetation cover, and these authors reported a growth between 1.96 and 3.70 mm/year, thus supporting the hypothesis that *A. altissima* established in old-growth gaps can reach the canopy by virtue of rapid growth during a single period of release, thus exhibiting a gap-obligate strategy of forest recruitment.

This dispersal capacity, associated with its adaptive capacity to such a wide range of types of climate and soils, makes its control very difficult [42–45]. There are numerous works referring to cases of uncontrolled invasion and the efforts made to contain the territorial expansion of the species, and it is possible to refer examples from the most diverse origins. For example, Radtke et al. analyzed the evolution of *A. altissima* across the

European continent, together with another exotic and invasive species on this continent, *Robinia pseudoacacia* L., originally from North America [24], while Knüsel et al. analyzed the dispersion of *A. altissima* in Switzerland, which saw this species spread throughout the territory from the 1950s onwards [46], or even Gutiérrez-López et al., who analyzed the impacts of the species on soils and arthropod communities [47].

This widespread distribution led to efforts to control it, which, however, have not shown satisfactory results. The methods used are, preferably, cutting, and chemical control [1,48–50]. However, as reported by several studies, it is a very difficult task to be successful, given the capacity for recovery that *A. altissima* stands have. Burch & Zedaker indicate chemical attack as being the most effective, as it not only eliminates existing trees, but also prevents resprouting [51]. The authors also indicate the need for follow-up for several years, to ensure that the treatment has achieved its goals and prevented the resurgence of new *A. altissima* specimens. On the other hand, cutting down trees is the least efficient process given the capacity of the species to germinate from the roots, as portrayed by Constán-Nava et al. [49]. However, both solutions are costly and have a low rate of effectiveness. Biomass recovery, as indicated by Nunes et al. for the control of species of the genus *Acacia*, seems to be a possibility, since the incorporation of *A. altissima* biomass in processes tending to energy recovery, such as its use in biomass thermoelectric plants, or in the production process of biomass pellets, can allow the sustainability of control actions by creating a value chain that offsets the costs associated with control actions [52]. On the other hand, it is necessary to investigate more effective and efficient forms of control of the species, which, in the case of chemical control, do not have the negative impacts on soils and ecosystems normally associated with this type of action [1,49,53,54].

The present work intends to assess the potential of *A. altissima* biomass for energy recovery as an opportunity to create a value chain, with the objective of contributing to the sustainability of control and eradication actions. It is intended as well to discuss other possibilities based on the bibliographic review, such as the potential of *A. altissima* for the extraction of herbicide nature-based compounds, taking advantage of the allelopathic potential of the species, and thus finding more sustainable alternatives for the control of this and other invasive species.

2. Materials and Methods

2.1. Bibliometric Analysis

The Bibliometrix package was used for the literature review, more specifically the Biblioshiny routine, in RStudio, according to the procedure presented by Aria and Cuccurullo (2017), based on the research carried out in the Web of Science ™ (Clarivate) search engine [55]. For the research, the keywords shown in Table 1 were used. After evaluating the relevance of the lists of documents generated by the research for each set of keywords, the lists were merged to eliminate duplicates, also with using a routine in RStudio, creating a single file with the documents to be analyzed in the bibliographic review. This operation resulted in the selection of 78 documents totaling 5467 citations.

Table 1. Keywords used in the search.

Keywords	Nr. of Documents
"Ailanthus" and "altissima"	772
"Ailanthone"	67
"Ailanthus" and "altissima" and "ecosystem" and "impacts"	60
"Ailanthus" and "altissima" and "invasive" and "behavior"	49
"Ailanthus" and "altissima" and "allelopathy"	12
"Ailanthus" and "altissima" and "control" and "actions"	5
"Ailanthus" and "altissima" and "value" and "chains"	1

2.2. Collection and Preparation of *A. altissima* Samples

The occurrences of *A. altissima* in Portugal are abundant, both in number and in the dimension of the stands [56–62]. However, there are some regions of the country that stand out for the impact they cause, mainly, on biodiversity. From North to South, both on the coast and in the interior of the country, the advance of *A. altissima* is already being noticed, and being the object of control campaigns [63,64]. The regions that stand out in Portugal for the size of these settlements are Minho, for the quality of the soil and high rainfall, and the region of Serra da Estrela, shared by the provinces of Beira Alta and Beira Baixa, not so much for the quality of the soil, or by the levels of precipitation, but rather by the availability of space, the result of the abandonment of subsistence agriculture, which kept these lands free for opportunistic invasion by species such as *A. altissima* [65]. Figure 2 presents some examples of occurrences of *A. altissima*, in Minho (North of Portugal) and Serra da Estrela (Center of Portugal).

(**a**) (**b**) (**c**)

Figure 2. Occurrences of *A. altissima*: (**a**) resprouting 6 weeks after cutting, located in Guimarães (North Portugal); (**b**) adult specimens, located in Guimarães (North of Portugal); and (**c**) young specimens, located in Seia (Serra da Estrela, Portugal).

Thus, these three stands of *A. altissima* are in Serra da Estrela, more specifically in the municipality of Seia (Guarda, Central Portugal), corresponding to Location 1, and in the municipality of Guimarães (Braga, Northern Portugal), corresponding to Location 2 and 3, were selected to be sampled. In these stands, woody fragments were randomly cut from five trees in each location, with different diameters representing different ages. Subsequently, the samples were packaged and taken to laboratory processing. They were dried for 24 h at 105 °C to ensure their preservation and prevent changes in the composition of the samples. The collection of samples was carried out to ensure that there is enough material to allow the execution of all laboratory characterization tests, also allowing for several tests to be carried out to enable the statistical assessment of the results. The results are presented with the average values for each location, and the average and standard deviation of the obtained average values are calculated.

2.3. Laboratory Characterization

The laboratory characterization of *A. altissima* samples was performed with the aim of analyzing the relevant parameters for the energy recovery of this biomass. Thus, it was understood as necessary to carry out analyzes leading to the determination of the low heating value (LHV) and the high heating value (HHV), elemental chemical composition (C, N, O, H), thermogravimetric analysis (ash, volatile, moisture and fixed carbon), sulfur (S) and chlorine (Cl) content and chemical composition of micro and macro elements. All laboratory characterization tests were carried out in accordance with commonly used standards, for example, in the ENPlus® certification, as it allows comparison of the results obtained with other raw materials, namely those that can be considered traditional in the production of pellets from biomass, such as *Pinus pinaster* and *Eucalyptus globulus*, were analyzed three samples in each one of the laboratory characterization tests, so that the mean and standard deviation for all parameters could be calculated, and were used the procedures described in the following reference standards:

- ISO 17225-1: 2014—Solid biofuels—Fuel specifications and classes—Part 1: General requirements;
- ISO 16948: 2015—Solid biofuels—Determination of total content of C, H and N;
- ISO 16967: 2015—Solid biofuels—Determination of major elements—Al, Ca, Fe, Mg, P, K, Si, Na and Ti;
- ISO 16968: 2015—Solid biofuels—Determination of minor elements—Ar, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Sb, V and Zn;
- ISO 16994: 2016—Solid biofuels—Determination of total content of S and Cl;
- ISO 18125: 2017—Solid biofuels—Determination of calorific value;
- ISO 21404: 2020 (en)—Solid biofuels—Determination of ash melting behavior;
- ASTM E870-82 (2019)—Standard Test Methods for Analysis of Wood Fuels (with reference documents: ASTM D1102-84 (2021)—Standard Test Method for Ash in Wood; ASTM E871-82 (2019)—Standard Test Method for Moisture Analysis of Particulate Wood Fuels; ASTM E871-82 (2019)—Standard Test Method for Moisture Analysis of Particulate Wood Fuels)—Determination of proximate analysis by thermogravimetry.

3. Results

3.1. Results of Bibliographic Analyses

The results obtained for the first set of keywords, "Ailanthus" and "altissima", returned 772 documents, stretching from 1937, the date of the first published reference to *A. altissima*, to the year 2022. Regarding the thematic analysis of the published documents, as shown in Figure 3a, the documents have been distributed preferentially in the field of motor themes, such as the development of works on the ecology of species, diversity, and developmental patterns. The works on the constituent compounds and quassinoids also appear with some prominence in the niche themes. However, neither the niche themes nor the motor themes present a great relevance nor a high degree of development. This information reveals the importance of continuity and the need for further studies on the topic *A. altissima*. The works distributed in the basic themes are mainly framed in aspects related to the development of the species as a forest-type species, which also does not yet have a significant relevance or degree of development. The same happens with the response of forests to externalities, framed in the emerging and declining themes. The issues related to the control of the species present a high relevance and a high degree of development. Among the obtained results, the 20 most relevant documents were selected. The relevance was determined by the number of citations, its availability, and the accessibility of the document. When the document was not available via the DOI address, the document was replaced by the document immediately following in the list.

The search carried out for the keyword "Ailanthone" returned a set of 67 documents distributed from the year 1964 to 2020. The thematic analysis of this set of documents, shown in Figure 3b, already indicates differentiation of the thematic areas, which are preferentially distributed by the niche, motor, and basic themes. No documents are found in the case of emerging and declining themes, thus demonstrating that the theme is already at a more advanced stage of development and interest. On the other hand, the degree of development and relevance of topics such as plant growth, constituent compounds, effects, and potential use of the compounds and allelopathic processes present relevance and a moderate degree of development, justifying the investment in more research in the referred topics. The identification of compounds, such as chaperone and cochaperone-p, and the contribution that certain compounds may have in fighting diseases and metabolism, have already presented a high degree of development and relevance.

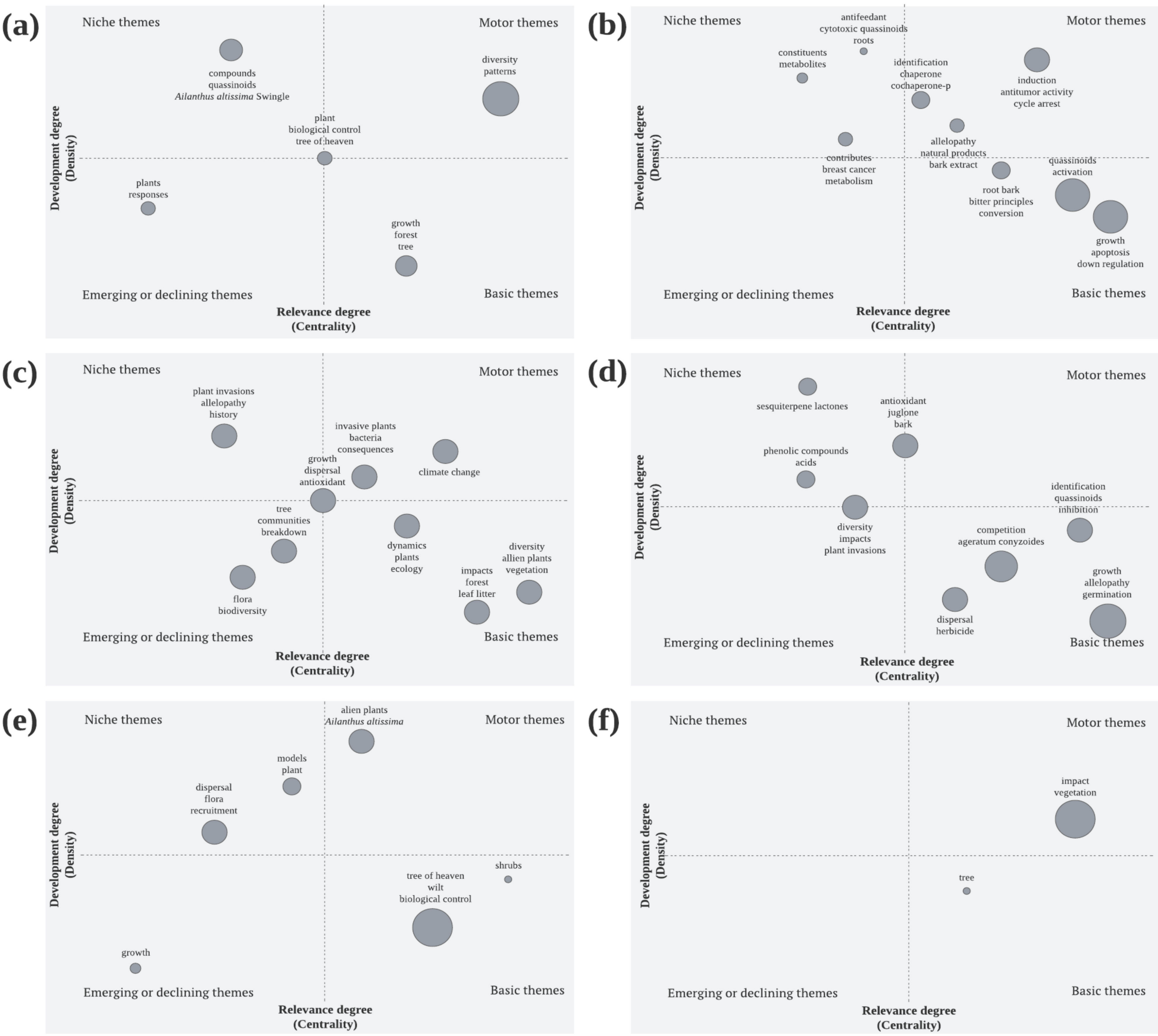

Figure 3. Distribution of thematic areas for each set of keywords used in the search in the Web of Science database and which were processed in the Bibliometrix package (Biblioshiny routine) in RStudio: (**a**) set of keywords "Ailanthus" and "altissima"; (**b**) "ailanthone"; (**c**) set of keywords "Ailanthus" and "altissima" and "ecosystem" and "impacts"; (**d**) set of keywords "Ailanthus" and "altissima" and "invasive" and "behavior"; (**e**) set of keywords "Ailanthus" and "altissima" and "allelopathy"; and (**f**) set of keywords "Ailanthus" and "altissima" and "control" and "actions".

Regarding the set of keywords "Ailanthus" and "altissima" and "ecosystem" and "impacts", the search found 60 documents distributed from 2006 to 2022 of a set of topics that acquire a high degree of relevance and development, as is the case of topics related to the growth, dispersion, compounds, and impacts of the species on ecosystems. On the other hand, innovative themes emerge, which are placed in the quartile of emerging and declining themes, such as the establishment of communities of the species, the relationship with other species, impacts on biodiversity and impacts on microbial biomass, which still present a state of relevance and moderate development and justifies the continuity of work on these themes. In the remaining quartiles, the niche, motor, and basic themes continue to present moderate degrees of relevance and development, being also the themes that present a more significant number of documents. Figure 3c shows the distribution of themes from the set of keywords "Ailanthus" and "altissima" and "ecosystem" and "impacts".

For the set of keywords "Ailanthus" and "altissima" and "invasive" and "behavior", a set of 49 documents was obtained, distributed from 1990 to 2022. This temporal dispersion may be related to the fact that the most considerable concern about the species *A. altissima* is its invasive behavior. In the thematic distribution of the results that were obtained for this set of keywords, which is shown in Figure 3d, most of the documents address basic themes, such as its control, competition with other species, allelopathy, germination capacity and constituent compounds of the species. On the other hand, niche topics, such as obtaining phenolic compounds, impacts on biodiversity and the production of antioxidants already have a considerable level of relevance and development.

For the set of keywords "Ailanthus" and "altissima" and "allelopathy", 12 documents were found, distributed from 2010 to 2020. This short and recent time interval demonstrates the innovative interest in the topic. Figure 3e shows the distribution of themes. As can be seen, all themes present a moderate degree of relevance and development, with most documents falling into the quartiles of basic, motor and niche themes. In the quartile of emerging or declining themes, growth models of the species emerge as a topic to be triggered, mainly to understand the processes of dispersion and the invasive potential of the species. Perhaps because it is still a recent topic, the number of articles is insignificant, and only one article has a considerable number of citations.

For the set of keywords "Ailanthus" and "altissima" and "control" and "actions", only 5 documents were obtained, distributed from 1992 to 2021. Figure 3f shows the distribution of the topics covered in the identified works. As can be seen, the motor themes are limited to the impacts of the species on the vegetation, although it is a theme that presents a high degree of development. On the other hand, basic topics, such as plant growth, have relevance, although with few documents. It was found that only one of the documents has a significant number of citations, which suggests that this work seems to be the reference for the topic.

For the set of keywords "Ailanthus" and "altissima" and "value" and "chains", only one document was obtained, published in 2018, which does not justify the thematic analysis of the documents.

Concerning sources, Figure 4 shows the list of the most relevant journals that contribute the larger number of documents. As can be seen, the journals dedicated to the themes of biological invasions, ecological aspects and phytochemistry are the ones that contribute the most with documents on the broader topic with the set of keywords "Ailanthus" and "altissima".

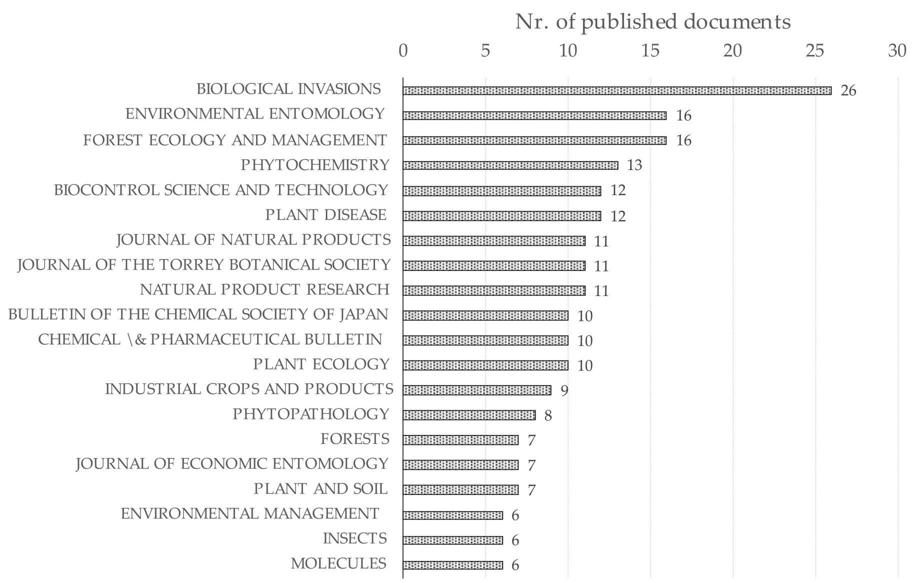

Figure 4. List of the most representative and relevant sources for the set of keywords "Ailanthus" and "altissima".

Concerning the origin of documents, as shown in Figure 5, the countries that originated the most were the USA and China, with, respectively, 166 and 140 documents leading the way in the study of the topic *A. altissima*. One second group of countries appears, including Italy, Japan, Spain, Germany, and Korea. As can be inferred, the interests of this group of countries are different. On the one hand, there are the countries where the species originates, such as China and Korea, where studies essentially address the ecological aspects of the species and the importance of the constituent compounds. On the other hand, countries such as the USA, Germany, Italy, or Spain, where the species is considered invasive and where studies essentially address issues related to its control and eradication, impacts on ecosystems and models of dispersion of the species.

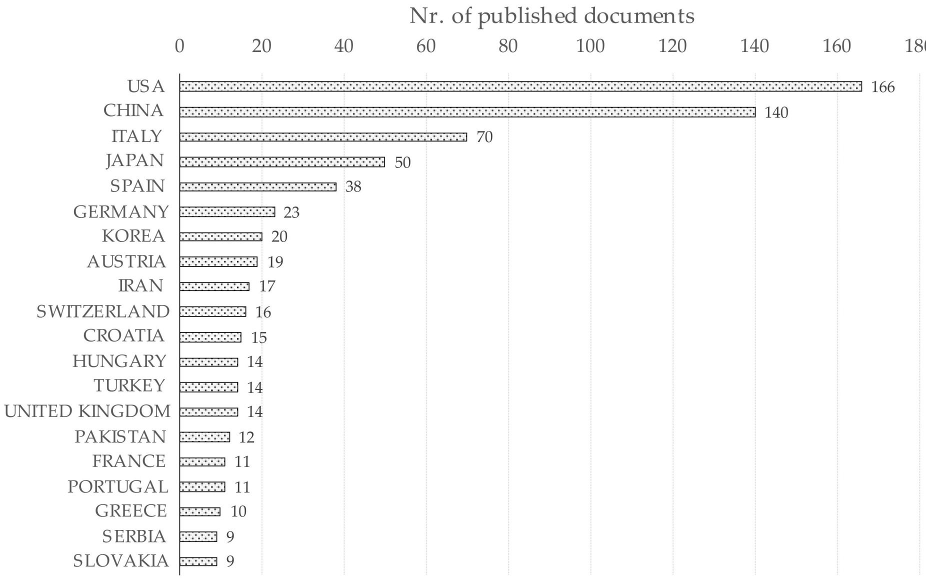

Figure 5. List of countries that contribute most to the publication of documents on the topic *A. altissima*.

3.2. *Laboratorial Characterization of the A. altissima Samples*

The results obtained for the characterization of the elemental analysis are presented in Table 2.

Table 2. Elemental analysis with Cl and S of *A. altissima*.

	C (%)	H (%)	N (%)	O (%)	S (%)	Cl (%)
Location 1	47.30	5.94	0.511	46.25	0.0258	0.0912
Location 2	47.56	5.82	0.498	46.12	0.0284	0.1034
Location 3	47.71	5.12	0.523	46.65	0.0225	0.1051
Average	47.52	5.63	0.51	46.34	0.0225	0.0999
Standard deviation	0.21	0.44	0.01	0.27	0.003	0.008

The C content has an average value of 47.52 ± 0.21%. The H content has an average value of 5.63 ± 0.44%, and the N content has an average value of 0.51 ± 0.01%. The O content was calculated by difference and presented an average value of 46.34 ± 0.27%. The S content had an average value of 0.0255 ± 0.003%, while the chlorine content had an average value of 0.0999 ± 0.008%.

The results obtained for the low and high heating value are shown in Table 3.

Table 3. Low and high heating value of *A. altissima*.

	LHV (MJ/kg)	HHV (MJ/kg)
Location 1	20.68	21.97
Location 2	21.59	22.88
Location 3	21.36	21.84
Average	21.21	22.23
Standard deviation	0.473	0.567

The low heating value presented an average value of 21.21 ± 0.473 MJ/kg, while the high heating value had an average value of 22.23 ± 0.567 MJ/kg.

The following results were obtained from the chemical analysis, divided by major and minor elements, which are presented in Tables 4 and 5.

Table 4. Major elements of *A. altissima*.

Major Elements	Al (mg/kg)	Ca (mg/kg)	Fe (mg/kg)	Mg (mg/kg)	P (mg/kg)	K (mg/kg)	Si (mg/kg)	Na (mg/kg)	Ti (mg/kg)
Location 1	43.0	7108.4	326.4	1639.4	1980.0	6844.4	41.2	178.9	3.7
Location 2	27.9	8083.2	198.0	1640.6	2173.4	6238.5	18.3	192.5	4.5
Location 3	12.3	6006.8	168.0	1364.2	1816.1	5368.7	27.9	78.2	3.1
Average	27.7	7066.2	230.8	1549.7	1984.8	6150.6	29.1	149.9	3.8
Standard deviation	15.4	1038.9	84.2	156.4	178.9	741.9	11.5	62.4	0.7

Table 5. Minor elements of *A. altissima*.

Minor Elements	As (mg/kg)	Cd (mg/kg)	Co (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Mn (mg/kg)	Ni (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
Location 1	1.9	0.2	8.9	18.6	10.2	<0.01	10.1	3.1	25.9
Location 2	1.2	0.2	6.3	13.5	12.7	<0.01	9.8	3.1	26.3
Location 3	1.6	0.1	8.0	17.3	8.8	<0.01	11.2	3.5	21.6
Average	1.6	0.2	7.9	16.5	10.6	-	10.4	3.2	24.6
Standard deviation	0.3	0.1	1.1	2.6	2.0	-	0.7	0.2	2.6

From the results, the distribution of the elements follows a similar pattern to that presented for other invasive species in Portugal, such as *Acacia dealbata* Link. or *Acacia melanoxylon* R. Br., which have also been characterized to verify the feasibility of energy recovery from biomass resulting from control actions [66,67]. In the results obtained for *A. altissima*, however, there is a result that seems to be contrary to the usual pattern mentioned above, namely concerning Ti, which, being a major element, has lower content than some minor elements, as is the case for Cr, Ni and Zn. No reference was found in the literature that could contribute to the clarification of this issue. The most plausible explanation may be related to the chemical nature of the geological substrate where the samples were collected.

3.3. Statistical Analysis

The one-way analysis of variance (ANOVA) procedure is one of the most used methods to compare three or more groups of means to determine if any groups have a mean (or median) different from the other groups. For this analysis, the one-way ANOVA was selected, as it is intended to verify the conformity of the means of three groups. Thus, as each group has $n < 30$, since each group has $n = 5$, it is necessary to test the normality and homogeneity of the results obtained in the laboratory characterization tests. The Shapiro–Wilk test was used to assess normality, which gave $p > 0.05$ for all sets of results obtained for the three sets of locations. In this way, the test confirms the normality of all result sets for each location since $p > 0.05$ confirms H_0, which postulates that the distribution of results follows a normal distribution. Next, the one-way ANOVA procedure was carried out, which includes the evaluation of the homogeneity of the results using the Levene test. The test presented a $p > 0.05$ for all sets of results obtained in the laboratory characterization tests for the three locations, confirming that the premise of homogeneity of the results is verified since H_0 is confirmed, which postulates that the variances are homogeneous. Finally, in the ANOVA analysis, the result obtained for all sets of results obtained for the three locations, with $p > 0.05$, also confirms H_0, which postulates that the means of the groups are equal. In other words, from the results obtained, it can be inferred that there are no differences between the properties of the *A. altissima* samples collected in the different sampling locations.

4. Discussion

The relevant documents selected for the bibliographic review are distributed from 1964 to 2022. The selection carried out had as its primary focus the potential use of extractable compounds, namely and prominently, ailanthone, which was characterized for the first time in 1964 by Casinovi and Ceccherelli [68]. These authors presented the first three-dimensional compound model, which was updated by Naora et al. in 1982 [69]. On the other hand, in this same period, in the 1980s of the 20th century, the works dedicated to ailanthone were essentially about its use, properties and applications. Examples of this are the works presented by Casinovi et al., Liu et al., Helsey, De Feo et al., Helsey and Helsey, Pedersini et al., Rehorska et al., or Caser et al. [50,70–75].

However, the various works available are not only about allelopathic effects or natural-based herbicide effects. There are also numerous works on the potential effects of ailanthone as an inhibitor of tumour activity, with the first works also appearing in the 1980s, as is the case of the works presented by Honda et al., Kato et al., or Zhuo et al. [76–78]. It was precisely from 2015 onwards that studies on the antitumor potential of ailanthone began to appear in large numbers, as demonstrated by the critical works presented by He et al., Chen et al., Ni et al., Peng et al., Weng et al., Wei et al., Yang et al., Daga et al., Gao et al., Liu et al., Zhang et al., Tang et al., Bailly, Cucci et al., Ding et al., Che net al., Wang et al., or Ding et al. [79–96].

Concerning applications in the health area, in addition to works in the field of oncology, there are also several works in other areas, such as tuberculosis, with Rahman et al. to treat the anti-tuberculosis effects of quassinoids [97], or the effects of the antiplasmodial activity of quassinoids, presented by Okumade et al. [98], or even the effects of ailanthone in reversing multidrug resistance through the inhibition of P-glycoprotein mediated effelux in resistant K562/A02 cells, as presented by Han et al. [99]. However, this area of research still needs to be deepened to confirm the alleged effects presented by many authors. Proof of this seems to be the odd number of retractions with works presented recently on this topic. Examples of this are the works presented by Hou et al., Kong et al., Liu et al., and Hou et al., which were all retracted by the journals where they were initially published [88,100,101].

The valuation of ailanthone thus seems, for the current state-of-the-art, to present greater applicability concerning the allelopathic potential of the species as a natural-based herbicide, as extensively analyzed recently by Caser et al., Demasi et al., Li et al., or Novak et al. [50,102–104]. The valorization of *A. altissima* biomass using the processes customarily used through energy recovery processes does not seem to have aroused the interest of researchers, having found a reference that analyzes the production of biochar from *A. altissima* biomass [105]. Thus, the approach discussed here appears to be innovative.

The creation of value chains as a measure to promote the sustainability of actions to control and eradicate invasive species has been presented in several works [106,107]. In these works, the authors analyzed the possibility of valuing the biomass of species of the genus *Acacia* to fund the control actions of these invasive species, presenting as a solution the incorporation of these species in the supply chain of wood pellet production industries, since these species have physicochemical characteristics that enhance this use. However, for this possibility to be effective in the case of *A. altissima*, the properties of this species must be compatible with the requirements imposed by the regulatory norms that govern the sector of wood pellet production, namely the standard ENPlus®.

This sector has acquired a growing demand concerning the quality of the products it introduces to the market since consumers/users of wood pellets have also acquired a higher degree of knowledge about the materials they consume and are no longer just focused on the price. These consumers also started looking for wood pellets that meet the quality criteria required and stipulated by standards, such as ENPlus®. The search for higher quality wood pellets is a way that consumers have found to circumvent aspects related to the preservation of combustion equipment, such as stoves or boilers, depending on the type of use, since the corrosive processes of this type of equipment are directly related to the type of materials used. For example, fuels with a high chlorine content enhance the corrosion of the passageways of the fumes produced during combustion. While the high content of alkali metals and calcium, the ash generated has a low fusing temperature and, in this way, contributes to increased corrosion of the combustion equipment grates.

The results obtained in the present work, compared to the results presented by Nunes et al. for *P. pinaster*, indicate a clear divergence concerning the conformity of the obtained values compared to *P. pinaster* since it is a species that usually presents values in conformity with what is explicit in the standard ENPlus® [108]. Table 6 shows the values obtained in the laboratory characterization of *A. altissima*, in comparison with the values presented for *P. pinaster*, as well as the reference limit values presented in the standard ENPlus®.

Table 6. Comparison of values for the reference parameters of the standard ENPlus® for *P. pinaster* and *A. altissima* (adapted from [108]).

Parameter	Units	ENPlus® Reference Values			*P. pinaster*	*A. altissima*
		A1	A2	B		
Moisture	%		≤10.0		6.42	8.29
Ashes	%	≤0.7	≤1.2	≤2	0.62	2.96
LHV	MJ/kg		≥16.5		17.87	21.21
N	%	≤0.3	≤0.5	≤1.0	0.08	0.511
S	%	≤0.04	≤0.05		0.0045	0.026
Cl	%	≤0.02		≤0.03	0.02	0.100
$T_{deformation}$	°C	≥1200	≥1100		1215	1138
As	%		≤1		0.94	1.55
Cd	%		≤0.5		0.34	0.18
Cr	%		≤10		1.99	16.46
Cu	%		≤10		3.55	10.56
Pb	%		≤10		0.71	3.23
Hg	%		≤0.1		≤0.01	≤0.01
Ni	%		≤10		1.08	10.36
Zn	%		≤100		8.08	24.58

As can be seen from the results obtained, the ash content produced by *A. altissima* is considerably higher than that presented by *P. pinaster*, which has 0.62%, while *A. altissima* reaches 2.96%. This value is outside the limit presented by the ENPlus® standard, which presents as limit values for each of the categories of wood pellets A1, A2 and B, respectively, ≤0.7%, ≤1.2% and ≤2%. In other words, *A. altissima* could not be used as the only raw material for wood pellets subject to a certification process under the ENPlus® standard. The ash content is a significant parameter concerning the quality of wood pellets as fuel, as it is crucial for, for example, the definition of the number of interventions for cleaning the equipment, in case it has not been incorporated an automatic ash extraction system, since its permanence for an excessive time inside the equipment can contribute to the clogging of the combustion zone. This situation, if combined with other parameters, namely the content of alkali metals, calcium, silica, and a low melting temperature, this accumulation can lead to structural damage to the equipment caused by corrosion of the metal surfaces of the furnace and the background grid. As can be seen in the results obtained, both the calcium content and the alkali metal and silica content are high, so the corrosive potential of this species is considerable, further enhanced by the low fusibility temperature presented by the ash. The occurrence of several minor elements with contents above the limit values presented by the ENPlus® standard was also verified, such as As, Cr, Cu and Ni. These occurrences may be related to the soil composition where the samples were collected, so additional analyses will be necessary with samples collected in other locations to confirm, or not, a prevalence of such high concentrations of these elements in the species. The nitrogen content also presents high values. However, these values would still allow its use as a raw material in the production of category B wood pellets, which, following the ENPlus® standard, may have nitrogen concentrations between >0.5 and $\leq$1.0%. Chlorine content is the other parameter totally outside the limit values presented by the ENPlus® standard, exceeding the limit value by tens of times, even for the most permissive wood pellets in category B. This parameter is also critical regarding the corrosive effect of fuels once this element contributes significantly to the corrosion of surfaces where heat transfers occur and which are frequent in boilers, related to the formation of HCl during the combustion of these biomasses.

Thus, due to the values presented for the analyzed parameters and the comparison with the limit values presented and allowed by the ENPlus® standard, it is not feasible to use energy through the incorporation of *A. altissima* biomass in the production of wood pellets, mainly if these are intentionally produced to be certified. However, as shown in other studies with species that also presented parameters with values outside the permitted limits, these biomasses can be incorporated into mixtures with good quality raw materials [106,107,109–111]. These values are diluted and maintained the final product within the quality parameters. Nevertheless, although this possibility may allow the creation of a value chain for this species, its use both in wood pellets and in large-scale industrial uses must be restrained, given the risks associated with the corrosive effects already described. The only possibility for the energy recovery of *A. altissima* high seems to be either the production of non-certified wood pellets, intended for use in the domestic market, in non-regular and infrequent consumers, or in the production of firewood for domestic fireplaces, also in non-regular and infrequent consumers, which in this way create a value chain, but without the risk of corrosive effects on the equipment, since these would be uses with less fuel and less frequent and regular. However, the pelletizing of these biomasses can open another possibility of valorization using these wood pellets, for example, for animal bedding. Figure 6 presents the average market price for the most common types of these biomasses, according with the potential destinations and processing uses. The market value of these biomasses is directly related to the diameter of the materials available. In this way, small-diameter bushy type biomass, is considered residual and preferentially used in the production of electrical and thermal energy directly in combustion processes. Medium diameter biomasses (15 to 25 cm) are commonly used in wood pellets and charcoal production, while diameters bigger than 25 cm are more commonly used in firewood.

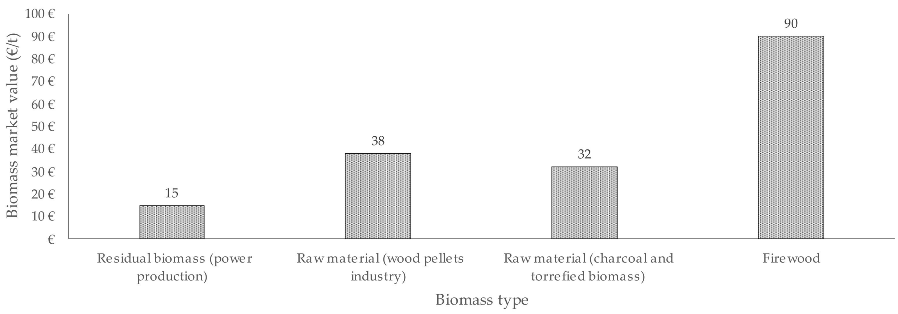

Figure 6. Biomass average market prices in Portugal for other species than maritime pine and eucalyptus.

The costs for cutting a hectare of *A. altissima* can be framed in the values shown in Table 7 (adapted from http://www.icnf.pt, accessed on 20 December 2021) for reference costs for forestry work.

Table 7. Forestry operations reference costs map (adapted from www.icnf.pt, accessed on 20 December 2021).

Operation	Average Value (€/t)
Cut and branches cleaning	35.00
Retrieval and extraction	27.50
Transport with loading and unloading	36.00

From the analysis of the results, energy recovery does not seem to be the most viable option for creating a value chain, given the restrictions imposed concerning the quality of the biomass as a fuel.

The possibility of choosing another pathway for the creation of a value chain to the *A. altissima* biomass, for example, related to the allelopathic effect presented by the species, may be an option. Allelopathy is a process that allows some species to have a competitive advantage over other species, or else, to attract other species to their proximity, to take advantage of this proximity. This advantage is achieved by the production of certain chemical compounds, which are released into the soil, with direct impacts on other species found around them, but also often impacting other individuals of their own species, for example, by inhibiting its growth. There are many and old references to this process, and as reported by Reigosa et al., while Theophrastus (372–285 BC), a disciple of Aristotle, referred to the inhibiting effect of pigweed on alfalfa. But also in other parts of the world, specifically in China, uses of plants for herbicidal purposes are described [112]. In fact, many of the references from the ancient period and the Middle Ages are from China. The same authors continue their historical journey on the identification and characterization of the allelopathic process, until they reach Molisch, who in 1937, and as previously presented by Putman & Duke [113], coined the term allelopathy from two Greek words of "allelo" and "pathy" meaning "mutual harm", as a natural phenomenon in which a plant releases inhibiting substances that disturb the growth of other plants that share the same habitat. On the other hand, Rice, in 1984, defined allelopathy as the stimulatory and inhibitory effects of a plant on others, including microorganisms.

With regard to *A. altissima*, Heisey presents as evidence the allelopathy of the species, with the author indicating that it has one or more phytotoxic compounds in the roots and leaves [114]. The study showed that ground root bark strongly inhibited the growth of herbaceous species and demonstrated that the inhibitory effect in soil was short-lived, disappearing after four weeks in the test pots and after three days in the Petri dishes in the laboratory. The work suggested that allelopathy caused by toxic root execution may contribute to the aggressiveness and persistence of *A. altissima* in certain habitats. The same author presents a sequence of works where he continues his reasoning on the effects of *A. altissima* allelopathy, mainly on its effects as herbicide [72,115,116].

This allelopathic ability makes *A. altissima* extremely aggressive with native species, and this ability is one of the competitive advantages that the species presents. Small et al. reported yet another issue that may prove to be extremely important, as they reported the possibility that *A. altissima*, in addition to inhibiting the growth of native species, may also facilitate the dispersal of other exotic species in the invaded community [117]. This dual action can certainly enhance the decline of native species, to the detriment of the success of invasive species, which are slowly occupying the space previously occupied by native species, or even while contributing to the change of the parameters of the ecosystem, adapting it to your needs. For example, Meng et al. reported that the allelopathic capacity of *A. altissima* can significantly alter the environment, including presenting algicidal properties, revealing, and as previously demonstrated by other studies, that the use of allelochemicals can be an environmentally friendly and promising method to control other species, given its herbicidal, fungicidal, or simply growth inhibitory properties [118].

Previously, De feo et al. isolated phytotoxic compounds from *A. altissima*, and later studied their effects on the growth of common herbaceous species [73]. These authors isolated the following active compounds: ailanthone, ailanthinone, chaparrine and ailanthinol B (quassinoid derivatives). They further isolated the alkaloid compound 1-methoxicanthin-6-one, which was not active. In the results obtained, the authors verified that the compound with the greatest inhibitory capacity is ailanthone ($C_{20}H_{24}O_7$), having concluded that the use of *A. altissima* root extracts as natural herbicides is possible. This conclusion also follows the work presented by Helsey, who also isolated the phytotoxic compound extracted from the root bark of *A. altissima*, ailanthone, which is a quassinoid compound [72]. The author concludes that the high level of postemergence herbicidal activity in conjunction with its rapid biodegradation in soil suggest that ailanthone has potential for the development of a natural-product herbicide to be used in the control of invasive species. These products can be used to control other invasive species, such as *A. dealbata*, or *A. melanoxylon*, among others, and in organic farming applications, where the use of phytotoxic products is increasingly restricted, because the compounds isolated in several studies showed a high capacity to decompose in the soil after a few weeks, thus not causing the cumulative effects that may be harmful to crops after their use in the soil for weed control. Thus, valuing the species through the extraction of allelopathic compounds seems an excellent possibility. However, it still needs in-depth investigation, namely, defining which species may present the most significant effects, thus and identifying potential adverse effects on soils and other species.

5. Conclusions

A. altissima can present a very aggressive invasive behavior, entering in competition with the native species of the habitats that they are occupying. In this way, can endanger native biodiversity, as they are more capable of occupying space and are equipped with a set of evolutionary and adaptive advantages, such as allelopathy. The control and eradication actions necessary to contain this species entails costs, which often prevent them from continuing. In this way, creating value chains can allow the sustainability of the control processes, such as energy recovery or natural-based compounds extraction, such as those that underlie allelopathic capacity. *A. altissima*, although it can be used as a source of bioenergy, presents some constraints, namely concerning the levels of chlorine and alkali metals, which make its use on a large scale unfeasible. Also, the average market value for this type of biomass is relatively low. It depends on the available diameters, which are usually small, not allowing the valorization of the biomass to allow the sustainability of the control actions. On the other hand, other options, such as the extraction and concentration of the allelopathic compounds, such as ailanthone, can be of great importance as nature-based herbicides, thus creating a value-added chain that allows the maintenance of eradication and control actions.

Funding: L.J.R.N. was supported by proMetheus—Research Unit on Energy, Materials and Environment for Sustainability—UIDP/05975/2020, funded by national funds through FCT—Fundação para a Ciência e Tecnologia.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are available per on request to the corresponding author.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Ding, J.; Wu, Y.; Zheng, H.; Fu, W.; Reardon, R.; Liu, M. Assessing potential biological control of the invasive plant, tree-of-heaven, *Ailanthus altissima*. *Biocontrol Sci. Technol.* **2006**, *16*, 547–566. [CrossRef]
2. Sladonja, B.; Sušek, M.; Guillermic, J. Review on invasive tree of heaven (*Ailanthus altissima* (Mill.) Swingle) conflicting values: Assessment of its ecosystem services and potential biological threat. *Environ. Manag.* **2015**, *56*, 1009–1034. [CrossRef] [PubMed]
3. Kožuharova, E.; Lebanova, H.; Getov, I.; Benbassat, N.; Kochmarov, V. *Ailanthus altissima* (Mill.) Swingle-a terrible invasive pest in Bulgaria or potential useful medicinal plant. *Bothalia J.* **2014**, *44*, 213–230.
4. Pötzelsberger, E.; Spiecker, H.; Neophytou, C.; Mohren, F.; Gazda, A.; Hasenauer, H. Growing non-native trees in European forests brings benefits and opportunities but also has its risks and limits. *Curr. For. Rep.* **2020**, *6*, 339–353. [CrossRef]
5. Gregory, S.V.; Swanson, F.J.; McKee, W.A.; Cummins, K.W. An ecosystem perspective of riparian zones. *BioScience* **1991**, *41*, 540–551. [CrossRef]
6. Pouyat, R.V.; Yesilonis, I.D.; Golubiewski, N.E. A comparison of soil organic carbon stocks between residential turf grass and native soil. *Urban Ecosyst.* **2009**, *12*, 45–62. [CrossRef]
7. Styger, E.; Rakotondramasy, H.M.; Pfeffer, M.J.; Fernandes, E.C.; Bates, D.M. Influence of slash-and-burn farming practices on fallow succession and land degradation in the rainforest region of Madagascar. *Agric. Ecosyst. Environ.* **2007**, *119*, 257–269. [CrossRef]
8. Motti, R.; Zotti, M.; Bonanomi, G.; Cozzolino, A.; Stinca, A.; Migliozzi, A. Climatic and anthropogenic factors affect *Ailanthus altissima* invasion in a Mediterranean region. *Plant Ecol.* **2021**, *222*, 1347–1359. [CrossRef]
9. Landenberger, R.E.; Kota, N.L.; McGraw, J.B. Seed dispersal of the non-native invasive tree *Ailanthus altissima* into contrasting environments. *Plant Ecol.* **2007**, *192*, 55–70. [CrossRef]
10. Rebbeck, J.; Jolliff, J. How long do seeds of the invasive tree, *Ailanthus altissima* remain viable? *For. Ecol. Manag.* **2018**, *429*, 175–179. [CrossRef]
11. Hierro, J.L.; Callaway, R.M. The ecological importance of allelopathy. *Annu. Rev. Ecol. Evol. Syst.* **2021**, *52*, 25–45. [CrossRef]
12. Kaproth, M.A.; McGraw, J.B. Seed viability and dispersal of the wind-dispersed invasive *Ailanthus altissima* in aqueous environments. *For. Sci.* **2008**, *54*, 490–496.
13. Meloche, C.; Murphy, S.D. Managing tree-of-heaven (*Ailanthus altissima*) in parks and protected areas: A case study of Rondeau Provincial Park (Ontario, Canada). *Environ. Manag.* **2006**, *37*, 764–772. [CrossRef] [PubMed]
14. Kota, N.L.; Landenberger, R.E.; McGraw, J.B. Germination and early growth of Ailanthus and tulip poplar in three levels of forest disturbance. *Biol. Invasions* **2007**, *9*, 197–211. [CrossRef]
15. Walker, G.A.; Robertson, M.P.; Gaertner, M.; Gallien, L.; Richardson, D.M. The potential range of *Ailanthus altissima* (tree of heaven) in South Africa: The roles of climate, land use and disturbance. *Biol. Invasions* **2017**, *19*, 3675–3690. [CrossRef]
16. Albright, T.P.; Chen, H.; Chen, L.; Guo, Q. The ecological niche and reciprocal prediction of the disjunct distribution of an invasive species: The example of *Ailanthus altissima*. *Biol. Invasions* **2010**, *12*, 2413–2427. [CrossRef]
17. Bullock, J.M.; White, S.M.; Prudhomme, C.; Tansey, C.; Perea, R.; Hooftman, D.A. Modelling spread of British wind-dispersed plants under future wind speeds in a changing climate. *J. Ecol.* **2012**, *100*, 104–115. [CrossRef]
18. Kowarik, I.; Säumel, I. Biological flora of central Europe: *Ailanthus altissima* (Mill.) swingle. *Perspect. Plant Ecol. Evol. Syst.* **2007**, *8*, 207–237. [CrossRef]
19. Baskin, C.C.; Baskin, J.M.; Leck, M.A. Afterripening pattern during cold stratification of achenes of ten perennial Asteraceae from eastern North America, and evolutionary implication. *Plant Species Biol.* **1993**, *8*, 61–65. [CrossRef]
20. Pan, E.; Bassuk, N. Effects of soil type and compaction on the growth of *Ailanthus altissima* seedlings. *J. Environ. Hortic.* **1985**, *3*, 158–162. [CrossRef]
21. Day, S.D.; Bassuk, N.L. A review of the effects of soil compaction and amelioration treatments on landscape trees. *J. Arboric.* **1994**, *20*, 9–17. [CrossRef]
22. Xu, Z.; Guo, X.; Caplan, J.S.; Li, M.; Guo, W. Novel plant-soil feedbacks drive adaption of invasive plants to soil legacies of native plants under nitrogen deposition. *Plant Soil* **2021**, *467*, 47–65. [CrossRef]
23. Niinemets, Ü.; Valladares, F. Tolerance to shade, drought, and waterlogging of temperate northern hemisphere trees and shrubs. *Ecol. Monogr.* **2006**, *76*, 521–547. [CrossRef]
24. Radtke, A.; Ambraß, S.; Zerbe, S.; Tonon, G.; Fontana, V.; Ammer, C. Traditional coppice forest management drives the invasion of *Ailanthus altissima* and *Robinia pseudoacacia* into deciduous forests. *For. Ecol. Manag.* **2013**, *291*, 308–317. [CrossRef]
25. Arbona, V.; López-Climent, M.F.; Pérez-Clemente, R.M.; Gómez-Cadenas, A. Maintenance of a high photosynthetic performance is linked to flooding tolerance in citrus. *Environ. Exp. Bot.* **2009**, *66*, 135–142. [CrossRef]
26. Yigit, N.; Sevik, H.; Cetin, M.; Kaya, N. Determination of the effect of drought stress on the seed germination in some plant species. In *Water Stress in Plants*; IntechOpen: London, UK, 2016; pp. 43–62.
27. Adhikari, P.; Lee, Y.H.; Park, Y.-S.; Hong, S.H. Assessment of the Spatial Invasion Risk of Intentionally Introduced Alien Plant Species (IIAPS) under Environmental Change in South Korea. *Biology* **2021**, *10*, 1169. [CrossRef]
28. Sîrbu, C.; Anastasiu, P.; Urziceanu, M.; Camen-Comănescu, P.; Sîrbu, I.-M.; Popa, A.-M.; Ioja, C.; Gavrilidis, A.-A.; Oprea, A. Invasive alien plant species in Romania of European Union concern. *Environ. Socio-Econ. Stud.* **2021**, *9*, 32–44. [CrossRef]
29. Domina, G. Invasive Aliens in Italy: Enumeration, History, Biology and Their Impact. *Invasive Alien Species Obs. Issues Around World* **2021**, *3*, 190–214.

30. Sohrabi, S.; Pergl, J.; Pyšek, P.; Foxcroft, L.C.; Gherekhloo, J. Quantifying the potential impact of alien plants of Iran using the Generic Impact Scoring System (GISS) and Environmental Impact Classification for Alien Taxa (EICAT). *Biol. Invasions* **2021**, *23*, 2435–2449. [CrossRef]
31. Celesti-Grapow, L.; Ricotta, C. Plant invasion as an emerging challenge for the conservation of heritage sites: The spread of ornamental trees on ancient monuments in Rome, Italy. *Biol. Invasions* **2021**, *23*, 1191–1206. [CrossRef]
32. Brooks, R.K.; Barney, J.N.; Salom, S.M. The invasive tree, *Ailanthus altissima*, impacts understory nativity, not seedbank nativity. *For. Ecol. Manag.* **2021**, *489*, 119025. [CrossRef]
33. Montagnani, C.; Gentili, R.; Brundu, G.; Caronni, S.; Citterio, S. Accidental Introduction and Spread of Top Invasive Alien Plants in the European Union through Human-Mediated Agricultural Pathways: What Should We Expect? *Agronomy* **2022**, *12*, 423. [CrossRef]
34. Bardsley, D.K.; Edwards-Jones, G. Invasive species policy and climate change: Social perceptions of environmental change in the Mediterranean. *Environ. Sci. Policy* **2007**, *10*, 230–242. [CrossRef]
35. Drucker, H.R.; Brown, C.S.; Stohlgren, T.J. Developing regional invasive species watch lists: Colorado as a case study. *Invasive Plant Sci. Manag.* **2008**, *1*, 390–398. [CrossRef]
36. Castro-Díez, P.; Valle, G.; Gonzalez-Munoz, N.; Alonso, A. Can the life-history strategy explain the success of the exotic trees *Ailanthus altissima* and *Robinia pseudoacacia* in Iberian floodplain forests? *PLoS ONE* **2014**, *9*, e100254. [CrossRef]
37. Kheloufi, A.; Mansouri, L.M.; Zerrouni, R.; Abdelhamid, O. Effect of temperature and salinity on germination and seedling establishment of *Ailanthus altissima* (Mill.) Swingle (Simaroubaceae). *Reforesta* **2020**, *9*, 44–53. [CrossRef]
38. Wickert, K.L.; O'Neal, E.S.; Davis, D.D.; Kasson, M.T. Seed production, viability, and reproductive limits of the invasive *Ailanthus altissima* (tree-of-heaven) within invaded environments. *Forests* **2017**, *8*, 226. [CrossRef]
39. Mortensen, D.A.; Rauschert, E.S.; Nord, A.N.; Jones, B.P. Forest roads facilitate the spread of invasive plants. *Invasive Plant Sci. Manag.* **2009**, *2*, 191–199. [CrossRef]
40. Motard, E.; Muratet, A.; Clair-Maczulajtys, D.; Machon, N. Does the invasive species *Ailanthus altissima* threaten floristic diversity of temperate peri-urban forests? *Comptes Rendus Biol.* **2011**, *334*, 872–879. [CrossRef]
41. Knapp, L.B.; Canham, C.D. Invasion of an old-growth forest in New York by *Ailanthus altissima*: Sapling growth and recruitment in canopy gaps. *J. Torrey Bot. Soc.* **2000**, *127*, 307–315. [CrossRef]
42. Kowarik, I.; Säumel, I. Water dispersal as an additional pathway to invasions by the primarily wind-dispersed tree *Ailanthus altissima*. *Plant Ecol.* **2008**, *198*, 241–252. [CrossRef]
43. Peñuelas, J.; Sardans, J. Global change and forest disturbances in the Mediterranean basin: Breakthroughs, knowledge gaps, and recommendations. *Forests* **2021**, *12*, 603. [CrossRef]
44. Nunes, L.J.; Raposo, M.A.; Pinto Gomes, C.J. A historical perspective of landscape and human population dynamics in Guimarães (Northern Portugal): Possible implications of rural fire risk in a changing environment. *Fire* **2021**, *4*, 49. [CrossRef]
45. Barudanović, S.; Zečić, E.; Macanović, A.; Duraković, B.; Mašić, E. Invasive alien plant species in global perspectives with special references to Bosnia and Herzegovina. *Invasive Alien Species Obs. Issues Around World* **2021**, *3*, 215–252.
46. Knüsel, S.; Conedera, M.; Rigling, A.; Fonti, P.; Wunder, J. A tree-ring perspective on the invasion of *Ailanthus altissima* in protection forests. *For. Ecol. Manag.* **2015**, *354*, 334–343. [CrossRef]
47. Gutiérrez-López, M.; Ranera, E.; Novo, M.; Fernández, R.; Trigo, D. Does the invasion of the exotic tree *Ailanthus altissima* affect the soil arthropod community? The case of a riparian forest of the Henares River (Madrid). *Eur. J. Soil Biol.* **2014**, *62*, 39–48. [CrossRef]
48. DiTomaso, J.M.; Kyser, G.B. Control of *Ailanthus altissima* using stem herbicide application techniques. *Arboric. Urban For.* **2007**, *33*, 55–63. [CrossRef]
49. Constán-Nava, S.; Bonet, A.; Pastor, E.; Lledó, M.J. Long-term control of the invasive tree *Ailanthus altissima*: Insights from Mediterranean protected forests. *For. Ecol. Manag.* **2010**, *260*, 1058–1064. [CrossRef]
50. Heisey, R.M.; Heisey, T.K. Herbicidal effects under field conditions of *Ailanthus altissima* bark extract, which contains ailanthone. *Plant Soil* **2003**, *256*, 85–99. [CrossRef]
51. Burch, P.L.; Zedaker, S.M. Removing the invasive tree *Ailanthus altissima* and restoring natural cover. *Arboric. Urban For.* **2003**, *29*, 18–24. [CrossRef]
52. Nunes, L.J.; Raposo, M.A.; Meireles, C.I.; Pinto Gomes, C.J.; Ribeiro, N.; Almeida, M. Control of invasive forest species through the creation of a value chain: *Acacia dealbata* biomass recovery. *Environments* **2020**, *7*, 39. [CrossRef]
53. Byun, C.; Lee, E.J. Ecological application of biotic resistance to control the invasion of an invasive plant, *Ageratina altissima*. *Ecol. Evol.* **2017**, *7*, 2181–2192. [CrossRef] [PubMed]
54. Caser, M.; Demasi, S.; Caldera, F.; Dhakar, N.K.; Trotta, F.; Scariot, V. Activity of *Ailanthus altissima* (Mill.) swingle extract as a potential bioherbicide for sustainable weed management in horticulture. *Agronomy* **2020**, *10*, 965. [CrossRef]
55. Aria, M.; Cuccurullo, C. bibliometrix: An R-tool for comprehensive science mapping analysis. *J. Informetr.* **2017**, *11*, 959–975. [CrossRef]
56. Almeida, M.; Mouga, T.; Barracosa, P. The weathering ability of higher plants. The case of *Ailanthus altissima* (Miller) Swingle. *Int. Biodeterior. Biodegrad.* **1994**, *33*, 333–343. [CrossRef]
57. Raposo, M.A.; Nunes, L.J.; Quinto-Canas, R.; del Río, S.; Pardo, F.M.V.; Galveias, A.; Pinto-Gomes, C.J. *Prunus lusitanica* L.: An endangered plant species relict in the central region of mainland Portugal. *Diversity* **2021**, *13*, 359. [CrossRef]

58. Neto Duarte, L.; Pinto Gomes, C.; Marchante, H.; Marchante, E. Integrating knowledge of ecological succession into invasive alien plant management: A case study from Portugal. *Appl. Veg. Sci.* **2020**, *23*, 328–339. [CrossRef]
59. Ururahy-Rodrigues, A.; Rafael, J.A.; Pujol-Luz, J.R. Temporal distribution of blowflies of forensic importance (Diptera: Calliphoridae), in man-size domestic pigs carcasses, in the Forest Reserve Adolpho Ducke, Manaus, Amazonas, Brazil. *EntomoBrasilis* **2013**, *6*, 09–22. [CrossRef]
60. Aguiar, F.; Ferreira, M. Plant invasions in the rivers of the Iberian Peninsula, south-western Europe: A review. *Plant Biosyst.-Int. J. Deal. All Asp. Plant Biol.* **2013**, *147*, 1107–1119. [CrossRef]
61. Aguiar, F.; Ferreira, M.; Moreira, I. Exotic and native vegetation establishment following channelization of a western Iberian river. *Regul. Rivers Res. Manag. Int. J. Devoted River Res. Manag.* **2001**, *17*, 509–526. [CrossRef]
62. Martins, F.; Alegria, C.; Artur, G. Mapping invasive alien Acacia dealbata Link using ASTER multispectral imagery: A case study in central-eastern of Portugal. *For. Syst.* **2016**, *25*, e078. [CrossRef]
63. Brunel, S.; Brundu, G.; Fried, G. Eradication and control of invasive alien plants in the M editerranean B asin: Towards better coordination to enhance existing initiatives. *EPPO Bull.* **2013**, *43*, 290–308. [CrossRef]
64. Sitzia, T.; Campagnaro, T.; Kowarik, I.; Trentanovi, G. Using forest management to control invasive alien species: Helping implement the new European regulation on invasive alien species. *Biol. Invasions* **2016**, *18*, 1–7. [CrossRef]
65. Fernandes, M.; Devy-Vareta, N.; Rangan, H. Plantas exóticas invasoras e instrumentos de gestão territorial. O caso paradigmático do género Acacia em Portugal. *Rev. Geogr. Ordenam. Territ.* **2013**, *1*, 83–107. [CrossRef]
66. Nunes, L.J.; Raposo, M.A.; Meireles, C.I.; Gomes, C.J.P.; Ribeiro, N.; Almeida, M. The Impact of Rural Fires on the Development of Invasive Species: Analysis of a Case Study with *Acacia dealbata* Link. in Casal do Rei (Seia, Portugal). *Environments* **2021**, *8*, 44. [CrossRef]
67. Santos, A.; Simões, R.; Tavares, M. Variation of some wood macroscopic properties along the stem of *Acacia melanoxylon* R. Br. adult trees in Portugal. *For. Syst.* **2013**, *22*, 463–470. [CrossRef]
68. Casinovi, C.G.; Ceccherelli, P. On the Structure of Ailanthone. *Tetrahedron Lett.* **1964**, *5*, 3991–3997. [CrossRef]
69. Naora, H.; Furuno, T.; Ishibashi, M.; Tsuyuki, T.; Takahashi, T.; Itai, A.; Iitaka, Y.; Polonsky, J. On the Structure of Ailanthone, A Bitter Principle from *Ailanthus altissima*. *Chem. Lett.* **1982**, *11*, 661–662. [CrossRef]
70. Casinovi, C.G.; Fardella, G.; Grandolini, G.; Burinato, C. Anti-Amebic Property of Some Derivatives of Ailanthone and Quassin. *Farm.-Ed. Sci.* **1981**, *36*, 116–122.
71. Lin, L.J.; Peiser, G.; Ying, B.P.; Mathias, K.; Karasina, F.; Wang, Z.; Itatani, J.; Green, L.; Hwang, Y.S. Identification of Plant-Growth Inhibitory Principles in *Ailanthus altissima* and *Castela tortuosa*. *J. Agric. Food Chem.* **1995**, *43*, 1708–1711. [CrossRef]
72. Heisey, R.M. Identification of an allelopathic compound from *Ailanthus altissima* (Simaroubaceae) and characterization of its herbicidal activity. *Am. J. Bot.* **1996**, *83*, 192–200. [CrossRef]
73. De Feo, V.; De Martino, L.; Quaranta, E.; Pizza, C. Isolation of phytotoxic compounds from tree-of-heaven (*Ailanthus altissima* Swingle). *J. Agric. Food Chem.* **2003**, *51*, 1177–1180. [CrossRef] [PubMed]
74. Pedersini, C.; Bergamin, M.; Aroulmoji, V.; Baldini, S.; Picchio, R.; Pesce, P.G.; Ballarin, L.; Murano, E. Herbicide Activity of Extracts from *Ailanthus altissima* (Simaroubaceae). *Nat. Prod. Commun.* **2011**, *6*, 593–596. [CrossRef] [PubMed]
75. Rehorska, R.; Jamnig, J.; Lernbeiss, J.; Drescher, A.; Muller, M.; Pfeifhofer, H.W. Growth Stimulating Effects of *Ailanthus altissima* Root and Leaf Extractives on Radicle and Hypocotyl Growth of Garden Cress (*Lepidium sativum*) and a Possible Evidence for Growth Inhibiting Root Exudates. *Phyton-Ann. REI Bot.* **2016**, *56*, 49–59. [CrossRef]
76. Honda, T.; Imao, K.; Inoueshiraishi, M.; Nakatsuka, N.; Tatsuoka, T.; Nakanishi, T.; Noguchi, T. Studies on Antitumor-Activity of Quassinoids—Synthesis and Antitumor-Activity of Novel Ailanthone Analogs. *J. Pharm.-Dyn.* **1987**, *10*, S61.
77. Kato, T.; Suzumura, Y.; Fukushima, M.; Honda, T.; Nakanishi, T.; Noguchi, T. Antitumor-Activity of Novel Ailanthone Derivatives Invitro and Invivo. *Anticancer Res.* **1988**, *8*, 573–580.
78. Zhuo, Z.J.; Hu, J.Y.; Yang, X.L.; Chen, M.F.; Lei, X.P.; Deng, L.J.; Yao, N.; Peng, Q.L.; Chen, Z.S.; Ye, W.C.; et al. Ailanthone Inhibits Huh7 Cancer Cell Growth via Cell Cycle Arrest and Apoptosis In Vitro and In Vivo. *Sci. Rep.* **2015**, *5*, 16185. [CrossRef]
79. He, Y.D.; Peng, S.H.; Wang, J.H.; Chen, H.; Cong, X.N.; Chen, A.; Hu, M.C.; Qin, M.; Wu, H.G.; Gao, S.M.; et al. Ailanthone targets p23 to overcome MDV3100 resistance in castration-resistant prostate cancer. *Nat. Commun.* **2016**, *7*, 13122. [CrossRef]
80. Chen, Y.X.; Zhu, L.; Yang, X.; Wei, C.; Chen, C.R.; He, Y.; Ji, Z.N. Ailanthone induces G(2)/M cell cycle arrest and apoptosis of SGC-7901 human gastric cancer cells. *Mol. Med. Rep.* **2017**, *16*, 6821–6827. [CrossRef]
81. Ni, Z.Y.; Yao, C.; Zhu, X.W.; Gong, C.Y.; Xu, Z.H.; Wang, L.X.; Li, S.Y.; Zou, C.P.; Zhu, S.G. Ailanthone inhibits non-small cell lung cancer cell growth through repressing DNA replication via downregulating RPA1. *Br. J. Cancer* **2017**, *117*, 1621–1630. [CrossRef]
82. Peng, S.H.; Yi, Z.F.; Liu, M.Y. Ailanthone: A new potential drug for castration-resistant prostate cancer. *Chin. J. Cancer* **2017**, *36*, 2. [CrossRef] [PubMed]
83. Wang, R.X.; Lu, Y.J.; Li, H.; Sun, L.X.; Yang, N.; Zhao, M.Z.; Zhang, M.L.; Shi, Q.W. Antitumor activity of the *Ailanthus altissima* bark phytochemical ailanthone against breast cancer MCF-7 cells. *Oncol. Lett.* **2018**, *15*, 6022–6028. [CrossRef] [PubMed]
84. Wei, C.; Chen, C.R.; Cheng, Y.X.; Zhu, L.; Wang, Y.; Luo, C.; He, Y.; Yang, Z.M.; Ji, Z.M. Ailanthone induces autophagic and apoptotic cell death in human promyelocytic leukemia HL-60 cells. *Oncol. Lett.* **2018**, *16*, 3569–3576. [CrossRef]
85. Yang, P.Z.; Sun, D.Z.; Jiang, F. Ailanthone Promotes Human Vestibular Schwannoma Cell Apoptosis and Autophagy by Downregulation of miR-21. *Oncol. Res.* **2018**, *26*, 941–948. [CrossRef] [PubMed]

86. Daga, M.; Pizzimenti, S.; Dianzani, C.; Cucci, M.A.; Cavalli, R.; Grattarola, M.; Ferrara, B.; Scariot, V.; Trotta, F.; Barrera, G. Ailanthone inhibits cell growth and migration of cisplatin resistant bladder cancer cells through down-regulation of Nrf2, YAP, and c-Myc expression. *Phytomedicine* **2019**, *56*, 156–164. [CrossRef]
87. Gao, W.; Ge, S.K.; Sun, J.Y. Ailanthone exerts anticancer effect by up-regulating miR-148a expression in MDA-MB-231 breast cancer cells and inhibiting proliferation, migration and invasion. *Biomed. Pharmacother.* **2019**, *109*, 1062–1069. [CrossRef]
88. Liu, W.J.; Liu, X.N.; Pan, Z.H.; Wang, D.; Li, M.J.; Chen, X.Y.; Zhou, L.; Xu, M.L.; Li, D.F.; Zheng, Q.S. Ailanthone Induces Cell Cycle Arrest and Apoptosis in Melanoma B16 and A375 Cells. *Biomolecules* **2019**, *9*, 275, Retraction in *Biomolecules* **2020**, *10*, 627. [CrossRef]
89. Zhang, Y.; Zhang, C.Z.; Min, D.J. Ailanthone up-regulates miR-449a to restrain acute myeloid leukemia cells growth, migration and invasion. *Exp. Mol. Pathol.* **2019**, *108*, 114–120. [CrossRef]
90. Tang, S.W.; Ma, X.R.; Lu, J.; Zhang, Y.J.; Liu, M.Y.; Wang, X. Preclinical toxicology and toxicokinetic evaluation of ailanthone, a natural product against castration-resistant prostate cancer, in mice. *Fitoterapia* **2019**, *136*, 104161. [CrossRef]
91. Bailly, C. Anticancer properties and mechanism of action of the quassinoid ailanthone. *Phytother. Res.* **2020**, *34*, 2203–2213. [CrossRef]
92. Cucci, M.A.; Grattarola, M.; Dianzani, C.; Damia, G.; Ricci, F.; Roetto, A.; Trotta, F.; Barrera, G.; Pizzimenti, S. Ailanthone increases oxidative stress in CDDP-resistant ovarian and bladder cancer cells by inhibiting of Nrf2 and YAP expression through a post-translational mechanism. *Free Radic. Biol. Med.* **2020**, *150*, 125–135. [CrossRef] [PubMed]
93. Ding, H.X.; Yu, X.C.; Hang, C.; Gao, K.J.; Lao, X.F.; Jia, Y.T.; Yan, Z.L. Ailanthone: A novel potential drug for treating human cancer. *Oncol. Lett.* **2020**, *20*, 1489–1503. [CrossRef] [PubMed]
94. Chen, L.; Wu, C.; Wang, H.M.; Chen, S.N.; Ma, D.H.; Tao, Y.; Wang, X.Y.; Luan, Y.H.; Wang, T.D.; Shi, Y.; et al. Analysis of Long Noncoding RNAs in Aila-Induced Non-Small Cell Lung Cancer Inhibition. *Front. Oncol.* **2021**, *11*, 652567. [CrossRef] [PubMed]
95. Wang, C.M.; Li, H.F.; Wang, X.K.; Li, W.G.; Su, Q.; Xiao, X.; Hao, T.F.; Chen, W.; Zhang, Y.W.; Zhang, H.Y.; et al. *Ailanthus altissima*-derived Ailanthone enhances Gastric Cancer Cell Apoptosis by Inducing the Repression of Base Excision Repair by Downregulating p23 Expression. *Int. J. Biol. Sci.* **2021**, *17*, 2811–2825. [CrossRef] [PubMed]
96. Ding, H.X.; Yu, X.C.; Yan, Z.L. Ailanthone suppresses the activity of human colorectal cancer cells through the STAT3 signaling pathway. *Int. J. Mol. Med.* **2022**, *49*, 11. [CrossRef]
97. Rahman, S.; Fukamiya, N.; Okano, M.; Tagahara, K.; Lee, K.H. Anti-tuberculosis activity of quassinoids. *Chem. Pharm. Bull.* **1997**, *45*, 1527–1529. [CrossRef]
98. Okunade, A.L.; Bikoff, R.E.; Casper, S.J.; Oksman, A.; Goldberg, D.E.; Lewis, W.H. Antiplasmodial activity of extracts and quassinoids isolated from seedlings of *Ailanthus altissima* (Simaroubaceae). *Phytother. Res.* **2003**, *17*, 675–677. [CrossRef]
99. Han, F.; Liu, G.Q.; Sun, C.F.; Wei, J.N. Ailanthone reverses multidrug resistance by inhibiting the P-glycoprotein-mediated efflux in resistant K562/A02 cells. *Cell. Mol. Biol.* **2018**, *64*, 55–61. [CrossRef]
100. Hou, S.Z.; Cheng, Z.M.; Wang, W.L.; Wang, X.D.; Wu, Y.B. Ailanthone exerts an antitumor function on the development of human lung cancer by upregulating microRNA-195. *J. Cell. Biochem.* **2019**, *120*, 10444–10451, Retraction in *J. Cell. Biochem.* **2021**, *122*, 489. [CrossRef]
101. Kong, D.L.; Ying, B.D.; Zhang, J.R.; Ying, H.L. The anti-osteosarcoma property of ailanthone through regulation of miR-126/VEGF-A axis. *Artif. Cell. Nanomed. Biotechnol.* **2020**, *48*, 1254, Retraction of *Artif. Cell. Nanomed. Biotechnol.* **2019**, *47*, 3913. [CrossRef]
102. Demasi, S.; Caser, M.; Caldera, F.; Dhakar, N.K.; Vidotto, F.; Trotta, F.; Scariot, V. Functionalized dextrin-based nanosponges as effective carriers for the herbicide ailanthone. *Ind. Crops Prod.* **2021**, *164*, 113346. [CrossRef]
103. Li, X.; Li, Y.; Ma, S.B.; Zhao, Q.Q.; Wu, J.S.; Duan, L.R.; Xie, Y.H.; Wang, S.W. Traditional uses, phytochemistry, and pharmacology of *Ailanthus altissima* (Mill.) Swingle bark: A comprehensive review. *J. Ethnopharmacol.* **2021**, *275*, 114121. [CrossRef]
104. Novak, M.; Novak, N.; Milinovic, B. Differences in allelopathic effect of tree of heaven root extracts and isolated ailanthone on test-species. *J. Cent. Eur. Agric.* **2021**, *22*, 611–622. [CrossRef]
105. Alidou-Arzika, I.; Lebrun, M.; Miard, F.; Nandillon, R.; BAYÇU, G.; Bourgerie, S.; Morabito, D. Assessment of compost and three biochars associated with *Ailanthus altissima* (Miller) Swingle for lead and arsenic stabilization in a post-mining Technosol. *Pedosphere* **2021**, *31*, 944–953. [CrossRef]
106. Nunes, L.J.; Raposo, M.A.; Meireles, C.I.; Pinto Gomes, C.J.; Almeida Ribeiro, N. Carbon Sequestration Potential of Forest Invasive Species: A Case Study with *Acacia dealbata* Link. *Resources* **2021**, *10*, 51. [CrossRef]
107. Nunes, L.J.; Rodrigues, A.M.; Loureiro, L.M.; Sá, L.C.; Matias, J.C. Energy Recovery from Invasive Species: Creation of Value Chains to Promote Control and Eradication. *Recycling* **2021**, *6*, 21. [CrossRef]
108. Nunes, L.J.; Loureiro, L.M.; Sá, L.C.; Matias, J.C.; Ferraz, A.I.; Rodrigues, A.C. Energy Recovery of Agricultural Residues: Incorporation of Vine Pruning in the Production of Biomass Pellets with ENplus® Certification. *Recycling* **2021**, *6*, 28. [CrossRef]
109. Nunes, L.J.; Raposo, M.A.; Meireles, C.I.; Gomes, C.J.P.; Ribeiro, N.; Almeida, M. Energy Recovery of Shrub Species as a Path to Reduce the Risk of Occurrence of Rural Fires: A Case Study in Serra da Estrela Natural Park (Portugal). *Fire* **2021**, *4*, 33. [CrossRef]
110. Nunes, L.J. Characterization of *Cytisus striatus* (Hill) Rothm.: Waste Biomass Energy Recovery as a Measure to Reduce the Risk of Rural Fires. *Recycling* **2021**, *6*, 36. [CrossRef]
111. Samsatli, S.; Samsatli, N.J. The role of renewable hydrogen and inter-seasonal storage in decarbonising heat—Comprehensive optimisation of future renewable energy value chains. *Appl. Energy* **2019**, *233*, 854–893. [CrossRef]

112. Reigosa, M.J.; Pedrol, N.; González, L. *Allelopathy: A Physiological Process with Ecological Implications*; Springer Science & Business Media: Berlin/Heidelberg, Germany, 2006.
113. Putnam, A.R.; Duke, W.B. Allelopathy in agroecosystems. *Annu. Rev. Phytopathol.* **1978**, *16*, 431–451. [CrossRef]
114. Heisey, R.M. Evidence for allelopathy by tree-of-heaven (*Ailanthus altissima*). *J. Chem. Ecol.* **1990**, *16*, 2039–2055. [CrossRef]
115. Heisey, R.M. Allelopathy and the secret life of *Ailanthus altissima*. *Arnoldia* **1997**, *57*, 28–36.
116. Heisey, R.M. Allelopathic and herbicidal effects of extracts from tree of heaven (*Ailanthus altissima*). *Am. J. Bot.* **1990**, *77*, 662–670. [CrossRef]
117. Small, C.J.; White, D.C.; Hargbol, B. Allelopathic influences of the invasive *Ailanthus altissima* on a native and a non-native herb1, 2. *J. Torrey Bot. Soc.* **2010**, *137*, 366–372. [CrossRef]
118. Meng, P.; Pei, H.; Hu, W.; Liu, Z.; Li, X.; Xu, H. Allelopathic effects of *Ailanthus altissima* extracts on *Microcystis aeruginosa* growth, physiological changes and microcystins release. *Chemosphere* **2015**, *141*, 219–226. [CrossRef]