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Mugwort (*Artemisia vulgaris* L.) Aqueous Extract: Hormesis and Biostimulant Activity for Seed Germination and Seedling Growth in Vegetable Crops

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Abstract: The evaluation of potential biostimulants to be used in sustainable horticulture production is a crucial goal of research. Most research has focused on the effects of biostimulants on plant growth, and less on the effects on seed germination and seedling growth. This study evaluated the biostimulatory effects of mugwort extract on seed germination and seedling growth in several vegetable crops (onion, carrot, tomato, rapeseed, cauliflower and lettuce), in order to test its application as a potential biostimulant. The phenolic acid composition of the extract and the acids' rankings were: homovanillic > gentisic > gallic > caffeic = chlorogenic > salicylic = syringic > p/m-coumaric = ferulic = synaptic = p-hydroxybenzoic. The extract of mugwort (at 0.2, 0.4, 0.8, 1.56, 3.13, 6.25 and 12.5 % *w/v* concentrations) was analyzed using Petri dish bioassays, quantifying its stimulatory effects on seed germination and the radicle and hypocotyl length of the seedlings, according to hormetic log-logistic models. The mugwort extract was not able to biostimulate all the tested species. Seed germination was stimulated in carrot (+70%) and rapeseed (+11%), while in the other species, no effects (i.e., onion, tomato and lettuce) or inhibition (i.e., cauliflower) were observed. Hypocotyl length stimulation was observed in all the species except carrot and onion, while radicle length was mainly inhibited by mugwort extract, except in rapeseed (+30%). The biostimulation effects of mugwort extract seem to be "specie specific" and "part of plant specific", and need to be further investigated in terms of the involved substances and physiological aspects, although phytohormone activity is certainly involved.

Keywords: hormesis; horticulture; natural product; organic farming; plant-derived biostimulant

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1. Introduction

Hormesis is a dose–response phenomenon whereby low doses induce stimulation and high doses induce inhibition, and it is mainly concerned with the biphasic response of plants to certain stressors (herbicides, temperature, chemicals and radiation) [1,2]. This stimulation phenomenon has been observed in plants with both herbicides and allelopathic extracts applied at low concentrations [3–5]. From an agricultural point of view, hormesis could be exploited to increase crop production and quality, as is achieved by plant biostimulants [6–8]. The hormetic dose–response model applied in plant studies can lead to the determination of the biostimulant concentration at which the highest adaptive response is observed; the responses, which can be evaluated in terms of hormesis, are disease resistance, the production of some secondary metabolites, yields and growth, among others [1]. The evaluation of these responses in plants, via hormetic dose–response analysis, needs an approach based on a quantitative bioassay experiment with several doses of the biostimulant; this would allow us to define the range of doses able to stimulate a phenomenon and those that pose the potential risk of inhibiting the same phenomenon [1,3].

More recently, the new Regulation (EU) 2019/1009 has defined plant biostimulants as follows: "A plant biostimulant shall be an EU fertilising product the function of which is to stimulate plant nutrition processes independently of the product's nutrient content with the

sole aim of improving one or more of the following characteristics of the plant or the plant rhizosphere: (i) nutrient use efficiency, (ii) tolerance to abiotic stress, (iii) quality traits, or (iv) availability of confined nutrients in the soil or rhizosphere" [9]. This very recent definition emphasizes plant biostimulants as being distinguished and specified by their agricultural functions, and for this reason, they can be derived from a wide range of raw materials (protein hydrolysate, humic and fulvic substances, seaweed extracts, animal and vegetal protein extracts, beneficial microorganisms, arbuscular mycorrhizal fungi and nitrogen-fixing bacteria) with different bioactive substances [10,11]. Full identification of the components of plant biostimulants is impossible and the stimulatory effect exerted on plants can depend on the synergistic actions of more substances, instead of the single components [11,12].

In this context, plant extracts are also considered biostimulants, according the following definition: "A plant biostimulant is any substance or microorganism applied to plants with the aim to enhance nutrition efficiency, abiotic stress tolerance and/or crop quality traits, regardless of its nutrients content". Indeed, in this definition, a substance may be either a single chemical compound or a group of compounds with a well-established biological origin, e.g., plant extracts, but not necessarily a fully characterized composition [7,8].

Among plants, the genus Artemisia (*Asteraceae*), consisting of over 200 species of herbs and shrubs, is well known for its wide spectrum of biological activities, including medicinal ones, due to the presence of volatile oils [13]. *Artemisia vulgaris* L. (mugwort) is a rhizomatous perennial weed that commonly invades degraded areas such as roadsides, waste areas and old fields, but also crop fields [14]. A remarkable number of secondary metabolites have been isolated from mugwort tissue and many of these are terpenes and phenolic compounds [14,15]. The rhizomes contain large quantities of 1,8-cineole, ascorbic acid, quercetin and vulgarin, a sesquiterpene lactone [16]. Mugwort exhibits strong allelopathic properties, either by foliar-produced or living rhizome-exudated phytotoxins, inhibiting the growth of several weeds and crops [8,17–19]. However, mugwort extract has also been found to allow hormesis, with biostimulant effects on potato cultivation [20] and on the mesocotyl/hypocotyl and radicle lengths of green bean (*Phaseolus vulgaris* L., cv. Blue lake s7) and maize (*Zea mays* L. subsp. indurata, "flint corn", cv. 65b) [8]. Phenolic compounds derived from plants shown biostimulant activities, such as enhancing seed germination, rooting, shooting and fruiting, as well as bioprotectant activities (i.e., antimicrobial, insecticidal, nematicidal and herbicidal) [21]. Phenolic compounds can stimulate growth and development in plants by increasing the levels of phytohormone growth promoters, such as auxins, cytokinins and gibberellins, and decreasing the levels of phytohormone growth inhibitors, such as abscisic acid [22].

A lot of research has been undertaken to identify potential biostimulants to be used in sustainable horticulture production to improve plant growth, productivity, and food quality and security, as well as to help plants overcome different types of environmental stress. Indeed, nowadays, horticultural production has to cope with the increasing challenges of meeting high productivity, with global demands for environmentally friendly crop management practices [23]. In this regard, biostimulants can play an important role in reducing the reliance on agro-chemicals and/or increasing their efficiency of use under a changing climate, enabling an increase in production at a relatively low cost sustainably [24]. In this context, from an agronomical point of view, rapid and uniform germination and emergence are desirable for stand establishment and high competition against weeds in some vegetables and minor crops [25,26]. The utilization of biostimulants as seed-coating material has tremendous potential to accelerate early stand establishment and seedling growth. Seed treatments need an even smaller concentration of biostimulant per hectare as compared to the foliar applications, predominantly due to reduced surface area, and they accelerate germination and improve plant growth compared to non-treated seeds [27]. These substances are effective in small concentrations and promote nutrition, resilience towards environmental stressors and good quality of vegetable crops, irrespective of their existing nutritional composition [28]. For vegetable crops, tolerance to abiotic stressors is an important trait because their cash value is usually higher than that of field crops, they

require more resources for farming, and they provide a source of many nutrients, fiber, minerals and carbohydrates, which are essential in a healthy diet; therefore, growing high-quality vegetables has become one of the most important goals of current agriculture, [29].

Based on several reviews published on the effects of biostimulants in vegetable crops, most research has been focused on the effects of biostimulants on plant growth, while less knowledge is available on the effects of biostimulants on seed germination and seedling growth.

The aim of this study was to evaluate the biostimulatory effects of the aqueous extract of the aerial biomass of *A. vulgaris* on seed germination and seedling growth in several vegetable crops in order to assess its application as a potential biostimulant.

2. Materials and Methods

2.1. Plant Sampling and Aqueous Extract Preparation

The plants of mugwort were collected from an uncultivated field in Marsciano, Perugia, central Italy (42°56′ N, 12°23′ E, 165 m a.s.l.) at the growth stage scale of 61–62 BBCH (Biologische Bundesanstalt, Bundessortenamt and CHemical industry; beginning of flowering: 10–20% of flowers open). Fresh mugwort plants were dried in a hot-air oven at 45 °C for 5 days, and the aerial biomass (leaves + stems) was ground using an electric grinder, sieved through a 1 mm sieve, and kept in a dry, dark bag at 10 °C for future use. In the laboratory, aerial biomass at 12.5 g dry tissue was soaked in 100 mL of distilled water (12.5% *w*/*v*) for 24 h at 24 °C. After soaking, the aqueous solution was filtered through 4-layers of cheesecloth to remove the fiber debris; then, the aqueous extract was filtered again through filter paper [8,17]. The resulting filtrate was used as stock extract in the following experiments.

2.2. Petri Dish Bioassay Experiments

Petri dish bioassays were carried out according to the methodology already shown by Pannacci et al. [4,8,17,30]. The seeds of onion (*Allium cepa* L., cv. Density), carrot (*Daucus carota* L., cv. Nantes Clodia), tomato (*Solanum lycopersicum* L., cv. UC82), rapeseed, (*Brassica napus* var. *oleifera* Del., cv. Excalibur), cauliflower (*Brassica oleracea* L., cv. Palla di neve) and lettuce (*Lactuca sativa* L., cv. Gentilina) were pre-sterilized using 2% sodium hypochlorite for 5 min and washed using distilled water. Fifty seeds of each species were evenly placed on one filter paper (Whatman 1001-125) per each separate sterilized plastic Petri dish (∅ 120 mm, height 20 mm). The stock extract of the aerial biomass was diluted using distilled water to prepare 0, 0.2, 0.4, 0.8, 1.56, 3.13, 6.25 and 12.5% *w/v* concentrations; these were added (the number varied from five to eight, depending on the species and preliminary tests) at 7 mL per Petri dish. The treatments were replicated thrice and all the Petri dishes were closed, sealed and placed in a growth chamber, under controlled conditions (20 °C, at dark) according to a completely randomized design with three replicates and each Petri disc as the experimental unit. The germinated seeds were counted 10 days after treatment and ten representative seedlings per Petri dish were chosen to determine their fresh weight and their radicle and hypocotyl lengths. The germination, fresh weight, radicle and hypocotyl length data for each species were converted to percentages relative to the untreated control [31].

2.3. Statistic al Analysis

The bioassay data were subjected to non-linear regression analysis using the log-logistic model proposed by Streibig et al. [32]:

$$Y = C + \frac{D - C}{1 + exp\{b[log(X) - log(a)]\}} \quad (1)$$

where Y is the response (i.e., the percentage of seed germination, fresh weight and radicle or hypocotyl length of the seedlings) of the test seed or seedling as a function of the extract concentration X, D is the upper asymptote (the response of the untreated control), C is the lower asymptote (the response at extremely high concentrations), a is the concentration

that gives a response halfway between the upper and lower asymptotes, and b is the slope of the rate of change around the inflection point.

In the cases of hormesis, growth stimulation was observed at low concentration doses; hence, the following peaked model was used [33]:

$$Y = C + \frac{D - C + fX}{1 + exp\{b[log(X) - log(a)]\}} \quad (2)$$

where, f is the parameter for stimulation and measures the rate of growth stimulation at doses close to zero.

In particular, the models were used with constraints in the upper and lower asymptotes at 100 and 0, respectively; this was needed given that the data were converted to percentages relative to the untreated control, with the latter normalized to 100%. In this way, the data were supposed to range from 0 to 100% without stimulation, and more than 100% with stimulation. The fitted equations were used to calculate the dose–response curve parameters, such as b, a and f.

The assumption that dose–response curves could be fitted to the data was assessed using an F-test for lack-of-fit comparing the residual sum of the squares of an analysis of variance and the non-linear regression (p = 0.05) [34].

The models were fitted to the experimental data using the EXCEL® add-in macro BIOASSAY97 [35].

3. Results and Discussion

The data on seed germination, hypocotyl length, root length and seedling fresh weight for the different species and the related nonlinear regressions, according to Equations (1) and (2), are shown in Figure 1. The parameters extrapolated from the regressions are given in Table 1. Hormetic effects were frequently observed and the data were well described by the peaked model (Equation (2)), as well as by model 1, for the data without biostimulation.

The choice to adopt a quantitative approach based on the bioassay experiment and hormesis evaluation using dose–response curves appeared to be useful in evaluating the effects of this potential biostimulant, allowing us to define the range of doses able to stimulate a phenomenon and those posing the potential risk of inhibiting the same phenomenon, as will be reported below.

The results showed that not all the test species were biostimulated in terms of seed germination and seedling growth (Figure 1 and Table 1).

In particular, onion never showed biostimulant effects (Figure 1c and Table 1), while growth-reducing effects in seedlings subjected to increasing concentrations of the extract were observed, so *A. vulgaris* extract seems not to be able to be applied as a potential biostimulant in this species. However, it is worth pointing out that other biostimulants, such as the microalgae *Scenedesmus subspicatus* combined with humic acid and the plant growth-promoting bacteria (PGPB) (*Pseudomonas* sp. 5Vm1K and *P. putida* S1Pf1), were able to increase the onion bulb size and weight [36,37].

In carrot, a strong biostimulation of germination was observed under the effect of *A. vulgaris* extract, with a statistically significant increase of 70% over the untreated control and the highest f value (47.4 ± 10.2) (Figure 1a; Table 1). Similar results were obtained using other biostimulants (vermicompost, karrikinolide and seaweed) for seed-priming treatments in carrot [38]. However, in our research, the stimulation of germination was not followed by biostimulation in seedling growth, which rather showed a reduction in hypocotyl and radicle length, and consequently, in seedling fresh weight with increasing extract concentrations (Figure 1a). In carrot, therefore, the potential biostimulant based on *A. vulgaris* extract could be applied, mainly for stimulating only the germination phase, against possible "hard" seeds or those with low seed germinability. However, Szczepanek et al. [39] found that the biostimulants Kelpak SL (produced from seaweed *Ecklonia maxima*) and Asahi SL (composed of nitrophenols) positively affected the root size distribution by

increasing the yield of medium roots (1.9–3.8 cm in diameter) as well as large roots (3.8–5.0 cm), by 30.5% and 15.8%, respectively.

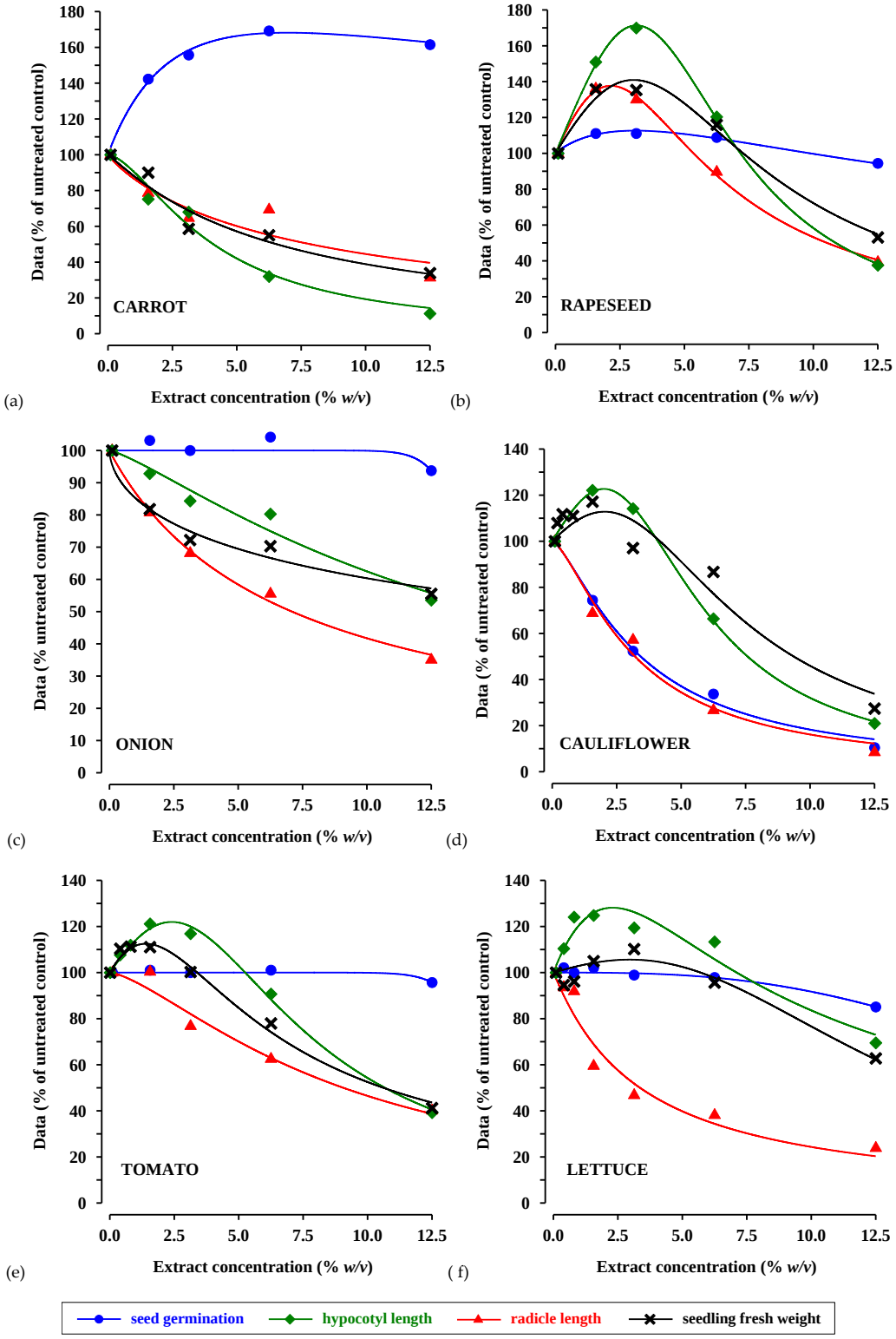

Figure 1. Dose–response curves of seed germination, hypocotyl length, radicle length and seedling weight of the tested crops at different mugwort aqueous extract concentrations (% *w/v*). Symbols show observed data in the bioassay experiments, and lines show fitted curves according to log-logistic models 1 and 2.

Table 1. Dose–response curve parameters (*b*, *a* and *f*) calculated from the fitted equations in Figure 1. Standard errors are in parentheses (not significant: n.s.; significant: * $p = 0.05$, ** $p = 0.01$, *** $p = 0.001$).

Species	Seed Germination									Hypocotyl Length								
	b			*a*			*f*			*b*			*a*			*f*		
Carrot	1.3	*(0.1)*	**	4.9	-	*n.s.*	47.4	*(10.2)*	*	1.6	*(0.3)*	***	4.1	*(0.5)*	***			
Onion	19.4	-	*n.s.*	14.4	-	*n.s.*				1.3	*(0.2)*	***	15.0	*(2.1)*	***			
Tomato	17.5	-	*n.s.*	14.9	-	*n.s.*				2.3	*(0.1)*	***	5.7	*(0.3)*	***	16.0	*(1.9)*	***
Rapeseed	1.4	*(0.1)*	***	7.5	*(2.1)*	**	14.9	*(5.2)*	*	3.0	*(0.1)*	***	5.3	*(0.1)*	***	34.3	*(1.1)*	***
Cauliflower	1.4	*(0.1)*	***	3.4	*(0.2)*	***				2.6	*(0.2)*	***	4.6	*(0.4)*	***	18.3	*(3.9)*	**
Lettuce	2.9	*(0.9)*	*	22.6	*(4.4)*	**				1.7	*(0.2)*	***	4.5	*(1.1)*	***	30.2	*(9.2)*	**
Species	**Radicle Length**									**Seedling fresh Weight**								
	b			*a*			*f*			*b*			*a*			*f*		
Carrot	0.9	*(0.3)*	*	7.9	*(2.0)*	**				1.1	*(0.2)*	***	6.6	*(0.9)*	***			
Onion	1.0	*(0.2)*	***	7.1	*(1.0)*	***				0.6	*(0.1)*	***	20.6	*(4.6)*	**			
Tomato	1.4	*(0.2)*	***	9.1	*(0.8)*	***				1.8	*(0.1)*	***	4.2	*(0.8)*	***	20.3	*(6.8)*	**
Rapeseed	2.2	*(0.1)*	***	4.2	*(0.3)*	**	31.8	*(3.1)*	**	2.4	*(0.2)*	***	5.8	*(0.7)*	***	23.3	*(4.5)*	***
Cauliflower	1.4	*(0.3)*	**	3.2	*(0.5)*	***				2.4	*(0.5)*	**	5.8	*(1.5)*	*	11.0	-	*n.s.*
Lettuce	1.0	*(0.1)*	***	3.4	*(0.4)*	***				2.4	*(0.6)*	**	11.4	*(2.0)*	***	3.2	-	*n.s.*

In tomato, seed germination was not affected by *A. vulgaris* extract; however, a significant biostimulatory effect of +20% with respect to the untreated control was observed in the hypocotyl length ($f = 16 \pm 1.9$), while the radicle length showed a decreasing trend, already at low concentrations of the extract (Figure 1e; Table 1). However, it should be pointed out that the phytotoxic effect of the extract toward the root was very low at the lowest concentrations of the extract (0.4% to 1.56% *w/v*), which were found to be biostimulatory for hypocotyl. Therefore, low concentrations of the *A. vulgaris*-based biostimulant could be used in tomato in order to enhance the initial seedling growth. This would be important in enhancing the success of sown tomato cultivation, both in the open field and in protected cultivation, also increasing the performance of this crop in the transplanting of seedlings in a horticultural nursery. Similar results were obtained using cerium (Ce) as a biostimulant in tomato cv. Vengador [40].

In rapeseed, unlike all the other species, significant stimulation of all the examined traits was observed as a result of *A. vulgaris* extract—which, in the case of hypocotyl length, reached 70% of the untreated control—while for seed germination, radicle length and seedling fresh weight, the stimulations were +11%, +30% and +35%, respectively (Figure 1b, Table 1). The *f* values were 14.9 ± 5.2, 23.3 ± 4.5, 31.8 ± 3.1 and 34.3 ± 1.1 for seed germination, seedling fresh weight, radicle length and hypocotyl length, respectively (Table 1). These results show that in rapeseed, the *A. vulgaris*-based biostimulant could be favorably employed in enhancing all the germination and growth "performances" of seedlings in order to improve their tolerance to abiotic stressors (water and salt stress), which are very common in growing environments [41,42].

Cauliflower and lettuce showed significant stimulation effects in hypocotyl length, which reached +22% ($f = 18.3 \pm 3.9$) and +25% ($f = 30.2 \pm 9.2$), respectively, while at the same, the extract concentrations were matched by significant radicle length inhibition effects (Figure 1d,f; Table 1). This seems to advise against the possible use of the extract as a biostimulant in these species for agricultural applications, since at the biostimulant extract concentrations for hypocotyl, the radicle is already quite inhibited. However, hypocotyl stimulation alone could be of interest in the production of sprouts intended for human or animal consumption as they are rich in phytochemicals and/or nutraceuticals [43].

These findings show that the biostimulation response to the *A. vulgaris* extract seems to be "specie specific" and "part plant specific", as reported in several reviews on the biostimulants [10,11,44–46]. Therefore, it would be appropriate, to investigate the biological and physiological phenomena underlying the hormetic and stimulatory effects found in these species; this could open up new scenarios in the biostimulation of plant species through the use of natural substances, with the goal of establishing their use in organic and sustainable agriculture. Povero et al. [47] proposed an integrated approach based on chemistry, biology and omics to understand the specific mode(s) of action of bioactive ingredients, an approach that should be taken to discover, evaluate and validate potential

new biostimulants. Furthermore, the study of biostimulant effects using hormetic dose–response curves allows us to define the range of doses able to stimulate a phenomenon, avoiding those posing a higher risk of inhibiting the same phenomenon. However, according to Bulgari et al. [45], biostimulants should be characterized based on their action in plants or on the plant's physiological response toward the biostimulants, rather than on their composition. Nonetheless, understanding the composition of biostimulants remains valuable from a quality-control perspective.

In this context, the *A. vulgaris* extract used in this research was recently analyzed in terms of chemical composition, highlighting twelve different phenolic compounds: hydroxycinnamic acids (caffeic, sinapic, p/m-coumaric, ferulic, homovanillic and chlorogenic) and hydroxybenzoic acids (p-hydroxybenzoic, gallic, syringic, salicylic and gentisic) [15]. The phenolic compounds and their quantities were: homovanillic (52 $mg \cdot g^{-1}$ dry tissue), gentisic (25 $mg \cdot g^{-1}$ d.t.), gallic (16 $mg \cdot g^{-1}$ d.t.), chlorogenic (11 $mg \cdot g^{-1}$ d.t.), caffeic (10 $mg \cdot g^{-1}$ d.t.), salicylic and syringic (8 $mg \cdot g^{-1}$ d.t.), sinapic (3 $mg \cdot g^{-1}$ d.t.) and p/m-coumaric, ferulic, p-hydroxybenzoic (2 $mg \cdot g^{-1}$ d.t.). These phenolics could be involved in the biostimulant activities observed in this research, as reported by Kisiriko et al. [21] with phenolics extracted from medicinal and aromatic plants that enhanced seed germination, rooting, shooting and fruiting. Indeed, phenolic compounds can stimulate plant growth and development by increasing the levels of phytohormone growth promoters such as auxins, cytokinins and gibberellins, and decreasing the levels of phytohormone growth inhibitors such as abscisic acid [22]. The exposure of plants to phenolic compounds induces morphological changes that reflect variations in hormonal balance. Several studies suggest that phenolic compounds may induce rooting, influencing the metabolism of indole-3-acetic acid (IAA), one of the auxin hormones that is mainly involved in this process. This hormone can be inactivated via conjugation or decarboxylation (catalyzed by the enzyme IAA oxidase), and phenolic compounds can stimulate rooting by preventing the decarboxylation of IAA, or by stimulating IAA oxidase degradation [48]. The decarboxylation of IAA is inhibited by *meta*- and *ortho*-diphenols and polyphenols, while it is stimulated by monophenols [49]. De Klerk et al. [50] reported that phenolic compounds increase rooting in the stem slices of *Malus* 'Jork 90, particularly in the presence of sub-optimal concentrations of IAA. The effect was observed for *o*-diphenols (caffeic and chlorogenic acids, and catechol), methylated *o*-diphenols (ferulic acid and vanillin) and triphenols (gallic and tannic acids, phloroglucinol and pyrogallol). The induction of rooting seems to be related to the massive inhibition of the decarboxylation of IAA. The same phenomenon could be involved in the stimulation of radicle length in rapeseed in our research, considering that most of the involved phenols were also found in the mugwort extract. However, phenols can also inhibit root growth, as observed by Salvador et al. [51] with cinnamic acid, which significantly increased the activity of IAA oxidase, and thus, the reduction in the endogenous levels of IAA, reducing the growth of *Glycine max* roots. Similarly, Devi and Prasad [52] found that ferulic acid increased the activity of IAA oxidase and peroxidases in *Zea mays*, which may have contributed to the degradation of endogenous IAA, reducing root and seedlings growth. In *Oriza sativa* plants, treatment with ferulic acid also inhibited the formation of lateral roots and root hairs and suppressed the expression of two related genes [53]. The role of ferulic acid in the inhibition of radicle growth could be also involved in the effects observed with mugwort extract in most of the vegetables tested in our research. Phenolic acids can also antagonistically influence the effects of abscisic acid (ABA). In particular, in *Lactuca sativa*, Li et al. [54] found that monohydroxylated phenolic acids (i.e., cinnamic and p/m-coumaric) inhibit the growth of *L. sativa* seedlings, while di- or polyhydroxylates (at low concentrations) (i.e., caffeic and ferulic) promote it, influencing the action of ABA. These results are in line with those obtained on *L. sativa* in our research, and can also help to explain the similar activity of mugwort extract, if considering its composition in terms of the involved phenolic compounds.

Finally, Pannacci et al. [8] found that *A. vulgaris* extract stimulated the radicle and mesocotyl length of maize and bean; however, it was also able to inhibit seed germination in

Amaranthus retroflexus, leading us to conclude that mugwort extract—thanks to biostimulant action on the crops and herbicidal activity against weeds—could be the ideal solution in an integrated crop-protection program in order to suppress weeds, increasing the competitive ability of crops. In this regard, other findings showed that the aqueous extract of mugwort aerial biomass at 25% *w/v* proved a potent inhibitor of seed germination and plant growth in *Lolium multiflorum*, but not that of *Triticum aestivum*. Efficacy against *L. multiflorum* and selectivity for wheat are two important qualities from which the development of the aqueous extract of mugwort as a pre-emergence bioherbicide could be considered. Furthermore, from an agronomic point of view, the use of water extracts from bioactive plants, such as mugwort extract, is economically viable for farmers, especially those living in poor communities, since they would only need to source the plants and mix them with water, which is inexpensive and does not require any specialist knowledge. Finally, based on this and the previous evidence on *A. vulgaris* extract, we would like to emphasize our interest in starting the process of its development for the market as a biostimulant for crops and as a bioherbicide against weeds.

4. Conclusions

The aqueous extract of mugwort appears to be a valid potential biostimulant to promote germination and seedling growth in sustainable horticulture production, as well as in sprout production for human or animal consumption.

The "specie specific" and "part of plant specific" responses of crops to mugwort extract require us to increase the data on its effects on other crop species in order to enhance its potential applications, while it seems that 2.5% *w/v* can be considered the concentration for maximal stimulation response.

Mugwort extract also seems to be an ideal solution for an integrated crop-protection program in order to suppress weeds, increasing the growth of crops and their competitive ability, for sustainable agriculture under climate change.

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