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Concept Paper

Biostimulants and Herbicides: A Promising Approach towards Green Deal Implementation

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Abstract: Biostimulants are products that can increase crop growth and can be applied either to the soil or to the plant and seed of a wide range of crops. However, there is a large gap in knowledge regarding the potential interactions of biostimulants with plant protection products like herbicides. The present review aims to highlight various effects of the combined use of biostimulants with herbicides in terms of weed management, crop yield and quality parameters. Special emphasis is given to the comparison between the combined use of biostimulants with herbicides and herbicides used alone (without biostimulants). In wheat and potato, the combined use of biostimulants with herbicides can in some cases be beneficial for the crop compared with herbicides alone, with recorded yield increases of up to 14.7% depending on the biostimulant, the herbicide, the year and the method of application (mixture or sequentially). Combining herbicides and biostimulants shows potential to achieve good weed management while improving crop yields and quality and thus lower herbicide rates could be probably used for sufficient weed control in full agreement with the goals of Green Deal and agroecology approaches.

Keywords: biostimulants; herbicides; combined use; weed management; crop yield; crop quality

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1. Introduction

Plants are threatened by several biotic factors like pests and weeds, especially in the case of low growth rate crops [1,2]. Herbicides are widely used due to the sufficient weed management they often provide [3,4]. However, the lack of new modes of action, the evolved resistance, the potential environmental harm and legislative issues are among the issues that cause problems with their use [1–3]. The European Council of environmental protection has demanded the reduction of the use and risk of herbicides by 50% by 2030, because of their harmful impacts not only on biodiversity but also on human health [5]. Such a challenging goal cannot be achieved without decision support systems and innovative tools like biostimulants in order not only to mitigate the negative impacts of weeds, but also to enhance crop yield [6,7].

Biostimulants are defined as compounds, substances and other products such as microorganisms, enzymes and plant growth regulators [8]. They do not, however, contain biologically significant amounts of plant nutrients, and their effects are due to stimulating plant functions and beneficial organisms. Examples include humic compounds (humic and fulvic acids, huminas), fungi and bacteria (symbiotic, parasitoid), seaweed extracts (brown algae, microalgae), inorganic compounds and biopolymers (chitin, chitosan, cellulose, alginate). They are applied to the plant, seed, soil or other growing media. Nevertheless, they should not be considered as nutrients even though they expedite their absorption [7]. Biostimulants are increasingly used as substitutes for plant protection agents. This could be potentially vital in the era of implementation of the European Green Deal, which has ordered the reduction of pesticides for agriculture [9].

The objective of this paper is to highlight the effects of combining biostimulants and herbicides on crop yield and quality and weed management.

2. Efficacy on Weeds

Matysiak et al. (2018) studied the efficacy of the addition of biostimulants to the herbicides in spring wheat against weeds like *Chenopodium album*, *Galium aparine*, *Matricaria indora*, *Veronica agrestis* and *Viola arvensis* [10]. Herbicides were applied either alone or with biostimulants (in a tank mixture or sequentially). The results revealed a slight reduction in the efficacy against *V. agrestis* and *V. arvensis* after the application of mixtures of biostimulants (Kelpak and Asahi) and herbicides (MCPA + dicamba and dicamba + triasulfuron). As shown in Table 1, the most significant decline was noted after the combination of biostimulants and florasulam + 2,4-D herbicides against these weeds species.

Table 1. Responses of *Chenopodium album* to the tank mixed application of herbicides and biostimulants (Kelpak, Asahi and Crop Booster) compared to the single herbicide treatments.

Treatments	Weed Control (% of Untreated)	Source
florasulam + 2,4-D	97.5	[10]
florasulam + 2,4-D + Kelpak	99.8	[10]
florasulam + 2,4-D + Asahi	99.5	[10]
glyphosate	99.0	[8]
glyphosate + Crop Booster	98.0	[8]
glyphosate + topramezone + atrazine	99.0	[8]
glyphosate + topramezone + atrazine + Crop Booster	99.0	[8]
glyphosate + thiencarbazone-methyl/tembotrione	94.0	[8]
glyphosate + thiencarbazone-methyl/tembotrione + Crop Booster	94.0	[8]

Soltani et al. [8] evaluated the effect of Crop Booster and RR Soy Booster biostimulants and herbicides on maize, oat and winter wheat. The efficacy of the combined applications of herbicides and biostimulants was studied against the weeds *Abutilon theophrasti*, *Amaranthus retroflexus*, *Ambrosia artemisiifolia*, *C. album*, *Setaria viridis* and other annual grasses. In maize, the addition of glyphosate to the Crop Booster biostimulant had no significant effect on the control of *C. album* and *A. retroflexus* (Table 1). In fact, in the majority of the trials, the addition of the biostimulants did not affect the performance of the herbicides, while in some cases (like in the combined application of glyphosate and topramezone + atrazine with Crop Booster), the efficacy on *A. theophrasti* was slightly higher [8]. Furthermore, the mixtures of biostimulants and herbicides caused minimal or no visible injury in maize, oat and wheat [8].

3. Effects on Crops' Yield and Quality

3.1. Crop Yield

It is widely known that biostimulants play an essential role in modern agricultural management, since they can increase crop yield or prevent crop yield losses due to abiotic stresses [11,12]. They improve water supply and increase nutrition efficiency, which is important for plant growth and productivity [13]. Consequently, it would have been interesting to know whether this positive effect of biostimulants on crop growth and yield is also valid after their mixed application with herbicides or any antagonistic relation exists.

There are several studies which examine the effects of herbicides with natural and synthetic biostimulants in spring wheat [10]. Matysiak et al. [10] showed that in the majority of cases, the combined use of biostimulants with herbicides was beneficial for the crop compared to the untreated control, with yield increases of up to 18.3% depending on the biostimulant, the herbicide, the year and the method of application (mixture or sequentially). Moreover, in many cases (like dicamba + triasulfuron with Kelpak), the combined use of biostimulants resulted in higher yields (up to 7.4%) even than the herbicides alone (Table 2).

In the case of MCPA + dicamba and florasulam + 2,4-D along with Kelpak, yield was either increased, the same or decreased depending on the year and the specific weather conditions. In comparison, the application of MCPA + dicamba, dicamba + triasulfuron or florasulam + 2,4-D with the biostimulant Asahi had no any beneficial effect on the grain yield, while in some cases decreases of up to 18.2% were also observed [10].

Table 2. Effects of the combined use of biostimulants and herbicides on the yield of different crops compared to the use of the respective herbicides alone (without biostimulants).

Crop	Treatments	Yield	Source
Wheat	MCPA + dicamba + Kelpak	Decreased by 10% or increased by 7.6% [2]	[10]
Wheat	dicamba + triasulfuron + Kelpak	Increased by 3.1–7.4%	[10]
Wheat	dicamba + triasulfuron/Kelpak [1]	Increased by 3.5–4.4%	[10]
Wheat	florasulam + 2,4- D + Kelpak	Same or increased by 6%	[10]
Wheat	florasulam + 2,4-D/Kelpak	Decreased by 5.9% or increased by 11.6%	[10]
Wheat	MCPA + dicamba + Asahi	Decreased by 6–18.2%	[10]
Wheat	dicamba + triasufluron + Asahi	Decreased by 3.6–11.6%	[10]
Wheat	dicamba + triasufluron/Asahi	Decreased by 5.8%	[10]
Potato	clomazone + metribuzin + PlonoStart	Increased by 10.1%	[9]
Potato	clomazone + metribuzin + Aminoplant	Increased by 3.9%	[9]
Potato	clomazone + metribuzin + Agro-Sorb Folium	Increased by 14.7%	[9]
Maize	glyphosate + CropBooster	Increased by 2.4%	[8]
Maize	glyphosate + topramezone + atrazine + CropBooster	Increased by 0.8%	[8]
Maize	glyphosate + thiencarbazone-tembotrione + CropBooster	Decreased by 1.5%	[8]
Wheat	bromoxynil + MCPA + CropBooster	Increased by 1.3%	[8]
Wheat	bromoxynil + MCPA + CropBooster	Increased by 2.5%	[8]

[1] /denotes separate application (sequentially). [2] differences were observed in different years.

In another study, Ginter et al. [14] revealed the beneficial effect of the use of biostimulants with herbicides on the total yield of potato. The herbicide mixture clomazone + metribuzin and the biostimulants PlonoStart, Aminoplant and Agro-Sorb Folium were tested. The results showed that the combined use of the herbicide along with the biostimulants increased total yield up to 14.7% and 23.3% compared to chemical (alone) and mechanical weed control, respectively (Table 2). In a previous study with the same herbicide (clomazone + metribuzin), Zarzecka et al. [15] also revealed a higher competition against the weeds and a significantly increased yield compared to the control.

Soltani et al. [8] evaluated the effect of the biostimulants CropBooster and RR SoyBooster combined with glyphosate, glyphosate + topramezone + atrazine or glyphosate + thiencarbazone/tembotrione herbicides on three crops (maize, oat, wheat). The use of biostimulants along with herbicides increased yields compared to the untreated (weedy) plots by up to 65.4%, 10.3% and 2.1% for maize, oat and wheat, respectively. In maize, the use of either CropBooster or RR SoyBooster biostimulants combined with either glyphosate or glyphosate + topramezone + atrazine herbicides resulted in an increase of crop yield by up to 2.4% compared to the herbicide mixture used without the biostimulant. On the other hand, the combination of those two biostimulants with glyphosate + thiencarbazone/tembotrione resulted in a not significant decline (1.5%). In oat and wheat, the combination of CropBooster biostimulant with bromoxynil/MCPA herbicide revealed a small but positive effect on yields, with increases of up to 1.3% and 2.5%, respectively [8]. Once again, the observed differences could be attributed to the different crops, weeds, herbicides, biostimulants and pedoclimatic conditions.

3.2. Quality Parameters

In the previously mentioned research by Matysiak et al. [10], results showed that the use of biostimulants has a positive effect on quality parameters of spring wheat [10]. It is notable that in the majority of the treatments, the combined use of biostimulants with herbicides was beneficial for the quality of wheat compared to the untreated control. In particular, protein content increases were up to 7.2% depending on the biostimulant, the herbicide, the year and the method of application (mixture or sequentially). Florasulam + 2,4-D herbicide applied alone resulted in the lowest content of gluten, protein and Zeleny sedimentation value, while in combination with the Asahi biostimulant, the grain quality characteristics were enhanced (Table 3). However, the combinations of florasulam + 2,4-D and Kelpak biostimulant and MCPA + dicamba with biostimulants resulted in an insignificant decline in grain quality. On the contrary, dicamba + triasulfuron herbicide with biostimulants had a positive effect on quality compared to the plants treated only with the herbicide (Table 3). In most cases, starch content was not significantly affected by the combined use of biostimulants and herbicides.

Table 3. Effects of the combined use of biostimulants and herbicides on quality parameters of different crops and products compared to the use of the respective herbicides alone (without biostimulants).

Crop	Treatments	Quality Parameters	Source
Wheat	florasulam + 2,4-D + Asahi	Gluten, protein content and Zeleny values increased up to 6.9%, 5.9% and 14.4%, respectively	[10]
Wheat	dicamba + triasulfuron + Asahi	Gluten, protein content and Zeleny values increased up to 5.2%, 5.8% and 6.2%, respectively	[10]
Potato (leaves)	metribuzin + Asahi	Glycoalkaloid content decreased by 1%	[15]
Potato (leaves)	linuron + clomazone + Kelpak	Glycoalkaloid content decreased by 0.8%	[15]
Potato (tubers)	linuron + clomazone + Kelpak	Glycoalkaloid content decreased by 0.6%	[15]
Potato (tubers)	metribuzin + Asahi	Glycoalkaloid content decreased by 0.2%	[15]
Potato (leaves)	metribuzin + Asahi	Polyphenol content increased by 0.6%	[16]
Potato (leaves)	linuron + clomazone + Kelpak	Polyphenol content increased by 0.7%	[16]
Potato (tubers)	clomazone + metribuzin + Agro-Sorb-Folium	Starch and protein content increased by 16.3% and 18.2%, respectively	[14]
Potato (tubers)	clomazone + metribuzin + PlonoStart	Starch and protein content increased by 9.5% and 16.5%, respectively	[14]
Potato (tubers)	clomazone + metribuzin + Aminoplant	Starch and protein content increased by 7.5% and 8.6%, respectively	[14]

Other quality characteristics influenced by biostimulants are polyphenol and glycoalkaloid content in potato cultivation [15,16]. Zarzecka et al. [16] evaluated the effects of biostimulants and herbicides on polyphenol content in tubers and leaves of three potato cultivars. Acording to this study, the use of biostimulants and herbicides significantly increased the polyphenol content in potato tubers, while in leaves there were not any significant effects (Table 3). Gugala et al. [15] studied the effects of the application of biostimulants and herbicides on glycoalkaloid content in potato tubers and leaves. The combination of metribuzin with Asahi biostimulant and linuron + clomazone with Kelpak biostimulant resulted in glycoalkaloid content similar to the corresponding values for the plants treated only with the herbicides, showing that the mixtures had no impact on glycoalkaloid levels.

In another study, Zarzecka et al. [14] examined the impact of herbicides and herbicide with biostimulants on dry matter yield, starch and total protein content of potato tubers. Five treatments were applied including the control object. The herbicide clomazone + metribuzin was either solely applied or as a tank mixture with PlonoStart, Aminoplant and Agro-Sorb-Folium biostimulants. The combination of the herbicide with Agro-Sorb-Folium resulted in starch content of 4.79 t ha^{-1} and protein yield of 1.22 t ha^{-1}. These values were 28.2–32.8% and 16.3–18.2% higher than the corresponding values for the untreated plots and the plots treated only with herbicides, respectively (Table 3).

4. Conclusions

This review highlights various effects of the combined use of biostimulants with herbicides in terms of weed management, crop yield and quality parameters. In many cases, the beneficial effects of the combined use of biostimulants and herbicides compared with the untreated plants were due to the weed control and the crop growth promotion provided by the herbicide and the biostimulant, respectively. Further emphasizing the comparison between the combined use of biostimulants with herbicides and herbicides used alone (without biostimulants) reveals some important findings. In wheat and potato, the combined use of biostimulants with herbicides achieved yield increases up to 14.7% compared with herbicides alone, depending on the biostimulant, the herbicide, the year and the method of application (mixture or sequentially). At the same time, there appeared to be limited antagonism between most herbicides and biostimulants, such that in most cases weed control is maintained. Crop quality has also been enhanced with parameters such as gluten, protein content and Zeleny values in wheat and starch and protein content in potato. Such information can be valuable for farmers and advisors since the combined use of biostimulants with herbicides might potentially result in a requirement for lower rates for a sufficient weed control in full agreement with the goals of Green Deal and agroecology approaches. Up to now there is a gap in the research as to whether combining herbicides and biostimulants can actually permit a reduction in herbicide use, e.g., by increasing crop competitiveness, or improving herbicide performance, allowing a reduction in the number of herbicide applications or use of reduced rates, the last point with a caveat around herbicide resistance. Consequently, more studies are required with more combinations under various conditions, with different rates and in a wider range of crops and weeds in order to confirm the general view, provide details and give the ability for tailor-made solutions.

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