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*Research article*

# DECREASE IN IMAZAMOX SELECTIVITY IN GREEN PEA (*Pisum sativum* L.) CULTIVATION UNDER IRRIGATION

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***ABSTRACT***

*The selectivity of imazamox, in two commercial formulations, was tested on two green pea varieties at two locations in 2017. The field trials were conducted following the OEPP/EPPO standard methods for selectivity testing. Both herbicides were applied at two rates: the maximum recommended dose (1.2 l/ha) and twice the recommended dose (2.4 l/ha). Visual assessments were performed during the growing season and plant height was measured when growth was significantly reduced. At harvest, both quantitative and qualitative yield parameters were measured, including seed yield, tenderometer index and seed size. The results indicate that under irrigation, imazamox has increased residual activity, leading to significant phytotoxicity. This is reflected in reduced vegetative growth, delayed generative development (flowering) and postponed harvest, with negative effects on both quantitative and qualitative yield parameters.*

***Key words:***
*green pea, imazamox, selectivity, phytotoxicity, irrigation*

**Abbreviations**:
OEPP/EPPO – European and Mediterranean Plant Protection Organization/Organisation Européene et Méditeranéenne pour la Protection des Plantes; POST-EM – post emergence; TI – tenderometer index

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## INTRODUCTION

The cultivation of green pea (*Pisum sativum* L.) for processing has a long tradition in Serbia, especially in the Banat region, where the soil quality and weather conditions are favorable for its cultivation. Nevertheless, despite the suitable conditions, irrigation is necessary as it improves growth parameters and influences developmental stages, including flowering, pod formation and ripening. Peas are highly sensitive to water deficit, especially during generative growth. Drought stress can decrease flower production and lead to reduced seed size and weight. Even minimal moisture stress during pod filling is more detrimental to yield than at any other growth stage (Fatima et al., 2024). Several factors influence the final texture quality of frozen green peas, including genotype, growing conditions, maturity at harvest and processing methods (Edelenbos et al., 2001). Green peas are usually harvested mechanically in a single-phase process, operating 24 hours a day to make the best use of expensive equipment and ensure a continuous supply to processing plants (Radojević et al., 2013). Harvesting is carried out at the stage of technological maturity when the grains are still soft and before the seeds become mealy and less sweet (Edelenbos et al., 2001). The timing of harvest is crucial, as green peas rapidly pass through their optimal maturity stage, especially in hot, dry and windy conditions, which accelerate the conversion of sugars to starch. Although delaying harvest by one to two days can increase the yields, it can negatively impact the yield quality.

Imazamox [(RS)-2-(4-isopropyl-4-methyl-5-oxo-2-imidazolin-2-yl)-5-methoxymethyl-nicotinic acid] is a selective herbicide from the imidazolinone chemical group, used to control different annual broadleaf weeds and certain grasses in legumes, as well as in imidazolinone-tolerant crops (Nelson and Renner, 1998; Nelson et al., 1998; Blackshaw et al., 2000; Vangessel et al., 2000; Haukkapää et al., 2005; Neshev et al., 2020). Imazamox is an ALS inhibitor (HRAC group 2/B) that disrupts the biosynthesis of branched-chain amino acids (valine, leucine and isoleucine) by inhibiting the enzyme acetolactate synthase (AHAS, E.C.4.1.3.18) (Shaner et al., 1984, 1991). It is used as a foliar (POST-EM) herbicide, most effective when applied to weeds at the recommended growth stages. Imazamox is also characterized by residual activity, or so-called soil activity, as the herbicide is absorbed by the root system of the plants. It occurs when the spray solution reaches the soil surface at the time of application, as both the plants and the weeds are still small. The effectiveness of the residual activity depends on the persistence of imazamox, which is influenced by soil properties (texture, pH, organic matter, clay content and microbial degradation activity) and meteorological conditions (temperature and precipitation) during the season following application (Cobucci et al., 1998; Bresnahan et al., 2002; Ball et al., 2003; Rood et al., 2012; Liu et al., 2016; Buerge et al., 2019). The half-life of imazamox is between 17 and 92 days, depending on these factors and adsorption to soil colloids (Baer and Calvet, 1999; Vischetti et al., 2002). Adsorption is more pronounced in dry soils, reducing availability of the herbicide for plant root uptake. In contrast, in soils with a pH ≥7, adsorption is slower and weaker, leading to increased residual levels and greater availability for plant uptake (Bresnahan et al., 2002; Aichelle and Penner, 2005; Pannacci et al., 2006).

Imazamox is registered for weed control in peas as a selective herbicide with a recommended application rate of 1.2 l/ha (48 g a.i. imazamox/ha). However, actual application doses are often reduced to 0.3 l/ha because of phytotoxicity and yield reductions. Since lower doses of imazamox are less effective in weed control, resulting in lower crop yields, the aim of this study was to investigate the selectivity of imazamox (in two commercial formulations) under field conditions following established methodologies, measuring all parameters necessary for valid conclusions.

## MATERIAL AND METHODS

The selectivity trials were carried out during the 2017 growing season at two locations: Krajišnik (N: 45° 24' 49.6"; E: 20° 44' 17.8" and altitude 80±3 m) and Opovo (N: 45° 03' 44.1"; E: 20° 31' 42.4" and altitude 90±2 m). Both of these locations are known for pea cultivation in accordance with Good Agricultural Practices (GAP). The soil in Krajišnik was classified as clay loam with the following properties: pH 7.8; 29.64% sand, 36.12% silt, 34.24% clay and 2.81% organic matter. In Opovo, the soil was silty loam with the following properties: pH 7.46; 3.81% sand, 62.19% silt, 34.0% clay and 3.76% organic matter. Two pea varieties were tested: Wolf at Krajišnik and Medionat at Opovo. Both varieties are cultivated as green peas for freezing.

The selectivity trials were conducted following standard OEPP/EPPO methods to test two herbicide formulations: Sinamon (40 g a.i./l; Agrosava) and Pulsar-40 (40 g a.i./l; BASF). Each herbicide was applied at two rates: the maximum recommended dose (1X) and twice the recommended dose (2X), i.e. 1.2 l/ha and 2.4 l/ha, respectively. The experimental design was a randomized complete block with four replications. Each plot was 4.2 x 6 m in size. Both herbicides were applied at the recommended pea growth stage (BBCH 11-13) using a hand-held $CO_2$-presurized sprayer equipped with two flat fan nozzles (XR Tee Jet 11002) at a distance of 60 cm, delivering a spray volume of 240 l/ha of water.

Table 1 presents the dates of sowing, herbicide application, assessment and harvest, while Table 2 provides meteorological data.

Table 1. Timing of crop sowing, herbicide application, assessments and harvest of peas

| Important dates | Krajišnik | Opovo |
|---|---|---|
| **Crop sowing** | 25.03.2017 | 04.04.2017 |
| **Herbicide application** | 25.04.2017 | 10.05.2017 |
| **1st assessment** | 09.05.2017 | 24.05.2017 |
| **2nd assessment** | 23.05.2017 | 07.06.2017 |
| **3rd assessment** | 30.05.2017 | - |
| **Harvest** | 11.06.2017 | 18.06.2017 |

Table 2. Meteorological data during 2017 growing season*

| | | Krajišnik | | | Opovo | |
|---|---|---|---|---|---|---|
| | | April | May | June | May | June |
| **Average temperature (°C)** | minimal | 5.7 | 12.1 | 16.6 | 13.2 | 18.7 |
| | maximal | 17.5 | 24.0 | 29.9 | 23.7 | 29.5 |
| | mean | 11.6 | 18.1 | 23.3 | 18.5 | 24.1 |
| **Precipitation, mm** | sum | 52.5 | 29.3 | 42.7 | 86.5 | 53.2 |
| **Precipitation during 10 days before herbicide application** | sum | 41.8 | | | 21.2 | |

Legend: *obtained from the nearest official meteorological stations

The meteorological conditions were favorable for pea growth and development. However, rainfall had no significant influence, as the peas were grown under irrigation, receiving the required amount of water throughout the growing season.

In accordance with OEPP/EPPO standards (OEPP/EPPO, 2007 - PP 1/91; OEPP/EPPO, 2014 - PP 1/135), two visual assessments of phytotoxicity were conducted up to two and four weeks after the application of imazamox. Phytotoxicity was assessed visually using a 0-100% scale, where 0% indicates no sypmtoms and 100% corresponds to crop failure. The third visual assessment was conducted only in Krajišnik during the flowering stage, as the peas in Opovo were already flowering at the time of the second assessment. Since a significant reduction in plant growth was observed, plant height was measured on 10 randomly selected plants in the central area of each plot (replication) for each treatment.

During the harvest, which was performed manually, the tenderometer index (TI) (as a qualitative parameter) was measured *in situ* for each replication and treatment immediately after pea seed collection using a portable Tenderometer® (type F-2, k+F Mérnökiroda Kft., Budapest). The tenderometer was used to determine pea maturity before harvest by measuring the "tenderness of the peas" i.e. the force required to press a pea sample through a standard grid (Everaarts and Sukkel, 2000). The tenderometer index indicates the ratio between lower carbohydrates, which are essential for seed quality, and starch, which increases with maturity but reduces seed quality.

The inner rows were harvested to measure seed yield (kg/ha), followed by seed size measurements (using a micrometer with a reading of 0.01 mm) on 100 randomly selected seeds for each replication in all treatments. These measurements were used as quantitative yield parameters. All measured seeds were categorized based on their diameter and according to Western European market regulations as follows: extra fine (EF) <7.5 mm, very fine (VF) = 7.6-8.2 mm, fine (F) = 8.3-8.7 mm, middle (M) = 8.8-9.3 mm, and middle II (M II) >9.4 mm for round seed varieties, which include both tested varieties.

The results were processed using the SPSS statistical package. The average values were calculated for each parameter, along with the coefficient of variation and the standard deviation. The LSD and t-test were applied to determine the statistical significance of differences between treatments for each analyzed parameter.

## RESULTS AND DISCUSSION

The first visual assessment of imazamox selectivity showed a clear and pronounced phytotoxicity in peas at both locations, as evidenced by stunted plant growth and development (Tables 3 and 4). Due to severe reductions in pea growth, plant height was measured to determine the statistical significance of phytotoxicity (Tables 5 and 6). Reductions in plant height were particularly pronounced in the 2X treatments for both tested imazamox formulations, while there were no visual differences between them. However, there were highly significant differences between these treatments and both the control and the 1X treatments, while the 1X treatments also showed highly significant differences compared to the control. Visual phytotoxicity was similar in the 1X treatments for both pea varieties.

Table 3. Visual assessment of the phytotoxicity of imazamox (variety Wolf, location Krajišnik)

| Dates of visual assessments | Herbicide treatment | | | |
|---|---|---|---|---|
| | Sinamon (1.2 l/ha) | Sinamon (2.4 l/ha) | Pulsar-40 (1.2 l/ha) | Pulsar-40 (2.4 l/ha) |
| | - Phytotoxicity, % - | | | |
| 09.05.2017 | 40.0 | 60.0 | 45.0 | 65.0 |
| 23.05.2017 | 15.0 | 25.0 | 15.0 | 30.0 |
| 30.05.2017 | 5.0 | 10.0 | 7.0 | 13.0 |

Table 4. Visual assessment of the phytotoxicity of imazamox (variety Medion, location Opovo)

| **Dates of visual assessments** | **Herbicide treatment** | | | |
|---|---|---|---|---|
| | **Sinamon (1.2 l/ha)** | **Sinamon (2.4 l/ha)** | **Pulsar-40 (1.2 l/ha)** | **Pulsar-40 (2.4 l/ha)** |
| | **- Phytotoxicity, % -** | | | |
| 24.05.2017 | 50.0 | 65.0 | 50.0 | 70.0 |
| 07.06.2017 | 10.0 | 17.0 | 10.0 | 20.0 |

Table 5. Average plant height of the pea varieties at the first assessment

| **Herbicide treatment** | **Plant hight** (cm) | | | |
|---|---|---|---|---|
| | **Wolf** (location Krajišnik) | | Medion (location Opovo) | |
| Control | **23.3** | SD = 0.216025<br>CV = 0.009271 | **26.88** | SD = 0.298608<br>CV = 0.01111 |
| Sinamon (1.2 l/ha) | **22.71** | SD = 3.672505<br>CV = 0.161695 | **21.00** | SD = 0.828654<br>CV = 0.03946 |
| Sinamon (2.4 l/ha) | **17.55** | SD = 2.284002<br>CV = 0.130143 | **12.80** | SD = 0.770281<br>CV = 0.060178 |
| Pulsar-40 (1.2 l/ha) | **22.43** | SD = 1.978846<br>CV = 0.088243 | **20.15** | SD = 0.929157<br>CV = 0.046112 |
| Pulsar-40 (2.4 l/ha) | **15.88** | SD = 0.925113<br>CV = 0.058275 | **12.20** | SD = 0.583095<br>CV = 0.047795 |

Legend: SD – standard deviation; CV – coefficient of variation

Table 6. ANOVA analysis for the plant height of the pea varieties

| | **LSD/t-test** | | | |
|---|---|---|---|---|
| | **Wolf** (Krajišnik) | **p** | **Medion** (Opovo) | **p** |
| Control vs. Sinamon (1.2 l/ha) | NS/NS | p=0.76026 | **/** | p=1.098E-05 |
| Control vs. Sinamon (2.4 l/ha) | **/** | p=0.00242 | **/** | p=4.254E-08 |
| Control vs. Pulsar-40 (1.2 l/ha) | NS/NS | p=0.41315 | **/** | p=9.080E-06 |
| Control vs. Pulsar-40 (2.4 l/ha) | **/** | p=4.341E-6 | **/** | p=8.282E-09 |
| Sinamon (1.2 l/ha) vs. Sinamon (2.4 l/ha) | **/NS | p=0.05422 | **/** | p=6.757E-06 |
| Sinamon (1.2 l/ha) vs. Pulsar-40 (1.2 l/ha) | NS/NS | p=0.89488 | NS/NS | p=0.221079 |
| Sinamon (1.2 l/ha) vs. Pulsar-40 (2.4 l/ha) | **/* | p=0.01122 | **/** | p=2.333E-06 |
| Sinamon (2.4 l/ha) vs. Pulsar-40 (1.2 l/ha) | **/* | p=0.01799 | **/** | p=1.863E-05 |
| Sinamon (2.4 l/ha) vs. Pulsar-40 (2.4 l/ha) | NS/NS | p=0.22288 | NS/NS | p=0.260540 |
| Pulsar-40 (1.2 l/ha) vs. Pulsar-40 (2.4 l/ha) | **/** | p=0.00097 | **/** | p=6.760E-06 |

Legend: NS – not significant; * – significant difference; ** – highly significant difference

At the second assessment, the phytotoxicity symptoms were still evident, though the differences between treatments were less pronounced. The severity of phytotoxicity was greater in Opovo, which could be attributed to different sensitivity of the pea varieties, but also to different soil properties and meteorological conditions. Soil properties such as pH, organic matter and clay content are known to significantly influence the adsorption (and persistence) of imazamox (Sakaliene et al., 2007). The comparison of the two study sites in terms of soil characteristics shows that both soils are slightly alkaline, which favors lower herbicide adsorption and desorption (Milan et al., 2017). Aichelle and Penner (2005) reported that at higher pH levels, a higher proportion of imazamox remains in the soil solution, making it more available for plant uptake. In addition, since both soils have similar clay content, the adsorption of imazamox occurs in the same way (Rani et al., 2019). The organic matter content is slightly higher in Opovo, leading to slightly increased adsorption and consequently reduced availability of imazamox residues for plant roots. In addition, the sand content is higher in Krajišnik, which allows imazamox to reach the root zone of the peas faster through the soil profile (before the roots develop and extend deeper). This also increases bioavailability of the herbicide to the plants (Pannacci et al., 2006).

In addition to soil properties, differences in meteorological conditions are also very important. Krajišnik is known for constant winds throughout the whole growing season, which dry out the soil quickly and reduce imazamox desorption compared to the soils with higher moisture content, such as those in Opovo. Previous research has established that higher soil moisture leads to increased uptake of imidazolinone by the roots and greater crop injury (Mangels, 1991). Under dry soil conditions, herbicide adsorption is increased, limiting its availability for plant uptake and reducing plant injury (O'Sullivan et al., 1998). Therefore, dry soil conditions after herbicide application or low soil moisture content are generally associated with slower degradation, resulting in longer residual activity.

The third visual assessment was conducted in Krajišnik to evaluate potential negative effects on flowering. The results indicated a delay in the generative phase, as evidenced by a lower number of flowers in the 1X treatments for both herbicide formulations. A similar delay, though more pronounced, in flowering and the number of flowers was observed in the 2X treatments for both herbicide formulations. At this time, there were no visible differences in plant height. Flowering of the pea variety Medion in Opovo had already started at the time of the second visual assessment, and the observed differences between the treatments and the control were similar to the Wolf variety in Krajišnik. At this time, reduced plant height was observed only in the 2X treatments for both herbicide formulations.

Previous studies have reported pea injuries from imazamox treatments (Miller, 2003), characterized by generalized chlorosis in new growth. These symptoms remained visible for up to 3 weeks and led to a delay in flowering by 6 to 7 days. The green gram (or mung bean - *Vigna radiata* L.), belonging to the legume family and mainly grown in Asia as a drought-tolerant crop, was also injured by POST-EM application of imazamox. Phytotoxicity was estimated at 18-35% but gradually weakened to 5-7% by 45 days after sowing. The symptoms included chlorosis, yellowing and stunting (Punia et al., 2015, 2018). Even imidazolinone-tolerant plants, such as certain IMI-R sunflower hybrids, were injured by imazamox application, displaying transient yellowing and growth retardation, which are symptoms often associated with stressful environmental conditions (Balabanova et al., 2016).

In this study, herbicide treatments had no significant effect on the seed yield of the pea variety Wolf in Krajišnik, although the yield in the control plots was slightly higher (Table 7). In Opovo, on the other hand, there were no significant differences in seed yield of the pea variety Medion between the control and the single treatment with 1X Sinamon, while all other herbicide treatments had highly significant lower yield compared to the control. In addition, there were also no significant differences between the 1X and 2X treatments (Table 7).

Table 7. Quantitative and qualitative parameters of pea varieties yield

| **Herbicide treatments** | **Wolf** (location Krajišnik) | | **Medion** (location Opovo) | |
|---|---|---|---|---|
| | **Seed yield** (kg/ha) | **Tenderometer index** (TI) | **Seed yield** (kg/ha) | **Tenderometer index** (TI) |
| **Control** | **4702.4** [a]<br>SD = 1877.207<br>CV = 0.39921 | **141.75** [a]<br>SD = 8.73212<br>CV = 0.06160 | **5570.5** [a]<br>SD = 602.3028<br>CV = 0.10813 | **131.25** [a]<br>SD = 6.29153<br>CV = 0.04794 |
| **Sinamon (1.2 l/ha)** | **4537.7** [a]<br>SD = 1865.46475<br>CV = 0.41111 | **131** [a]<br>SD = 3.55903<br>CV = 0.02717 | **4679.2** [ab]<br>SD = 1103.67583<br>CV = 0.23587 | **119.25** [ab]<br>SD = 13.98511<br>CV = 0.11728 |
| **Sinamon (2.4 l/ha)** | **4217.5** [a]<br>SD = 1693.281<br>CV = 0.40149 | **92** [b]<br>SD = 2.94392<br>CV = 0.032 | **3671.9** [b]<br>SD = 1258.5<br>CV = 0.34274 | **89.75** [c]<br>SD = 2.5<br>CV = 0.02785 |
| **Pulsar-40 (1.2 l/ha)** | **4436.4** [a]<br>SD = 966.37620<br>CV = 0.21783 | **130.25** [a]<br>SD = 3.77492<br>CV = 0.02898 | **3850.1** [b]<br>SD = 1204.95797<br>CV = 0.31297 | **117** [b]<br>SD = 4.76095<br>CV = 0.04069 |
| **Pulsar-40 (2.4 l/ha)** | **3607.7** [a]<br>SD = 1437.7619<br>CV = 0.39853 | **92.75** [b]<br>SD = 7.32006<br>CV = 0.07892 | **3842.7** [b]<br>SD = 950.3744<br>CV = 0.24732 | **86.25** [c]<br>SD = 4.64579<br>CV = 0.05386 |

Legend: SD – standard deviation; CV – coeficient of variation; a – values followed by the same letter are not significantly different from each other

For round-grain pea varieties, such as Wolf and Medion, TI values ranging from 90 to 130 indicate excellent and very good quality, values from 130 to 150 indicate satisfactory quality, while values above 150 indicate inferior quality. For optimal yield, it is important to harvest peas when TI values are within the range of 100 to 160. However, due to differences in ripening among seeds of the same plant and among different parts of the field, harvesting is normally carried out when the total TI values are between 90 and 180 (multiple samples). It is worth noting that harvesting peas at optimal TI values for processing is always recommended as, for example, yield can double when pea maturity increases from TI 85 to TI 120, which can happen in less than 5 days under certain weather conditions (Martin, 1981).

For the pea variety Wolf in Krajišnik, there were no statistically significant differences in the TI values between the control and the 1X treatments. These values correspond to the categories of good and satisfactory quality for the 1X treatments and the control, respectively. However, the TI values obtained for the 2X treatments indicate good quality (Table 7). It is important to note that the pea harvest in Krajišnik was delayed due to rainfall. In addition, the experimental plots were positioned at the edge of the field, which is always associated with higher TI values compared to the inner parts of the field. It is reasonable to assume that the TI values determined in this study are higher than those that would be expected under optimal conditions and within the field. This implies that, under optimal conditions, similar values can be expected both in the control and after imazamox application at the recommended dose. In contrast, if twice the recommended amount of imazamox is applied (which is required in selectivity trials and relevant in cases of overlapping in herbicide application), the TI values may be even lower than acceptable, potentially leading to delayed harvest. These observations are consistent with the visually observed delay in pea flowering. The harvest delay could be estimated at a maximum of one or two days, which in certain cases may affect mechanical harvesting in intensive pea cultivation.

In the pea variety Medion in Opovo, the TI values obtained were lower, with no statistically significant differences between the control and the 1X treatment with the Sinamon formulation. Furthermore, there were no statistically significant differences between the 1X treatments (Sinamon and Pulsar-40) and between the 2X treatments (Sinamon and Pulsar-40). However, highly significant differences were found between the 2X treatment and all other treatments (Table 7). In Opovo, the experimental plots were located in the inner part of the field, making them more representative. The TI values obtained show almost good, good and unacceptable quality levels for the control, 1X and 2X treatments, respectively. This suggests that the harvest is delayed by more than two days, negatively affecting both the mechanical harvest and the quantity and quality of the seed yield. Previous research has established the importance of assessing pea growth and maturity before harvesting, as the nutritional and organoleptic properties of raw peas selected for freezing may be lost or altered if harvested too late, as well as during processing. Variations in TI values reflect significant variations in pea quality, as pea protein quality can be estimated as a function of TI during the seed growth period (from EF to F size class), given that crude protein content and total sulphur content are both correlated to TI (Ros and Rincon, 1990). Increased TI values have been found to correlate positively with dry matter and negatively with moisture (Periago et al., 1996).

The results obtained for seed yield and TI values indicate differences between pea varieties and/or locations (with more pronounced variations in Opovo), which correspond to the differences in visual assessments. These findings could be attributed to differences in microclimatic conditions, as mentioned and discussed above.

The seed size analysis for the pea variety Wolf in Krajišnik showed that the highest proportion of small seeds was found in the 2X treatments (Figure 1). The differences between the control and the 1X treatments were less prominent. The significance of these differences arises from the fact that 91.75 % and 97.5 % of the seeds in the extra fine and very fine categories were found in the 2X Sinamon and 2X Pulsar-40 treatments, respectively. In the control, 84 % of the seeds belonged to these two categories, while in the 1X Sinamon and 1X Pulsar-40 treatments, the proportion of the seeds in these categories was 71 % and 79.5 %, respectively.

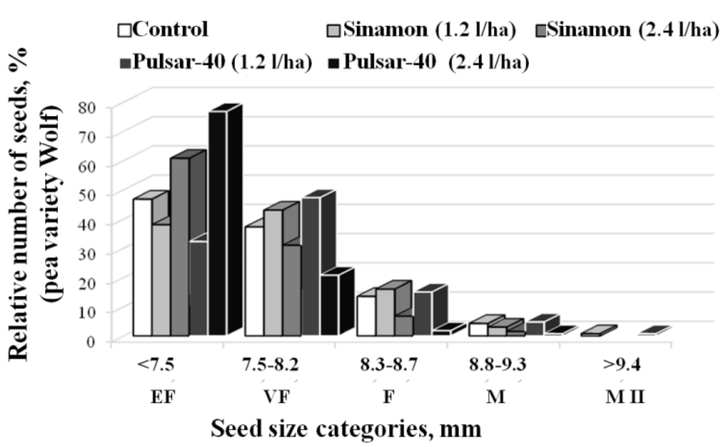


Figure 1. Effect of imazamox on seed size of green peas, variety Wolf, location Krajišnik (EF – extra fine; VF – very fine; F – fine; M – middle; M II – middle II)

It is important to note that the smallest seeds (extra fine category) differed between treatments, with seeds in the herbicide treatments being smaller than in the control. Since there is no classification for seeds smaller than 7.5 mm, further differentiation between treatments was not possible, but it was evident that the seeds in the herbicide treatments were too small. In addition, it was previously found that starch content significantly increases from EF to M size category in some green pea varieties. This shift indicates a reduction in soluble carbohydrates, which are used to form starch, showing that as yield increases, quality decreases (Periago et al., 1996).

In the pea variety Medion in Opovo, the proportion of the smallest seeds was quite uniform in all herbicide treatments and twice as high as in the control (Figure 2). The proportion of seeds in the extra and very fine categories was also significantly higher in all herbicide treatments (>90%) compared to the control (74.25%). In the Medion variety, the undersized seeds in the extra fine category were even more evident and pronounced.

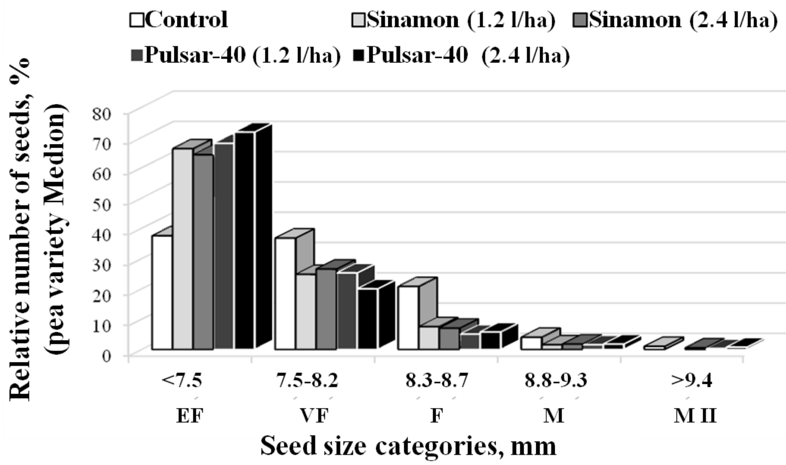


Figure 2. Effect of imazamox on seed size of green peas, variety Medion, location Opovo (EF – extra fine; VF – very fine; F – fine; M – middle; M II – middle II)

Seed size, as a parameter of yield quality, is consistent with other measured parameters. The observed differences are significant for ensuring timely mechanical harvesting and obtaining optimal yield in terms of both quantity and quality. To ensure continuous harvesting and processing of green peas, it is necessary to cultivate a range of varieties with different lengths of the growing season. Continuous harvesting rationalizes production as it facilitates continuity in processing. It reduces the production and processing costs while preserving the good taste and quality of green peas.

## CONCLUSION

The application of imazamox on green peas under irrigation is characterized by lower selectivity. While irrigation provides the plants with the necessary soil moisture, it simultaneously facilitates imazamox desorption. The herbicide is then available for root uptake which, together with the previous foliar uptake (after application), disrupts the expected metabolic degradation. As a result, severe phytotoxicity occurs shortly after herbicide application, leading to reduced growth and development. Although these symptoms diminish over time, the delay in the generative development stages has a negative effect on maturation, thus affecting both quantitative and qualitative yield parameters. This delay poses a serious challenge for mechanical harvesting at the optimal stage of technological maturity, as the pea varieties are sown based on the length of their growing season, and harvesting is planned as an uninterrupted process from the earliest varieties onwards.

Further studies are necessary to determine the minimum effective dose of imazamox in irrigated green pea production that would ensure its selectivity even under unfavorable conditions.

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**Conflict of interest:** The author declare that they have no conflict of interest.

## REFERENCES


Aichelle, T.M. & Penner, D. 2005. Adsorption, desorption and degradation of imidazolinones in soil. *Weed Technology*, 19(1): 154-159. https://doi.org/10.1614/WT-04-057R

Balabanova, D.A., Paunov, M., Goltsev, V., Cuypers, A., Vangronsveld, J. &Vassilev, A. 2016. Photosynthetic performance of the imidazolinone resistant sunflower exposed to single and combined treatment by the herbicide imazamox and an amino acid extract. *Frontiers in Plant Science*, 7: 1559. https://doi.org/10.3389/fpls.2016.01559

Ball, D.A., Yennish, J.P. &Alby, T. III 2003. Effect of imazamox soil persistence on dryland rotational crops. *Weed Technology*, 17(1): 161-165. https://doi.org/10.1614/0890-037X(2003)017[0161:EOISPO]2.0.CO;2

Baer, U. & Calvet, R. 1999. Fate of soil applied herbicides: experimental data and predictors of dissipation kinetics. *Journal of Environmental Quality*, 28(6): 1765-1777. https://doi.org/10.2134/jeq1999.00472425002800060012x

Blackshaw, R.E., Molnar, L.J., Muendel, H.H., Saindon, G. & Li, X. 2000. Integration of cropping practices and herbicides improves weed management in dry bean (*Phaseolus vulgaris*). *Weed Technology*, 14(2): 327-336. https://doi.org/10.1614/0890-037X(2000)014[0327:IOCPAH]2.0.CO;2

Bresnahan, G., Dexter, A., Koskinen, W. & Lueschen, W. 2002. Influence of soil pH-sorption interactions on the carry-over of fresh and aged soil residues of imazamox. *Weed Research*, 42(1): 45-51. https://doi.org/10.1046/j.1365-3180.2002.00261.x

Buerge, I.J., Bächli, A., Kasteel, R., Portmann, R., López-Cabeza, R., Schwab, L.F. & Poiger, T. 2019. Behavior of the chiral herbicide imazamox in soils: pH-dependent, enantioselective degradation, formation and degradation of several chiral metabolites. *Environmental Science & Technology*, 53(10): 5725-5732. https://doi.org/10.1021/acs.est.8b07209

Cobucci, T., Prates, H.T., Falcao, C.L.M. & Rezende, M.M.W. 1998. Effect of imazamox, fomesafen and acifluorfen soil residue on rotational crops. *Weed Science*, 46(2): 258-263. https://doi.org/10.1017/S0043174500090500

Edelenbos. M., Thybo, A., Erichsen, L., Wienberg, L. & Andersen, L. 2001. Relevant measurements of green pea texture. *Journal of Food Quality*, 24(2): 91-110. https://doi.org/10.1111/j.1745-4557.2001.tb00594.x

Everaarts, A.P. & Sukkel, W. 2000. Yield and tenderometer reading relationships for smooth- and wrinkled-seeded processing pea cultivars. *Scientia Horticulturae*, 85(3): 175-182. https://doi.org/10.1016/S0304-4238(99)00152-1

Fatima, S., Aslam, R., Shahzadi, K., Awan, H., Nadeem, M., Shabir, M., Shafiq, Y. & Hamid, M. 2024. Effect of drought stress at growth and development of pea (*Pisum sativum* L.). *Asian Journal of Research in Crop Science*, 9(1): 76-80. https://doi.org/10.9734/AJRCS/2024/v9i1247

Haukkapää, A-L., Junnila, S., Erikson, C., Tulisalo, U. & Seppänen, M. 2005. Efficacy of imazamox in imidazolinone-resistant spring oilseed rape in Finland. *Agricultural and Food Science*, 14(4): 377-388. https://doi.org/10.2137/145960605775897650

Liu, C., Yang, X., Lai, Y., Lu, H., Zeng, W. Geng, G., Yang, F. 2016. Imazamox microbial degradation by common clinical bacteria: *Acinetobacter baumannii* IB5 isolated from black soil in China shows high potency. *Journal of Integrative Agriculture*, 15(8): 1798-1807. https://doi.org/10.1016/S2095-3119(16)61344-8

Mangels, G. 1991. Behavior of the imidazolinone herbicides in soil – a review of the literature. In: D.L. Shaner & S.L. O'Connor, eds. *The Imidazolinone Herbicides*. pp. 191-209. CRC Press, Boca Raton, FL.

Martin, R.J. 1981. Yield–tenderometer relationships in vining peas. *New Zeland Journal of Experimental Agriculture*, 9(3-4): 387-391. https://doi.org/10.1080/03015521.1981.10425439

Milan, M., Ferrero, A., Fogliatto, S., De Palo, F. & Vidotto, F. 2017. Imazamox dissipation it two rice management systems. *Journal of Agricultural Science*, 155(3): 431-443. https://doi.org/10.1017/S0021859616000447

Miller, T.W. 2003. Effect of several herbicides on green pea (*Pisum sativum*) and subsequent crops. *Weed Technology*, 17(4): 731-737. https://doi.org/10.1614/WT02-127

Nelson, K.A. & Renner, K.A. 1998. Weed control in wide- and narrow-row soybean (*Glycine max*) with imazamox, imazethapyr and CGA-277476 plus quizalofop. *Weed Technology*, 12(1): 137-144. https://doi.org/10.1017/S0890037X00042706

Nelson, K.A., Renner, K.A. & Penner, D. 1998. Weed control in soybean (*Glycine max*) with imazamox and imazethapyr. *Weed Science*, 46(5): 587-594. https://doi.org/10.1017/S0043174500091141

Neshev, N., Yanev, M., Mitkov, A. & Tonev, T. 2020. Efficacy and selectivity of imazamox-containing herbicides at Clearfield® and Clearfield® Plus sunflower hybrids. *Scientific Papers. Series A. Agronomy*, LXIII(1): 450-457.

OEPP/EPPO. 2007. PP 1/91(3) Efficacy evaluation of herbicides - Weeds in *Phaseolus* and *Pisum*. *Bulletin OEPP/EPPO Bulletin*, 37(3): 478-481. https://doi.org/10.1111/j.1365-2338.2007.01152.x

OEPP/EPPO. 2014. PP 1/135(3) Phytotoxicity assessment. *Bulletin OEPP/EPPO Bulletin*, 44(3): 265-273. https://doi.org/10.1111/epp.12134

O'Sullivan, J., Thomas, R.J. & Bouw, W.J. 1998. Effect of imazethapyr and imazamox soil residues on several vegetable crops grown in Ontario. *Canadian Journal of Plant Science*, 78: 647-651.

Pannacci, E., Onofri, A. & Covarelli, G. 2006. Biological activity, availability, and duration of phytotoxicity for imazamox in four different soils of central Italy. *Weed Research*, 46(3): 243-250. https://doi.org/10.1111/j.1365-3180.2006.00503.x

Periago, M.J., Ros, G., Martínez, C., Rincón, F., Lopez, G., Ortuño, J. & Rodrigo, J. 1996. Relationship between physical-chemical composition of row peas and sensory attributes of canned peas. *Journal of Food Quality*, 19: 91-106.

Punia, R., Punia, S.S., Sangwan, M. &Thakral, S.K. 2018. Bioefficacy of herbicides against weeds in greengram (*Vigna radiata*) and their residual effect on succeeding Indian mustard (*Brassica juncea*). *Indian Journal of Agronomy*, 63(4): 467-471.

Punia, S.S., Yadav, D., Duhan, A. & Irfan, M. 2015. Bioefficacy and phytotoxicity of herbicides in greengram and their residual effect on succeeding mustard. *Indian Journal of Weed Science*, 47(4): 386-389.

Radojević, R., Gligorijević, K., Momirović, N. & Oljača, M. 2013. Research of green peas combine harvesters. Proceedings from The First International Symposium on Agricultural Engineering (ISAE-2013), pp. 81-92, 4-6 October 2013. Beograd, Serbia.

Rani, D., Duhan, A., Punia, S.S., Yadav, D.B. & Duhan S. 2019. Behavior of pre-mix formulation of imazethapir and imazamox herbicides in two different soils. *Environmental Monitoring and Assessment*, 191: 33. https://doi.org/10.1007/s10661-018-7161-x

Rood, J., Campbell, J., Till, D., Ball, D., Bennett, L., Yenish, J., Nelson, J., Rood, R., Shafii, B. & Price, W. 2012. Tillage affects imazamox carryover in yellow mustard. *Weed Technology*, 26(2): 308-315. https://doi.org/10.1614/WT-D-11-00012.1

Ros, G. & Rincón, F. 1990. Indices of quality and maturity for different comercial sizes of pea seed for canning. *Food Chemistry*, 38(1): 1-10. https://doi.org/10.1016/0308-8146(90)90201-E

Sakaliene, O., Papiernik, S.K., Koskinen, W.C. & Spokas, K. 2007. Sorption and predicted mobility of herbicide in Baltic soil. *Journal of Environmental Science and Health, Part B*, 42(6): 641–647. https://doi.org/10.1080/03601230701465601

Shaner, D.L. 1991. Physiological effects of imidazolinone herbicides. In: D.L. Shaner & S.L. O'Connor, eds. *The Imidazolinone Herbicides*. pp. 125-138. CRC Press, Boca Raton, FL,

Shaner, D.L., Anderson, P.C. & Stidham, M.A. 1984. Imidazolinones, potent inhibitors of acetohydroxyacid synthase. *Plant Physiology*, 76(2): 545-546. https://doi.org/10.1104/pp.76.2.545

Vangessel, M.J., Monks, D.W. & Johnson, Q.R. 2000. Herbicides for potential use in lima bean (*Phaseolus lunatus*) production. *Weed Technology*, 14(2): 279-286. https://doi.org/10.1614/0890-037X(2000)014[0279:HFPUIL]2.0.CO;2

Vischetti, C., Casucci, C. & Perucci, P. 2002. Relationship between changes of soil microbial biomass content and imazamox and benfluralin degradation. *Biology and Fertility of Soils*, 35(1): 13-17. https://doi.org/10.1007/s00374-001-0433-5