Effect of Pod Sealant Application on the Quantitative and Qualitative Traits of Field Pea (\textit{Pisum sativum} L.) Seed Yield

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Abstract: Field pea is used for human consumption or as livestock feed. The yield of pea seeds can be significantly decreased due to the genetically determined tendency of peas to pod shattering. This study aimed to evaluate the effect of pod sealant application on the quantitative and qualitative traits of the seed yield of two pea cultivars: Arwena and Tarchalska grown in south-western Poland in the years 2018–2019. Pod sealant application showed higher values of analysed quantitative and qualitative traits: number of pods per plant, number of seeds per plant, seed weight per pod, 1000-seed weight, seed yield, dry matter of seeds, protein content in seeds, and total protein productivity, except the number of seeds per pod. For both years (2018–2019), the interaction of cultivar and pod sealant application showed a significant effect on the number of seeds per plant, total protein content, total protein productivity, and seed weight per pod in 2019. Therefore, the pod sealant application can be a relatively simple way to improve the yielding of field peas.

Keywords: \textit{Pisum sativum}; pod sealant; pod shattering; yield; protein content

1. Introduction

In Poland, where due to the weather conditions soybean cultivation is limited, pea is a related species of great importance. The field pea can be grown both for food and feed. It is an inexpensive, easily available source of protein (24.2–27.5%), complex carbohydrates, vitamins, and minerals [1]. Due to its varied use and high yielding potential, pea is considered as one of the most important legumes grown in Poland. Pea belongs to pulses, crops harvested solely for dry grain. The FAO list covers eleven primary pulses [2]. In 2019, the average global yield of dry pea seeds was 1.98 t ha\(^{-1}\). The most important producers were Canada, the Russian Federation, and China. In 2019 in the European Union, the average yield was 2.63 tonnes per hectare, and Poland reached 1.7 t ha\(^{-1}\) of dry pea seeds [3]. In 2020 in Poland, the pea standard yields in the Research Centre for Cultivar Testing (COBORU) experiments amounted to 4.3 t ha\(^{-1}\) [4].

There are many reasons for lower pea seed yields in field production, mostly an inadequate plant density per 1 m\(^2\) and a delayed sowing date. This neglect of cultivation cannot be compensated for by any agronomic practice. In addition to improper cultivation, the genetically determined tendency of peas to pod shattering causes significant yield losses. In legumes, pod shattering is the opening of the mature pod along the dorsal or ventral sutures and accompanied by the shedding of the seeds after the plant reaches maturity [5]. Pod shattering resistance will be vital for breeding crops that are suited to the increasingly arid conditions expected in the coming decades [6]. Losses from shattering may be reduced by harvesting field peas before all pods are dry. Peas do not mature as evenly as other plants, so harvesting may be necessary while the leaves and pods are still green. This can be problematic due to the large amount of moist biomass. Another solution is plant desiccation to ensure even drying, when the seed moisture reaches 25 to 30% [7]. In Polish climatic conditions, due to high water requirements and resistance to low temperatures,
peas are sown early (third week of March). Seed germination begins at 2–3 °C, and in early growing stages seedlings tolerate frosts up to −5 °C. Pea is characterised by a short growing season, ca. 90–115 days [8]. High temperatures occurring in July, when the pods are ripe and dry, may cause their shattering. Research by Romkaew et al. (2007) [9] showed that low humidity during harvesting decreased the pod moisture content and resulted in higher shattering. Susceptibility to pod shattering is one of the major traits resulting in yield losses in many seed crops, especially in soybean, pulses, and Brassica species [10–14]. Pod shattering can be prevented by including the use of a pod sealant in cultivation technology. Preparations preventing pod shattering work on the basis of various active substances: synthetic latex (carboxylated styrene-butadiene copolymer), ethoxylated alcohol, natural terpene and pine resins, polymer resins, or acacia gum. There are also preparations containing several of the above substances for a comprehensive action [15,16]. According to the producers, the effectiveness of these preparations is based on a similar effect: by creating a kind of semi-permeable membrane on the plant surface, these preparations limit the ingress of water into the pods or siliques, and at the same time allow for the leakage of water to the outside. Thus, it prevents pods or siliques from shattering and shedding seeds, which allows for their further growth and development in the last days of the growing season.

The main objectives of this study were to investigate the effects of pod sealant use on pea seed yield, seed moisture, and total protein content. The hypothesis being tested is that the pod sealant application reduces pea seed loss before harvesting and improves seed yield and its quality.

The study of pod sealant effectiveness in pea cultivation can be important for practical applications. The results of this research can be practically applied to consider pod sealant use in pea, but also in the cultivation of other pulses. In the case of pulses, it is important to counteract yield losses and support the increase in the total protein content in seeds.

2. Materials and Methods
2.1. Field Experiment, Soil, and Weather Conditions

In the years 2018 and 2019, a field experiment was conducted on the experimental fields of the Wrocław University of Environmental and Life Sciences in Poland (51°10′ N, 17°06′ E) to evaluate the effect of an emulsion containing carboxylated styrene-butadiene copolymer application on the shattering resistance of field pea pods.

Both cultivars used in the field experiment were recommended in years of research for cultivation in Lower Silesia Voivodeship (Poland), where the experiment was located. Tarchalska and Arwena are Polish cultivars with white flowers, afila type (semi leafless), for general use. Tarchalska is a traditional, high yielding cultivar recommended for cultivation practically all over Poland. Arwena is a new cultivar, registered in 2015. Arwena is a promising cultivar, high and stable yielding, characterised by the lowest content of trypsin inhibitors among Polish cultivars of peas [17,18].

The field experiment had a split-plot design. Pea cultivars (Arwena and Tarchalska) were allocated in the main plots and pod sealant application (1.0 L ha⁻¹ at BBCH 79 phase and the control plot of 0 L ha⁻¹) was placed in the subplots. Four randomized repetitions were carried out in the experiment, and the area of a single subplot was 15 m² (10 m × 1.5 m). The field experiment was set up on Cutanic Stagnic Luvisol—developed from light loam underlain by medium loam, suitable for wheat production [19,20]. The following chemical characteristics were determined in the soil samples: soil pH—in 1 mol dm⁻³, KCl—potentiometrically, the contents of available P and K were determined according to the Egner–Riehm method, and Mg—Schachtschabel method. The soil properties are presented in Table 1 and are as follows: the pH of the soil was slightly acidic in 2018 and acidic in 2019. The soil was characterised by medium P₂O₅ content in 2018 and low in 2019, medium (2018) or high (2019) K₂O content, medium (2018) or very high (2019) Mg content [21].
Table 1. Soil properties in years of research (pH and content of macronutrients).

| Year | pH  | P₂O₅ (mg 100g⁻¹) | K₂O (mg 100g⁻¹) | Mg (mg 100g⁻¹) |
|------|-----|------------------|-----------------|--------------|
| 2018 | 6.1 | 11.8             | 18.8            | 6.6          |
| 2019 | 5.5 | 9.2              | 21.5            | 9.4          |

Before the establishment of the experiment, mineral fertilisation was applied (kg ha⁻¹): 60 P₂O₅ (46% triple superphosphate) and 120 K₂O (60% sylvinitc). Fertilizers were applied directly before sowing and were mechanically mixed with the soil to a depth of circa 5 cm. In each year of the field experiment, the preceding crop was winter wheat. Pea was sown on 20 March 2018 and 19 March 2019, at a row spacing of 15 cm; the number of sown seeds was 90 per 1 m². Each year, directly after sowing, weed infestation was regulated with the herbicide Boxer 800 EC (4.0 L ha⁻¹, active substance: 800 g L⁻¹ prosulfocarb; Syngenta, Warsaw, Poland), monocotyledonous weeds were controlled with the herbicide Fusilade Forte 150 EC (1.5 L ha⁻¹, active substance: 150 g L⁻¹ fluazifop-P-butyl; Syngenta Poland), and secondary weed infestation was limited by the herbicide Corum (1.25 L ha⁻¹, active substance: 480 g L⁻¹ bentazone and 22.4 g L⁻¹ imazamox; BASF) with the addition of Dash HC adjuvant (0.6 L ha⁻¹; BASF). The harvest was carried out on 12 July 2018 and 19 July 2019. Weather conditions in the years of research are presented in Table 2.

Table 2. Weather conditions in the years of field experiment.

| Month | Temperature (°C) | Precipitation (mm) |
|-------|------------------|--------------------|
|       | 2018  | 2019  | Average 1986–2015 | 2018  | 2019  | Average 1986–2015 |
| III   | 1.3   | 6.8   | 3.8              | 27.6  | 22.5  | 38.2             |
| IV    | 13.7  | 10.8  | 9.9              | 19.0  | 24.2  | 33.6             |
| V     | 17.1  | 12.1  | 14.4             | 54.3  | 76.8  | 54.1             |
| VI    | 18.8  | 22.1  | 17.3             | 36.6  | 27.0  | 67.4             |
| VII   | 20.1  | 19.3  | 19.6             | 79.1  | 50.1  | 78.9             |
|       | 14.2  | 14.2  | 12.8             | 216.6 | 200.6 | 272.2            |

2.2. Data Collection

Directly before the harvest (BBCH 86–87) on a sample of 10 plants from the central part of each subplot, the components of yield were determined: the number of pods per plant (NP, pcs), the number of seeds per plant (SNPL, pcs), the number of seeds per pod (SNP, pcs), and the weight of seeds per pod (SWP, g). After harvest, 1000-seed weight (TSW, g) from each subplot according to the International Rules for Seed Testing [22], and the seed yields (SY, Mg ha⁻¹) were determined. Seed yields from subplots into seed yields per hectare were converted with 15% moisture.

Qualitative evaluation of pea seeds was based on the results of chemical analyses, which was carried out in agreement with the methodology of food product analysis. Dry matter was established with the gravimetric method at a temperature of 105 ± 2 °C for 5 h, and total protein content (PC, g kg⁻¹ DM) was established with a modified Kjeldahl method (total nitrogen was established in the seeds and then converted into total protein using the coefficient of 6.25).

On the basis of the results of chemical analyses (dry matter and total protein content) and the obtained seed yield, total protein productivity (TPP, Mg ha⁻¹) was calculated in seed dry matter from an area of 1 ha.
2.3. Statistical Analyses

The analysis of variance (ANOVA) was done at the significance level \( p < 0.05 \) (F-test) using the program Statistica 13.1 (StatSoft, Kraków, Poland). The experiment included three factors: two years, two cultivars, two applications (pod sealant and control), and four randomized replicates arranged in a split-plot design. The \( p < 0.01 \) and \( p < 0.05 \) significance levels were used. Homogeneous groups were determined by Tukey’s multiple range test (at \( p < 0.05 \)) using consecutive letters starting from “a”—the most beneficial—to “d”—least beneficial in terms of values of analysed traits.

3. Results

Analysis of variance (ANOVA) has shown that the cultivars significantly differed in all analysed parameters. Application of pod sealant significantly affected all traits except SNP (Table 3). A significant effect of the weather conditions during this study on the tested quantitative and qualitative traits (except SNP) is shown, therefore the results are presented for each year separately.

Table 3. ANOVA for the effect of year, cultivar, and pod sealant application on the investigated parameters.

| Factor       | NP  | SNPL | SNP   | SWP   | TSW   | SY    | PC    | TPP   |
|--------------|-----|------|-------|-------|-------|-------|-------|-------|
|              | p-Value |      |       |       |       |       |       |       |
| Year (Y)     | 0.0000 | 0.0000 | 0.0669 | 0.0019 | 0.0161 | 0.0002 | 0.0262 | 0.0005 |
| Cultivar (C) | 0.0060 | 0.0000 | 0.0034 | 0.0149 | 0.0000 | 0.0000 | 0.0046 | 0.0000 |
| Application (A) | 0.0000 | 0.0000 | 0.1731 | 0.0000 | 0.0001 | 0.0000 | 0.0000 | 0.0000 |
| Y × C        | 0.7666 | 0.1952 | 0.1983 | 0.6670 | 0.0639 | 0.9436 | 0.0064 | 0.0384 |
| Y × A        | 0.1089 | 0.0184 | 0.0187 | 0.0625 | 0.4934 | 0.8092 | 0.3690 | 0.4828 |
| C × A        | 0.9289 | 0.0001 | 0.0697 | 0.1682 | 0.0962 | 0.8092 | 0.0000 | 0.0000 |
| Y × C × A    | 0.3358 | 0.9425 | 0.4828 | 0.0808 | 0.2069 | 0.0344 | 0.3939 | 0.0175 |

NP—number of pods per plant, SNPL—number of seeds per plant, SNP—number of seeds per pod, SWP—seed weight per pod, TSW—1000-seed weight, SY—seed yield, PC—protein content in seeds, TPP—total protein productivity.

The PC and TPP were significantly affected by the interaction of year and cultivar. The interaction of year and application of pod sealant significantly affected only SNPL and SNP. The effect of interaction of cultivar and application of pod sealant was observed in SNPL, PC, and TPP. The SY and TPP in different cultivars reacted differently to the application of pod sealant in years of research (Y × C × A) (Table 3).

Significant differences between cultivars were stated for the analysed parameters, except SWP in 2018 (Table 4). Averaged across pod sealant application, cultivar Tarchalska demonstrated the highest values of all investigated traits. Averaged across cultivars, the application of pod sealant significantly affected all quantitative and qualitative traits in 2018. Tested parameters were increased, except SNP, which was significantly lower when pod sealant was applied.
Table 4. Cultivar and pod sealant application effects on quantitative and qualitative traits in 2018.

| Factor | NP  | SNPL | SNP  | SWP  | TSW  | SY   | PC    | TPP  |
|--------|-----|------|------|------|------|------|-------|------|
| Cultivar | Arwena | 3.64 | 12.5 | 3.42 | 1.04 | 212.5 | 2.82 | 277.1 | 0.73 |
|         | Tarchalska | 3.84 | 14.2 | 3.71 | 1.07 | 240.7 | 3.21 | 291.7 | 0.88 |
| F test | C    | *    | **   | *    | ns   | **   | *    | **   |
| Application | Control | 3.29 | 12.2 | 3.71 | 1.01 | 224.6 | 2.88 | 279.1 | 0.75 |
|         | Pod sealant | 4.19 | 14.4 | 3.42 | 1.10 | 228.6 | 3.14 | 289.8 | 0.85 |
| F test | A    | **   | **   | *    | **   | *    | **   | **   |
| C × A | ns   | **   | ns   | ns   | ns   | ns   | s    | *    |
| Mean  | 3.74 | 13.3 | 3.57 | 1.05 | 226.6 | 3.01 | 284.4 | 0.80 |

NP—number of pods per plant, SNPL—number of seeds per plant, SNP—number of seeds per pod, SWP—seed weight per pod (g), TSW—1000-seed weight (g), SY—seed yield (Mg ha\(^{-1}\)), PC—protein content in seeds (g kg\(^{-1}\) DM), TPP—total protein productivity (Mg ha\(^{-1}\)). ** Significant at \(p < 0.01\); * significant at \(p < 0.05\); ns—not significant.

The interaction of the tested factors had a significant impact on SNPL, PC, and TPP (Table 4). In 2018, the Tarchalska cultivar, after the application of the pod sealant, was characterised by the significantly highest SNPL and the lowest was recorded for Arwena in the control subplots. However, in the case of both cultivars, a significant increase in SNPL was stated after the pod sealant application (Figure 1).

Figure 1. Significant effect of C × A interaction on analysed parameters in 2018. PS—pod sealant application. Different letters indicate a significant difference at \(p < 0.05\) (Tukey’s multiple range test).
The PC was significantly higher in the Tarchalska cultivar when pod sealant was applied (Figure 1).

A significant increase in the TPP was observed in both tested cultivars when pod sealant was applied. The significantly highest TPP was noted in the Tarchalska after the pod sealant application (Figure 1).

Significant differences between cultivars were stated for the SNPL, TSW, SY, and TPP in 2019 (Table 5). Averaged across pod sealant application, the cultivar Tarchalska was characterised by the highest values of all investigated traits. Averaged across cultivars, the application of pod sealant significantly affected all quantitative and qualitative traits in 2019, except SNP. Tested parameters increased after pod sealant application.

Table 5. Cultivar and pod sealant application effects on quantitative and qualitative traits in 2019.

| Factor | NP | SNPL | SNP | SWP | TSW | SY | PC | TPP |
|--------|----|------|-----|-----|-----|----|----|-----|
| Cultivar (C) | Arwena | 4.12 | 13.9 | 3.39 | 1.08 | 217.8 | 2.92 | 289.6 | 0.79 |
| Tarchalska | 4.36 | 15.3 | 3.52 | 1.12 | 241.6 | 3.32 | 290.0 | 0.90 |
| F test | C | ns | ** | ns | ** | ** | ns | ** |
| Application (A) | Control | 3.18 | 13.3 | 3.41 | 1.07 | 227.1 | 2.99 | 283.3 | 0.79 |
| Pod sealant | 4.57 | 15.9 | 3.50 | 1.13 | 232.2 | 3.25 | 296.3 | 0.90 |
| F test | C × A | ns | ** | ns | ** | ** | ns | ** |
| Mean | 4.24 | 14.6 | 3.46 | 1.10 | 229.7 | 3.12 | 289.8 | 0.84 |

NP—number of pods per plant, SNPL—number of seeds per plant, SNP—number of seeds per pod, SWP—seed weight per pod (g), TSW—1000-seed weight (g), SY—seed yield (Mg ha\(^{-1}\)), PC—protein content in seeds (g kg\(^{-1}\) DM), TPP—total protein productivity (Mg ha\(^{-1}\)). ** Significant at \(p < 0.01\); * significant at \(p < 0.05\); ns—not significant.

The interaction of C × A had a significant impact on SNPL, SWP, PC, and TPP in 2019 (Table 5).

The pod sealant application caused a significant increase in the SNPL in both cultivars. The highest SNPL was obtained from the Tarchalska cultivar after pod sealant application, while the lowest was for control for both tested cultivars (Figure 2).

Figure 2. Significant effect of C × A interaction on analysed parameters in 2019. PS—pod sealant application. Different letters indicate a significant difference at \(p < 0.05\) (Tukey’s multiple range test).
The SWP was the highest in the Tarchalska cultivar, when pod sealant was applied. Other interactions were not significantly different in this trait (Figure 2).

After pod sealant application, the Tarchalska cultivar was characterised by the highest value of PC in seeds and at the same time the lowest value of this trait for control subplots from all investigated interactions. In the case of the Arwena cultivar, the differences were not significant (Figure 2).

The Tarchalska cultivar had the highest value of TPP after pod sealant application. The lowest TPP was stated in the Arwena cultivar from the control variant (Figure 2).

In general, for both years, pod sealant application showed higher values of analysed quantitative and qualitative traits, except SNPL. For both years, the interaction of C x A showed a significant effect on SNPL, PC, TPP, and SWP in 2019.

4. Discussion

In crop plants, fruit shattering resistance is a preferred trait, because shattering fruits, i.e., pods or siliques, make harvesting difficult and often lead to a decrease in production [23,24]. Shattering resistance was likely to be one of the first traits strongly selected by plant breeders and investigated by plant biologists and physiologists. Therefore, many articles are available on the genetics and physiology of pod shattering and the breeding of new resistant varieties of pulses [10,25,26], soybean [5,27–29], and oilseed rape [30–32]. However, not all seed crops have fully shattered resistant fruits. To improve traits such as disease resistance and stress tolerance, breeders often need to use wild crop material that is prone to fruit shattering [33,34]. As a consequence, there is often some degree of shattering in seed material, especially in minor crops.

Legumes are sensitive to changing agroclimatic conditions. Constant cultivar traits may be modified by unfavourable habitat or weather [35]. This phenomenon as well as global challenges such as limited resources and climate change are forcing farmers to adopt innovative agriculture practices in legumes cultivation to protect the seed yield from losses immediately prior to harvest. There is a limited number of available articles related to agrotechnical ways to counteract pod shattering, especially strictly related to the pod sealant effect on the quantity and quality of seed yield of peas.

This study has shown that pod sealant application caused higher values of number of pods per plant, number of seeds per plant, seed weight per pod, 1000-seed weight, seed yield, protein content in seeds, and total protein productivity (Table 3). According to the breeder, the Tarchalska cultivar is characterised by high pod shatter resistance [17]. However, pod sealant application increased the values of the number of seeds per plant in 2018 and 2019 (Figures 1 and 2), and seed weight per pod in 2019 (Figure 2). These results suggest that pod sealant application is a favourable treatment in pea cultivation, which can interact with cultivar traits to maximize yield.

Furthermore, an increase in total protein content and total protein productivity was observed when pod sealant was applied (Figures 1 and 2). This finding shows that pod sealant application can improve the quality of legumes’ seeds. However, this should be confirmed by further research.

In 2018, the number of seeds per pod was significantly lower due to the higher number of no shattered pods on plants, when pod sealant was applied. In 2019, this trait was not significantly affected by pod sealant application.

The study of Aslan et al. (2018) [36] on the effect of polymer cyclohexane application on lentil pod shatter has shown that harvested yields were not significantly different when the polymer was used. Effects of polymer application were significant for pod shatter and loss percent. Results of our study are inconsistent with these findings. In this study, the seed yield increased in 2018 by 9.03% and in 2019 by 8.69% under the effect of pod sealant application (Table 3). However, an effect of pod sealant application on the increase in the number of pods per plant was observed, which is consistent with the above-mentioned results [36].
The effect of pod sealant use in oilseed spring rape cultivation was also investigated by Malarz (2008) [37] in agroecological conditions of south-west Poland. A significant increase in the weight of seeds in a silique was stated when pod sealant was used. This is in line with our results. In 2019, pod sealant application significantly affected seed weight per pod (Figure 2). Research of Steponavičius et al. (2019) [38] on evaluation of the effectiveness of pod sealants in increasing pod shattering resistance in oilseed rape has shown that using the experimental sealant, which combines an acrylic sealant with a surfactant trisiloxane, 2 weeks before harvest, reduced the natural loss of seed yield by 20–70%.

These results confirm the validity of the inclusion of pod sealant in the cultivation technology of crops. Pod sealants can improve seed yield quantity, as well as quality.

5. Conclusions

The pod sealant application is a treatment that can prevent yield losses due to pod shattering in pea cultivation, but also in other crops. Yield increased mostly by preventing pod shatter, which increases the number of seeds per plant. Moreover, the total protein content in the seeds of peas increased after pod sealant application, which is important in the case of pulses quality.

The application of pod sealant can be a relatively simple way to improve the yielding of many crops’ species. It can be included in cultivation technology when needed, i.e., due to unfavourable weather conditions during the vegetation period. Further research is needed to revise the effect of pod sealants on quantitative and qualitative traits of pulses and other crops, not only soybean and oilseed rape.

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