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Strawberry Yield and Marketable Quality as Affected by Different Flowering Inter-Crops

Gerard Podedworny[1]*, Małgorzata Tartanus[1], and Eligio Malusá[1]

ABSTRACT

A two-year field experiment evaluated the impact of three inter-crops on the agronomic performance of *Fragaria* × *ananassa* cv. 'Lycia' in an organic farming system. The multiple linear regression model indicated that the flower strip (a mixture of selected annual and perennial flowering plants grown on one side along the edge of the crop) and the flower islands (the same mixture grown as smaller patches within the strawberry rows) increased the cumulative marketable strawberry yield by 5.2 (95% CI: 0.6-9.9) and 5.4 (95% CI: 0.7-10.1) t ha^{-1} respectively, over the yield for the traditional management system of 6.5 (95% CI: 3.2-9.8) t ha^{-1}. Both practices also reduced the incidence of fruit damage. However, the white clover living mulch did not significantly improve the strawberry yield, while delaying fruit ripening and increasing the proportion of damage by slugs and pathogenic rot. Neither the average fruit weight nor fruit colouration were affected by the inter-cropping.

Keywords: Cover crop, Flower island, Floral strip, Fruit damage, Living mulch.

INTRODUCTION

Strawberry is a high-value horticultural crop, prised for its flavour and nutritional value. It is widely cultivated across temperate regions and in some cooler subtropical areas. With a harvest of 194,500 tonnes collected from about 30,000 hectares in 2023, Poland was the second-largest strawberry producer in the European Union (second only to Spain) and ranked eighth worldwide (FAO, 2025).

However, conventional strawberry cultivation relies heavily on external inputs to maintain high yield and quality, raising sustainability concerns (Tabatabaie and Murthy, 2016; Romero-Gámez and Suárez-Rey, 2020; Pergola *et al.*, 2023). Different inter-cropping practices, including living mulches and flower strips, have been gaining attention as potential strategies to enhance ecosystem services and improve crop resilience, particularly in the context of organic farming development (Bhaskar *et al.*, 2021; Kowalska *et al.*, 2022).

Flower strips have been proven to reduce the pressure of major strawberry pests, primarily through increasing the abundance and activity of their natural enemies (Sigsgaard *et al.*, 2013;

[1] Laboratory of Entomology, Department of Plant Protection, National Institute of Horticultural Research in Skierniewice, Poland.
*Corresponding author; e-mail: gerard.podedworny@inhort.pl

Hodgkiss *et al.*, 2019; Alhmedi *et al.*, 2024; Koller *et al.*, 2024). Research also shows that flower strips can improve crop pollination whilst helping to maintain pollinator diversity in agricultural land (Feltham *et al.*, 2015; Ganser *et al.*, 2018). In the case of living mulches, their role in suppressing the weed growth is mainly emphasised (Brennan and Smith, 2018) yet their contribution to preventing soil erosion (Tu *et al.*, 2021), providing nutrients for crops (Liu *et al.*, 2025) as well as enhancing above- (Las Casas *et al.*, 2022) and below-ground (Qian *et al.*, 2015; Furmańczyk *et al.*, 2025) biodiversity in fruit production is also considered.

While the studies cited above have documented individual benefits of inter-cropping practices, a comprehensive, biodiversity-based management system for berry crops remains to be developed. Agronomic performance data from such systems are not sufficient, nor has the effect of the spatial configuration of floral resources on these outcomes been explored. This study is among the first to address this research gap by designing and testing various spatial designs of flowering inter-crops within an organic strawberry production system.

The aim of the present study was to assess the impact of three flowering inter-crops, i.e. living mulch, flower islands and flower strip, on the strawberry yield and selected indicators of their marketable quality, as well as on the proportion and profile of fruit damage. It was hypothesised that the inter-cropping practices proposed would significantly increase the crop yield and reduce the share of non-marketable fruit.

MATERIALS AND METHODS

Experimental layout

An open-field trial was conducted in 2022 - 2024 on an organic experimental site belonging to the National Institute of Horticultural Research in Skierniewice, Poland (51°56'46.14"N 20°11'15.07"E). The experimental site featured loamy sand soil, characterised by a particle size distribution of 78% sand, 14% silt and 4% clay. The soil pH was 6.2.

The experimental plantation was established in the spring of 2022 with bare-root strawberry plants (*Fragaria* × *ananassa*) of the mid-early summer-fruiting cultivar ‘Lycia’**, expected to gain popularity amongst Polish growers owing to its high suitability for production of top-quality dessert fruits.** The plants of the A+ class (root collar diameter 14–15 mm) were sourced from a private nursery, and planted at a spacing of 0.9 × 0.2 m. The forecrop for the strawberries was yellow mustard (*Sinapis alba*), used as green manure. Standard tillage operations, i.e. autumn ploughing and spring harrowing, were performed to prepare the site for strawberry cultivation. During the first year of the trial, the plantation was managed to ensure full establishment, and measurements were taken in the next two years.

The inter-cropping practices of (i.) living mulch, (ii.) flower islands and (iii.) flower strip were tested against (iv.) the control, being the traditional cropping system without companion plants implemented (for more information, see Fig. 1). Each group was represented by a single plot of 200 m^2 (20 × 10 m), with a distance of approx. 50 m between the plots. The uniformity of the soil condition amidst the plots was confirmed by an analysis conducted of pH, nutrient content (nitrogen, phosphorus, potassium) and granulometric composition, subjected to the Conover squared ranks test of variance (Conover, 1999).

The living mulch consisted of a mixture of white clover (*Trifolium repens*) and sheep's fescue (*Festuca ovina*). The flower strip and flower islands were composed of the same mixture of selected annual (dill (*Anethum graveolens*), marigold (*Tagetes* spp.), sweet alyssum (*Lobularia maritima*), garden nasturtium (*Tropaeolum majus*), night-scented stock (*Matthiola longipetala*)) and perennial (common lungwort (*Pulmonaria officinalis*), betony (*Stachys officinalis*)) flowering species. **The species composition was selected to include plants that provide beneficial insects with accessible, high-quality nectar and/or pollen and exhibit complementary flowering periods, thereby ensuring a continuous supply of feeding resources throughout the growing season, whilst avoiding species considered invasive or posing phytosanitary risks to strawberry crops.** The living mulch was sown once in 2022, and then managed by three or four mowings during the growing season. The flower strip and islands were renewed annually in early spring and, if necessary, weeded by hand to maintain their species composition during the growing season.

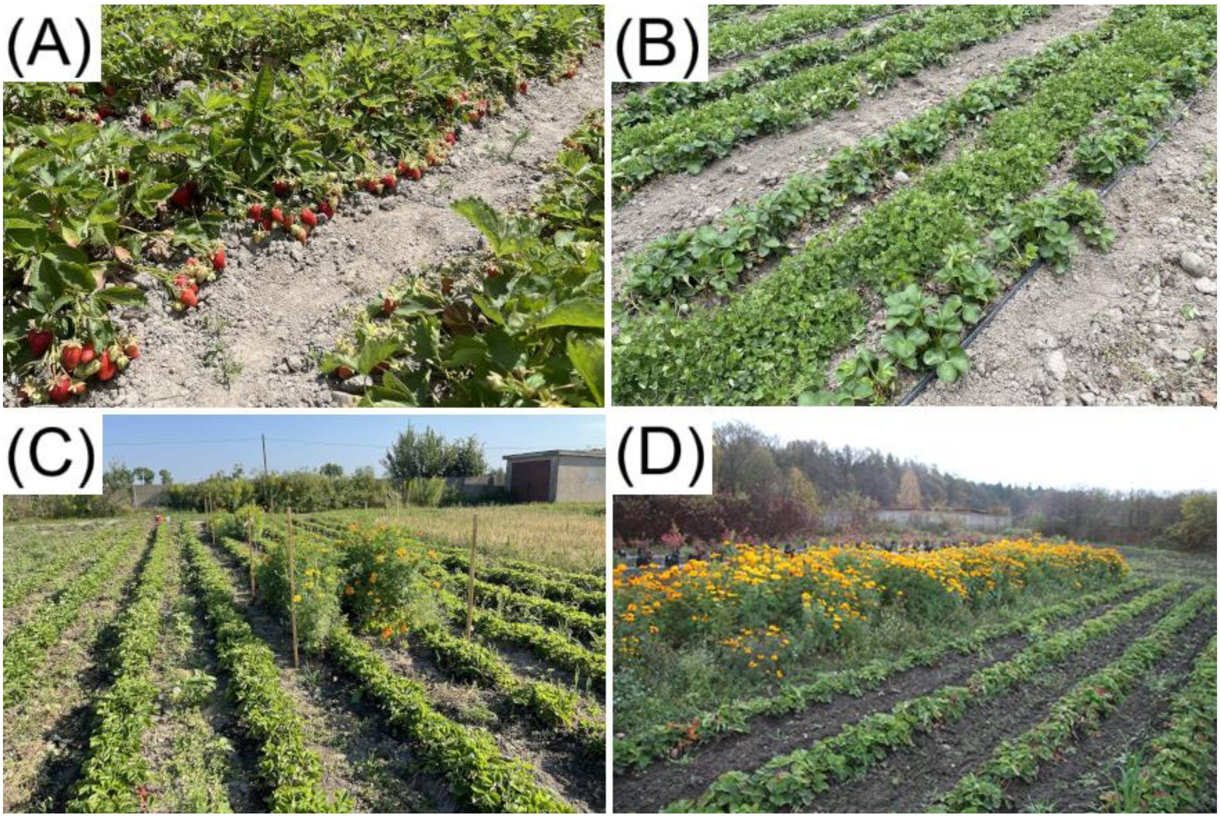

Figure 1. Comparison of the different inter-cropping practices in strawberry cultivation versus the control treatment (A). Perennial living mulch (B) was established every second inter-row. Four flower islands (C) of 2 m length each and a row in width were located in the central part of the plot within the crop plant rows, while a one-sided flower strip (D) with a size of 20 × 2 m was sown along the longer edge of the plot.

The experimental plantation was managed in accordance with organic fruit production principles (Somasundaram *et al*., 2022). Manual and mechanical weeding was used as a weed control method. No plant protection products were applied. Fertilisation was based on the annual early spring application of dried chicken manure at a dose of 600 kg ha^{-1}. The manure used contained 5.0% of total nitrogen, 1.3% of phosphorus and 2.5% of potassium, with a dry matter content of 90%. The plantation was drip irrigated according to need, determined using a tensiometer. Monthly meteorological data and the corresponding values of the Selyaninov's hydro-thermal coefficient (a drought indicator; Selyaninov, 1928) for the three consecutive growing seasons of the experiment are presented in Table 1.

Table 1. Meteorological conditions during the three consecutive growing seasons of the experiment.

	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.
					2022				
Total precipitation [mm]	1.8	48.9	50.6	58.5	129.8	89.7	31.6	24.6	21.7
Average air temperature [°C]	2.7	7.0	14.0	19.3	19.3	20.8	11.9	11.0	4.2
HTC*	n.a.**	n.a.	1.17	1.01	2.17	1.39	0.88	0.72	n.a.
					2023				
Total precipitation [mm]	47.4	47.9	36.8	43.2	44.0	106.4	8.6	68.7	62.6
Average air temperature [°C]	4.4	8.5	13.1	18.4	20.6	20.5	17.4	10.7	4.0
HTC	n.a.	1.88	0.90	0.78	0.69	1.67	0.16	2.08	n.a.
					2024				
Total precipitation [mm]	31.0	31.4	42.7	56.9	37.0	×***	×	×	×
Average air temperature [°C]	6.6	11.1	16.5	19.4	21.7	×	×	×	×
HTC	n.a.	0.94	0.83	0.98	0.55	×	×	×	×

* Selyaninov's hydro-thermal coefficient. Suggested interpretation (Chmist-Sikorska *et al.*, 2022): HTC < 0.4 – extremely dry, HTC ∈ ⟨0.4; 0.8) – very dry, HTC ∈ ⟨0.8; 1.1) – dry, HTC ∈ ⟨1.1; 1.4) – quite dry, HTC ∈ ⟨1.4; 1.7) – optimum, HTC ∈ ⟨1.7; 2.1) – quite humid, HTC ∈ ⟨2.1; 2.6) – humid, HTC ∈ ⟨2.6; 3.0) – very humid, HTC > 3 – extremely humid; **not applicable due to the average temperature, taking values < 8 ◦C; ***the experiment completed.
The data was obtained from a climate station belonging to the National Institute of Meteorology and Water Management. The station is located in Skierniewice, approx. 2.5 km from the experimental site.

Measurement methodology

The fruit was harvested at the **biological stage of berry ripening**, determined based on its skin colouration**, defined as full, uniform red coverage across the berry surface, indicating readiness for fresh-market sale.** Four harvests at weekly intervals were carried out in 2023, whereas three were sufficient in 2024. **The lower number of harvests in the second year resulted from a decline in plantation productivity.** The yield assessment at each harvest date consisted of collecting all ripe fruit from the entire plot by dividing it into (i.) marketable yield (fruit showing no signs of damage, suitable for sale regardless of its quality class, including fruit for processing) and (ii.) damaged fruit. Both of these sorts were weighed separately on an electronic, calibrated and officially legalised scale with a measurement accuracy of 0.1 kg. The marketable yield was converted to t ha^{-1}. The mass of damaged fruit at each harvest point was expressed as a percentage share of the total yield understood as the sum of the marketable yield and the mass of damaged fruit.

In 2023 and 2024, all fruits classified as damaged at each harvest point were divided into four classes specifying the cause of damage, and counted. These were: Lygus damage (berries deformed due to feeding by the European tarnished plant bug (*Lygus rugulipennis*) or related bug species of lesser economic importance, e.g. *Lygus pratensis*)), slug damage, sunscald, and pathogen rot.

Since a high slug population was found to be problematic in 2023, it was decided to include this in the study in 2024 and link it to the severity of damage. To this end, at the beginning of fruit ripening, a single Barber's pitfall trap (Barber, 1931; Brown and Matthews, 2016) with a volume of approx. 460 ml was dug into the ground at the centre of each experimental plot so that its upper edges were level with the soil surface. The area around the digging site was carefully cleared of vegetation. The traps were covered with a lid, allowing slugs to enter but protecting the content from rainfall. Pale pasteurised "Beczkowe Mocne" beer with an ethyl alcohol content of 7% vol. (Braniewo Brewery Ltd, Rakszawa, Poland) was used as bait (Laznik *et al.*, 2025). The monitoring lasted two weeks, with the traps having been emptied, the drowned slugs counted, and the beer refilled every 4-5 days.

In addition, in 2023, hundred fruit weight was assessed for each harvest date from five randomly selected samples of 100 marketable fruits, while mean fruit weight was based on a separate sample of 100 berries. An electronic, calibrated and officially legalised laboratory scale with a measurement accuracy of 0.01 g was used for these assessments. Fruit colouration was evaluated visually on a five-point redness scale, where 1 indicated the least coloured fruit, and 5 indicated the most intensely coloured fruit, based on a sample of 400 randomly selected marketable berries at each harvest date. The values of these parameters averaged at the harvest point level were used for the statistical analysis.

In 2023, at each harvest point, four samples of 100 randomly selected marketable fruits were divided into quality classes according to the standard for strawberries specified by the European Commission (EU Commission, 2002; modified). On this basis, strawberries with a diameter of not less than 28 mm were classified as extra class. Classes I/II (treated jointly) included berries with a diameter of 18 to 28 mm, while maintaining the other quality characteristics specified in the standard. Fruits smaller than 18 mm, suitable for processing, were classified as outgrade.

Statistical analyses

To assess the impact of the factors studied on the parameters expressed as quantitative continuous variables, relevant multidimensional regression models were applied (Table 2). For each model, the III type sum of squares was used. All categorical variables were subjected to dummy coding, with 'control', '2023' and 'the first harvest' being considered as reference categories for the treatment, year and harvest order variables, respectively.

Table 2. Specification of the statistical models applied.

No	Dependent variable	Explanatory variables	Model type
1.	Cumulative yield (total marketable yield from 2023 and 2024, considered independent)	Treatment*, year**	Multiple linear regression
2.	Early-season yield (marketable yield from the first harvests in 2023 and 2024, considered independent)	Treatment, year	Multiple linear regression
3.	Mid-season yield (marketable yield from the second and third harvests in 2023, and from the second harvest in 2024, considered independent)	Treatment, year	Multiple linear regression
4.	Late-season yield (marketable yield from the fourth harvest in 2023, and from the third harvest in 2024, considered independent)	Treatment, year	Multiple linear regression
5.	Proportion of damaged fruit (percentage share of damaged fruit weight in total yield at particular harvest points in 2023 and 2024, considered independent)	Treatment, year, harvest order***	General linear model
6.	Hundred fruit weight (data from particular harvest points in 2023)	Treatment, harvest order	General linear model
7.	Mean fruit weight (data from particular harvest points in 2023)	Treatment, harvest order	General linear model

*Levels: control, living mulch, flower islands and flower strip; **Levels: 2023 and 2024; ***Levels: first, second, third and fourth harvest.

The normality of the model residuals was assessed visually based on a normal Q-Q plot, with Lilliefors test applied as an adjunctive method. The homoscedasticity of the model residuals was evaluated visually based on plots presenting the residuals and residual squares against the predicted and observed values. The autocorrelation of the model residuals was controlled using the Durbin-Watson test, adopting critical values from the tables published by Savin and White (1977). Outliers were identified using a criterion whereby an observation was considered to be an outlier if its residual exceeds three standard deviations of the model residuals. Such observations in the dataset were examined for accuracy and validity, and found to be correct. To identify observations that could disproportionately affect model fit, Cook's distance (Di) was computed for each observation, considering cases above the 50th percentile of the Fisher-Snedecor distribution as potentially influential, i.e. $Di > F_{0.5}(k + 1, n - k - 1)$, where $k + 1$ denotes the number of model parameters and $n - k - 1$, the residual degrees of freedom. No observations exceeded this threshold.

In the case of statistically significant results following the factorial analyses of variance within general linear models, Fisher's Least Significant Difference (LSD) test was used as a post-hoc procedure.

Differences in fruit colouration (redness score) among the treatments were assessed using the Kruskal-Wallis one-way analysis of variance by rank, appropriate for ordinal data. Variables expressed on a nominal scale (fruit damage causes and marketable quality classes) were compared among the treatments using the chi-square (χ^2) test for large contingency tables (r × c), with the *P*-values in multiple comparisons having been subjected to the Šidák correction. Cochran's condition concerning high expected frequencies (Cochran 1952) was fulfilled for each chi-square procedure.

The significance level of α ≤ 0.05 was adopted for testing the hypotheses. The PQStat v.1.8.6 package (PQStat Software, Poznań, Poland) was used for all statistical calculations.

Data availability

The raw experimental data that supports the findings of this study is publicly available in the RepOD Repository for Open Data at https://doi.org/10.18150/EZSJAM.

RESULTS

Crop productivity

Considering the total marketable yield from all harvest dates, both the flower islands and flower strip significantly increased it compared to the control. However, the yield gain produced by the living mulch was not sufficient to exert a statistically significant effect (Fig. 2).

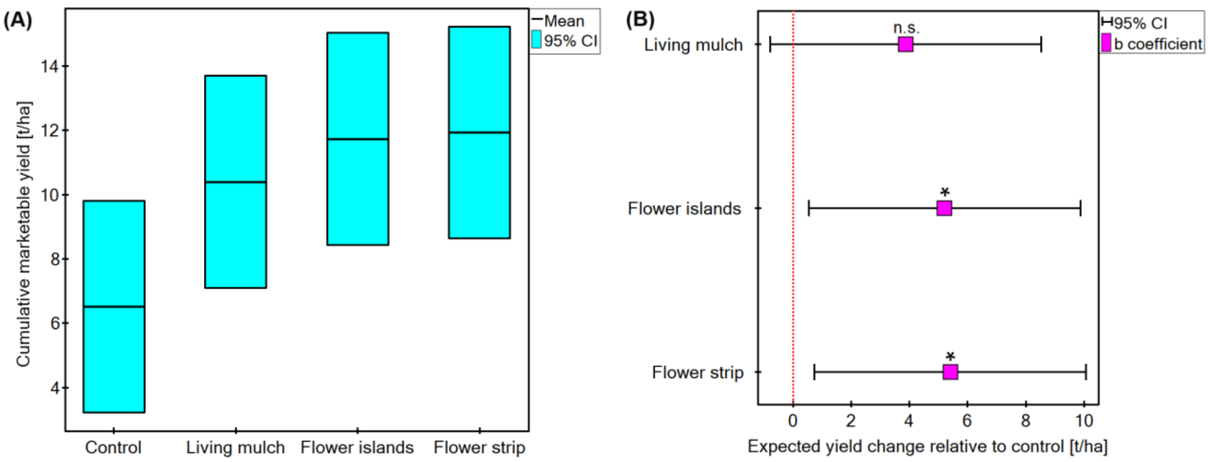

Figure 2. Cumulative marketable strawberry yield as affected by three inter-cropping practices, controlling for variability between the two experimental seasons (2023 and 2024). Panel A presents the expected means (95% CI) from the regression model, whilst panel B shows the regression coefficients b (95% CI), indicating the expected yield change compared to the control. Explanations: n.s. – not significant; *$P < .05$.

In the analysis of marketable yield broken down by particular harvest dates, the tendency of living mulch to delay fruit ripening should be noted, with this being expressed by a negative although statistically non-significant coefficient b in the early-season harvest, and a significantly positive coefficient in the late-season harvest. Nevertheless, the mid-season yield was not affected by any of the inter-cropping practices applied (Fig. 3).

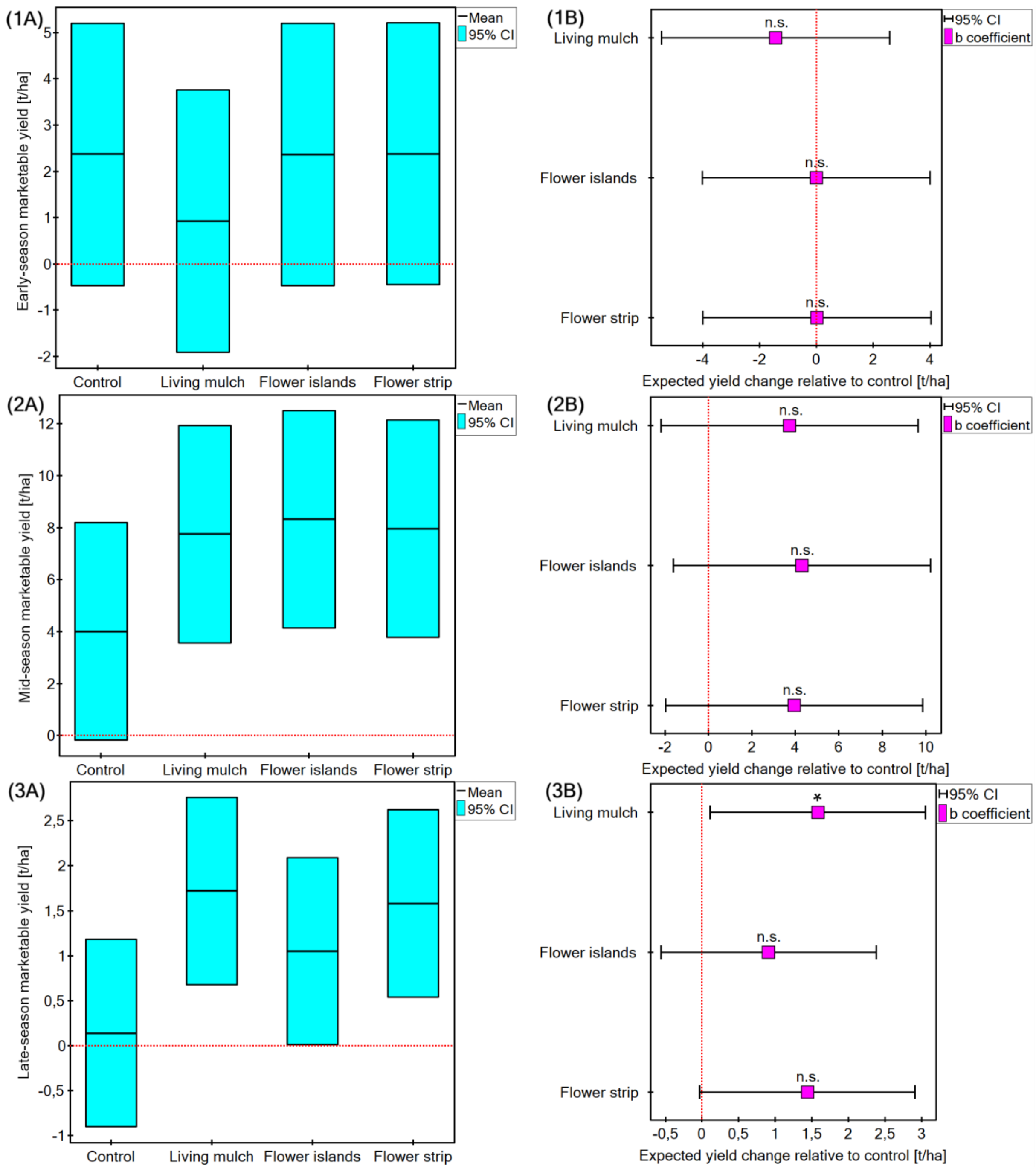

Figure 3. Early-season (1), mid-season (2) and late-season (3) marketable strawberry yield as affected by three inter-cropping practices, controlling for variability between the two experimental seasons (2023 and 2024). Panel A presents the expected means (95% CI) from the regression model, whilst panel B shows the regression coefficients b (95% CI), indicating the expected yield change compared to the control. Explanation: n.s. – not significant; *$P < .05$.

Yield components

Two major strawberry yield components, the average fruit weight ($F_{3,9} = 0.37$, $P = .77$, $\eta_p^2 = 0.11$) and the weight of one hundred fruit ($F_{3,9} = 0.23$, $P = .86$, $\eta_p^2 = 0.07$), were not affected by the inter-cropping practices applied (Fig. 4 and 5). **Instead, a highly significant effect due**

to harvest order on both parameters was observed ($F_{3,9}$ = 60.71, P < .001, η_p^2 = 0.95; and $F_{3,9}$ = 57.81, P < .001, η_p^2 = 0.95 in case of the mean fruit weight and the weight of hundred fruit, respectively), with a tendency for fruit size and mass to decrease over time.

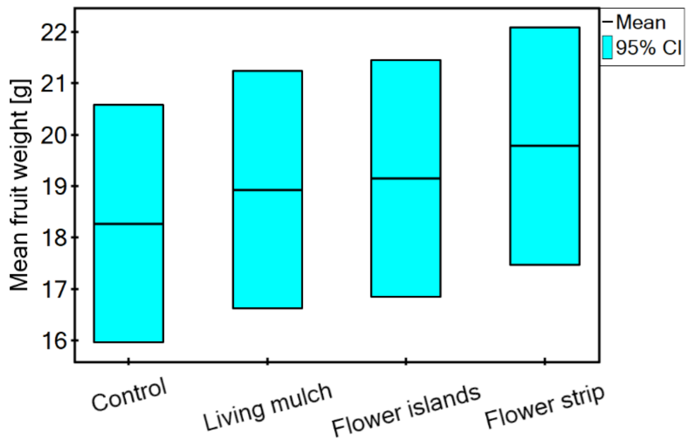

Figure 4. Effects of three inter-crops on the average weight of the strawberry fruit. The values presented are the expected means (95% CI) from the general linear model. The inter-crop factor had no statistically significant effect (P = .77).

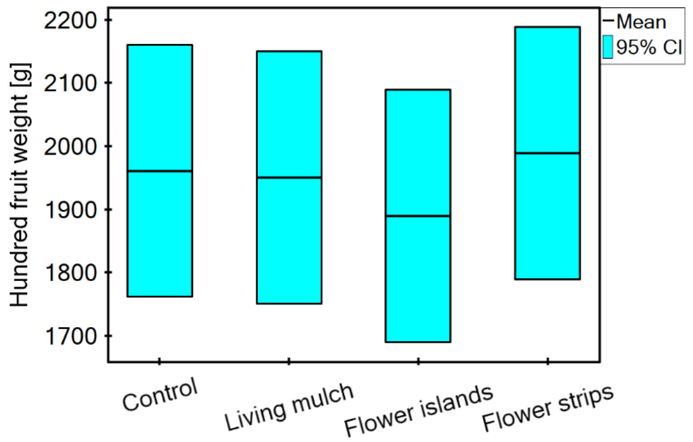

Figure 5. Effects of three inter-crops on the weight of one hundred strawberry fruit. The values presented are the expected means (95% CI) from the general linear model. The inter-crop factor had no statistically significant effect (P = .86).

Fruit marketable quality

Chi-square analysis proved there to be a weak but significant association between the management system and proportion of fruit in particular quality classes ($\chi^2_{(6, N = 6291)}$ = 84.0, P < .001, Cramér's V = 0.08). The flower strip treatment was characterised by a higher share of extra-class fruit with a corresponding reduction in outgrade, compared to the other groups (Fig. 6).

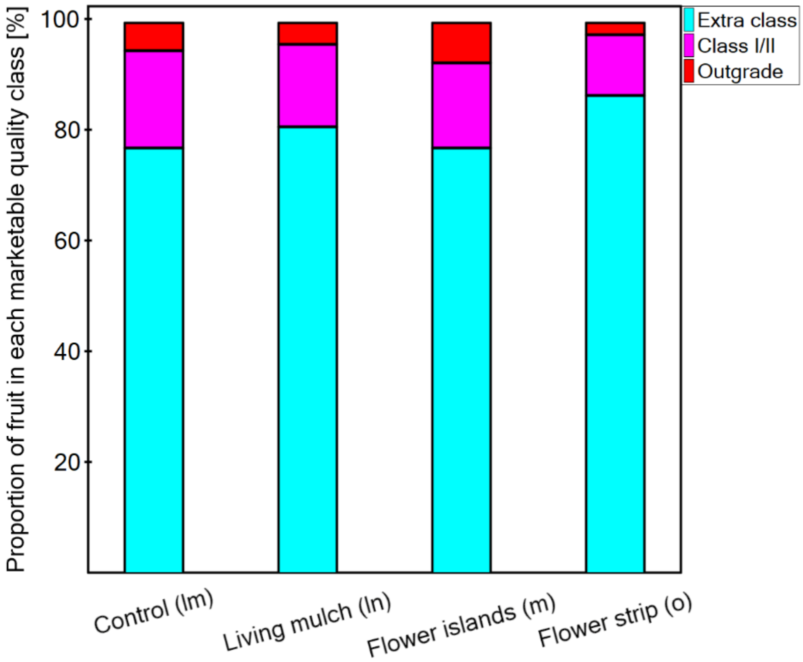

Figure 6. Proportion of strawberry fruit across marketable quality classes as affected by the inter-cropping practices applied. Groups designated with the same letter (given in brackets) are not significantly different, according to the chi-square multiple comparisons with Šidák correction, α = 0.05.

As shown in Fig. 7, the strawberry fruits were similarly well coloured, regardless of the inter-crop factor (Kruskal-Wallis test: $H_3 = 0.24$, $P = .97$).

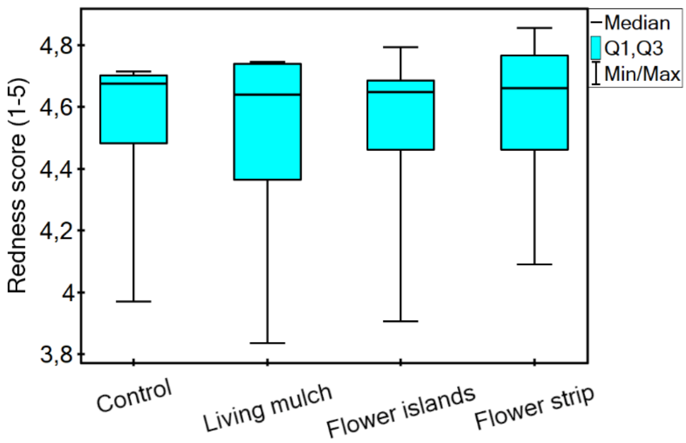

Figure 7. Effects of the three inter-crops on strawberry fruit colouration expressed on a five-point redness scale, where 1 indicates the least coloured fruit, and 5 indicates the most intensely coloured fruit. The medians do not differ significantly, according to the Kruskal-Wallis test ($P = .97$).

Frequency and characteristics of fruit damage

The results of the quantitative analysis of fruit damage are presented in Table 3. The inter-cropping practices exerted a statistically significant effect on the share of damaged fruit ($F_{3,20}$

= 3.87, $P < .05$, $\eta_p^2 = 0.37$), with the flower strip as well as flower islands reducing it compared to the control. In addition, the studied parameter depended significantly on the year of the experiment ($F_{1,20} = 11.31$, $P < .01$, $\eta_p^2 = 0.36$) and harvest order ($F_{3,20} = 16.86$, $P < .001$, $\eta_p^2 = 0.72$), showing a tendency to increase over time in both cases.

Table 3. The percentage share of the mass of damaged strawberry fruit out of the total yield by treatment, year and harvest order.

	Expected mean from the regression model (95% CI)	Regression coefficient b	
		Value (95% CI)	*P*
Treatment			
Control	22.69 (16.35; 29.02)^{m*}	Ref.**	Ref.
Living mulch	16.20 (9.87; 22.53)^{lm}	-6.49 (-15.44; -2,47)	.15
Flower islands	11.31 (4.98; 17.65)^{l}	-11.37 (-20.33; -2.41)	< .05
Flower strip	9.26 (2.92; 15.59)^{l}	-13.43 (-22.39; -4.47)	< .01

* Means sharing the same letter in the column within particular sections are not significantly different (the Fisher's LSD test, α= 0.05); **Reference category in regression analysis.

The chi-square analyses confirmed a statistically significant, albeit rather weak, association between the inter-cropping practices and fruit damage proportion in both years of the experiment (2023: $\chi^2_{(9, N = 3256)} = 133.8$, $P < .001$, Cramér's V = 0.12 and 2024: $\chi^2_{(6, N = 2148)} = 311.4$, $P < .001$, Cramér's V = 0.27). A visual interpretation of Fig. 8A facilitates the conclusion that in 2023, strawberries grown in the clover living mulch differed from the other groups in their higher proportion of rotten fruit but slightly lower percentage of fruit showing sun injury symptoms. Strawberries harvested from plants grown in the flower island system, on the other hand, were more frequently damaged by the European tarnished plant bugs. According to Fig. 8B, no sunscald occurred in 2024. However, the living mulch favoured the abundant slug population (107 individuals captured in beer traps during two weeks of monitoring, compared to 2, 17 and 2 in the control, flower islands and flower strip treatments, respectively), which was reflected in the increased share of slug-damaged fruit (Fig. 8B).

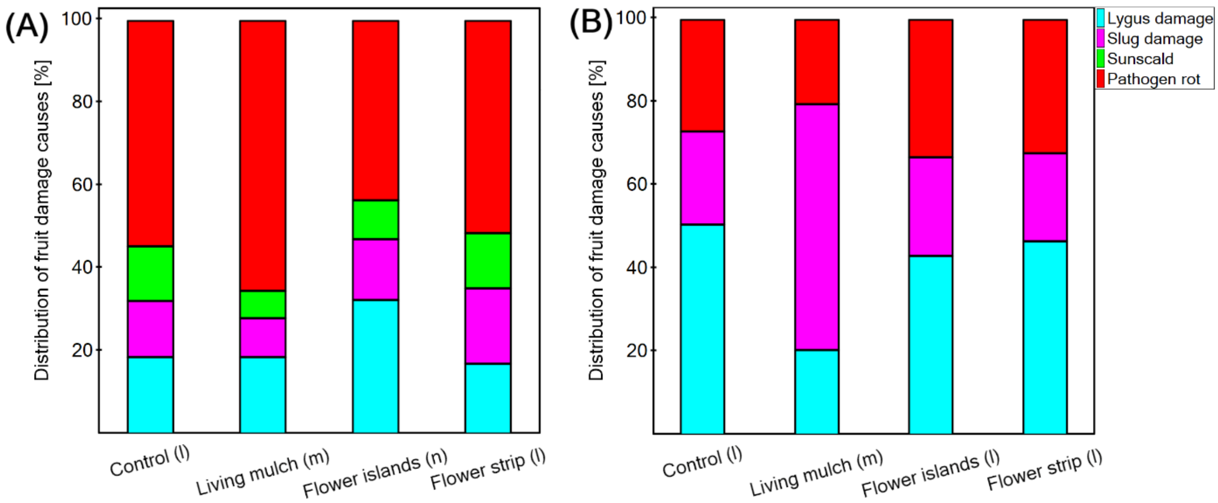

Figure 8. Proportion of strawberry fruit by type of damage in 2023 (A) and 2024 (B) under different inter-cropping practices. Within each year, groups sharing the same lowercase letter (given in parentheses) are not significantly different, according to chi-square multiple comparisons with Šidák correction, α = 0.05.

DISCUSSION

Flowering inter-crops are increasingly being discussed not only as a general method of conserving biodiversity in agricultural land (Geppert *et al.*, 2020; Zhu *et al.*, 2025) but equally as a means of providing various ecosystem services to crops (Kowalska *et al.*, 2022). However, the impact of inter-cropping on strawberry yields has not yet been elaborated on, despite the fact that pecuniary factors remain the main motivation for farmers to introduce this practice (Ha *et al.*, 2025). Hence, the increase in labour input, concerns about a decline in crop productivity due to competition from inter-crops, as well as the loss of productive land at the expense of uncultivated plants, may arouse a difficult-to-overcome reluctance among growers. In this context, the promising results obtained herein may support the adoption of biodiversity-based cropping systems in berry crops.

The hypothesis on the stimulating effect of the flower strip and islands on strawberry productivity was positively verified by the results of the present study, **as reflected by an almost twofold increase in marketable fruit relative to the standard growing system**. The estimated yield rise should be linked with the significant reduction in the share of damaged fruit **by more than half compared with the control.** This may have been an effect of enhanced natural pest control, presumably not limited to the fruit itself but also extended to earlier stages of plant growth and development. Many studies report an increase in the abundance and activity of pest predators and parasitoids in fruit crops due to the forage and shelter provided by flowering companion plants (Fountain, 2022). **In strawberry crops specifically, floral**

amendments have been found to promote *Copidosoma aretas*, a common parasitoid of the strawberry tortricid (Sigsgaard *et al.*, 2013). Alhmedi *et al.* (2024), in turn, reported that flowering inter-crops provided habitat for both predators (Coccinellidae, Syrphidae, Chrysopidae, Anthocoridae) and pest parasitoids (Braconidae), thereby improving biological aphid control.

However, the impact of flowering inter-crops on specific functional groups of natural enemies may vary (Balzan *et al*., 2014), with the species composition of floral mixtures playing a crucial role (Campbell *et al*., 2017). The same can be observed for pest species, some of which have been reported to increase in abundance in flower-amended cropping systems. For instance, McCabe *et al*. (2017) found that wildflower borders promoted plant bug density on a strawberry plantation, which could explain the increase in Lygus damage observed in the flower island treatment during the present experiment. At the same time, the significant reduction in the weight of damaged fruit noted in flower treatments suggests a more balanced interaction between pests and natural enemies, thereby enhancing the resilience of this management system.

By providing nectar, pollen and shelter, flowering companion plants also support pollinators, whose increased visitation rates might contribute not only to the observed yield gains but to some improvements in fruit quality as well (Fountain, 2022). **In a study by Castle *et al.* (2019), adjacent semi-natural habitats enhanced pollinator activity, leading to an increase in strawberry fruit weight, size, and the proportion of marketable yield.** A similar pattern could explain the increased share of extra-class fruit in the flower strip treatment reported in the present work. **However, it should be clearly stated that the analyses performed did not reveal any specific benefits for berry quality (size, weight, colouration).** A deeper insight into both pest-natural enemy and plant-pollinator interactions is necessary for a full interpretation of the results; this will be the subject of a separate publication (in preparation).

Several authors have reported that the positive impact of floral resources on crops is often spatially limited, with the effect diminishing as the distance from the flower strips increases (Azpiazu *et al*., 2020; Jacobsen *et al*., 2022; Han *et al*., 2025). To address this issue, the idea of flower islands was proposed herein which, unlike the large flower strip adjacent to the crop on one side, forms smaller but more numerous floral patches located within the crop with a circular effect (figuratively: 360° vs. 180°). **A drawback of this solution is the reduction in the area available for the cash crop. Alhmedi *et al.* (2024) confirmed the higher effectiveness of flowering plants positioned within strawberry rows in suppressing aphids compared with**

a flower strip placed at the field margin. However, the authors questioned the economic viability of this approach, as the flowering inter-crop replaced as much as 20% of the strawberry plants in their study. In contrast, the flower island system proposed herein requires replacing only about 8% of the crop, whilst the results obtained demonstrate that it achieves cumulative yields comparable to the flower strip approach and substantially higher than those in the control.

The living mulch was intended as a solution that would combine the benefits of flower strips with weed control, the stimulation of soil microbial activity, and increased nitrogen supply. Indeed, the proposed mixture of white clover and sheep's fescue created a dense soil cover that effectively supressed weed growth and decreased manual labour (personal observations of the authors, not supported by results). However, the obtained yield gain relative to the control was not statistically significant. Instead, excessive slug development and a higher proportion of disease-affected fruit were observed, most likely due to the living mulch favouring pathogenic rot by the increased plant wetness duration (Bulger *et al.*, 1987; MacKenzie and Peres, 2012) and providing slugs with humid shelter in the daytime (Kozłowski, 2007). An additional negative consequence of this practice was a delay in fruit ripening, likely resulting from either a reduction in soil temperature caused by shading from the cover crop (Neuweiler *et al*., 2003; Borowy, 2012) or an increase in soil nitrogen content following the mineralisation of organic matter in clover residues (Alexander *et al*., 2019). This is particularly undesirable when growing early cultivars such as the one tested in this study. Therefore, the living mulch may be not suitable for strawberry production, although it could prove effective in other berry crops with a taller habit, such as raspberries.

An important factor to consider when interpreting the results of this study is irrigation, which mitigated the impact of drought during critical periods (Table 1). It can be assumed that in the absence of a water supply system, both yield and fruit size would have been reduced due to competition with non-crop plants (Martin *et al.*, 1999). However, the marketable yield would have been higher if a full range of plant protection treatments approved for organic farming had been carried out. This was forgone in order to observe the pure effect of the implemented practices on the pest-beneficial interrelation.

Moreover, cultivar-specific responses to inter-cropping practices should be considered. Although the present study was conducted using a single strawberry cultivar ('Lycia'), literature from other crops shows that inter-cropping effects on yield, root system development, nutrient uptake and stress tolerance can vary amongst genotypes (Ren *et*

***al*., 2025; Wang *et al*., 2025). Therefore, evaluating multiple strawberry cultivars under various inter-crops represents a promising direction for future research, potentially enabling the selection of genotypes best suited to such practices.**

The main message of this study for horticultural practice is the usefulness of multispecies flower strips and flower islands in organic strawberry production. Their incorporation enhances plantation productivity and, consequently, the economic viability of the crop. It also reduces the proportion of damaged fruit — presumably through improved pollination and strengthened biological pest control — without compromising key commercial quality parameters such as colour and size. Importantly, the positive effect on yield persists even when only a small proportion of the crop (c. 8%) is replaced by floral resources. By contrast, the living mulch of white clover entails risks of delayed fruit ripening, increased pathogen rot and slug damage. Given the present findings, this practice cannot be recommended in organic strawberry production, where preventive disease and pest management is prioritised.

CONCLUSIONS

Both the strip and islands composed of various annual and perennial flowering plant species proved to be effective biodiversity-based practices for managing organic strawberry plantations. This was reflected **in an almost twofold increase** in marketable yield without compromising commercial quality parameters such as fruit size and colour. **Moreover, these treatments reduced the share of damaged fruit by more than half compared with the control.** In contrast, the performance of the living mulch was limited by its tendency to delay fruit ripening and increase the proportion of berries damaged by slugs and pathogenic rot. Consequently, the choice of inter-cropping practice must be carefully tailored to both the crop and its management context, with the proper selection of plant species and their spatial organisation requiring further research.

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