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Development of a “0-Pesticide Residue” Grape and Wine Production System for Standard Disease-Susceptible Varieties

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Abstract: In order to realize the goals of the EU Farm to Fork strategy, grape growers are introducing new grape-growing technologies. Among the new trends, “0-pesticide residue” protection is quite a promising one. Field trials were carried out in vineyards located in the Mediterranean part of Slovenia in 2021 and 2022 to test the “0-pesticide residue” (ZPR) grape protection system with the goal of producing wine without pesticide residues above the limit of 0.001 mg kg^{-1}. The standard integrated grape protection program (IP) was compared to the ZPR program. The level of infection of leaves and grapes by fungal pathogens did not significantly increase due to the implementation of the ZPR spray program. The amount of yield and quality of yield were not decreased significantly, but a small financial loss of EUR 70–400 ha^{-1} appeared at ZPR grape production when compared to the IP production system. The ZPR system enabled a significant decrease in pesticide residue concentration in wine at a rate of 27 applied pesticide active substances in a rage from 20% to 99%. The goal of producing wine without pesticide residues above the limit concentration of 0.001 mg kg^{-1} was not completely achieved in these experiments, but we came very close to it with the tested spraying programs. Further finetuning of pesticide positioning and alternative plant protection products in 0-pesticide residue systems is needed.

Keywords: grape; wine; pesticide; reduction; economics; IPM; alternative plant protection products

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1. Introduction

Grape growers are confronted with many challenges related to climate change and global economic and health crises. One of the additional important challenges is a request of the European community to significantly reduce the amount of applied synthetic chemical pesticides in order to address the issues of environmental and human health protection. Overall, the amount of pesticides used in the EU is largely related to grape growing, which is why changes in grape-growing systems significantly impact the overall EU pesticide usage statistics. The request to reduce chemical (target 1) and hazardous (target 2) pesticide use by 50% was presented in the Farm to Fork strategy. To reach these ambitious goals, growers will have to use a broad toolbox of integrated pest management solutions (IPM). Commonly proposed solutions are: cultivation of disease-resistant varieties (PIWI varieties; in German Pilzwiderstandsfähige Rebsorten), switch to organic production, the introduction of all possible digitalization tools, better pesticide application techniques and further upgrading of IPM concepts such as the introduction of better decision support systems [1–5].

One of the possible solutions to reduce the amount of applied synthetic chemical pesticides is introducing a “0-pesticide residue” grape protection system (ZPR). The “0-pesticide residue” protection concept was developed decades ago in apple fruit production in England to reduce the residues in fruits and is currently part of a well-established integrated and low-input fruit production system with developed marketing brands [6].

The first developments in marketing "0-pesticide residue" wines were documented in France during the last three years. Several publications about the endorsement of "0-pesticide residue" wines are available on wine producers' Internet sites. French wine producers started to sell wines under the market brand "Zero pesticide residue within the limits of quantification".

The basic concept of 0-pesticide residue grape protection is relatively simple. It is considered a kind of upgraded integrated production system where we apply all possible measures to reduce synthetic chemical pesticide application. Among the applied pesticides, we prefer to use active substances (a.s.) that degrade fast and have a low environmental and human toxicological impact. The backbone of the ZPR protection concept of disease-susceptible grape varieties that still prevails in our vineyards is dividing the growing season into two parts. In the first part, which usually lasts until two weeks after the finished flowering, chemical pesticides are applied with the highest possible efficacy. During the next two to three weeks, only preparations with active substances that decompose very fast (DT_{50} less than two weeks) within the prolonged pre-harvest interval (PHI), biological pesticides, or low-risk substances registered for organic grape production are applied. Afterward, until harvest, preparations used in the organic production system (biological products and low-risk substances) are applied. This concept significantly reduces the amount of applied synthetic chemical pesticides and pesticide residues in grapes and wine.

In integrated grape production, we usually expect grapes to contain 3 to 12 pesticide residues at a concentration from 0.005 to 2 mg kg^{-1} and wines containing 2–5 residues at levels 0.001–0.25 mg kg^{-1} [7–13]. Regarding pesticide residue concentration, the ZPR system aims to produce grapes with residues lower than 0.01 mg kg^{-1} and wines with residues lower than 0.001 mg kg^{-1}. The already endorsed marketing approach developed by the Collective Noveaux Champs in France follows this mentioned limit. They put the statement "without residues above limits of detection" on the wine brand label; in French, "Sans Résidu de Pesticide Détecté". Food analysis laboratories usually declare the limit of 0.001 mg kg^{-1} as the standard pesticide detection limit. The goal in 0-residue production is to produce wine with residues lower than the mentioned 0.001 mg kg^{-1} limit.

Like any grapevine protection system, the ZPR system has advantages and disadvantages, and there is a lack of information about them in available literature sources. Some information on the advantages and disadvantages of ZPR production is available for fruit production systems, but those are not entirely comparable to grape production systems [14]. The variety of ZPR concepts and features is well presented in the "Zero residue agriculture: the "third way" presentation, which is gaining ground in value-added production. It is described on the Spanish company SEIPASA [15]'s website and in many other online project presentations such as [16–18]. When examining these mentioned sources, it could be concluded that the reduction in applied chemical pesticides and, thus, a lower toxicological burden for the environment and humans is one positive side of ZPR. If farmers practiced this form of grapevine protection, they would have greater chances of obtaining environmental subsidies and better opportunities for wine marketing. Some weaknesses of ZPR are the increase in the cost of protecting the grapevine from harmful organisms and the slightly increased occurrence of some diseases and pests.

Research reports dealing with the economic analysis of ZPR grape protection and production are not available at the moment. The ZPR system is under investigation and is being further developed. The majority of materials on ZPR seem to be nonscientific opinions found on websites produced by the wine industry. The differences between the costs of chemical pesticide-based and alternative preparation-based spray programs and between different countries are very large, and the range of possible economic results due to the introduction of ZPR is very variable. Wine industry online postings rate that ZPR is paying off. According to wine industry opinions, the feasibility of ZPR is primarily a matter of successful marketing and not so much related to the costs of protecting the vines with alternative preparations. If marketing is successful, the higher cost of spray programs can easily be covered.

There is a lack of information on the performance of ZPR, and our research aimed to test the ZPR concept's executability in practice and to demonstrate its effects on; (1) yield, (2) diseases and pest control efficacy, (3) amount of pesticide residues in grape and wine, and (4) partially on financial results. Our research contributes to the development of a more sustainable grape and wine production system for disease-sensitive varieties, following the EU goals related to the Farm to Fork strategy, the sub-goal of a significant reduction of pesticide use (target 1) [19].

2. Materials and Methods

2.1. Trial Design and Statistics

Field trials were carried out in three vineyards in 2021 and in one vineyard in 2022. A standard randomized block design was used with randomly arranged plots consisting of 400–450 grapevines (approx. 1000 m^2 area each). One plot consisted of seven 70–85 m long rows. All evaluations were performed only in the middle row. For data analysis, standard analysis of variance (one-way ANOVA general linear model; F-test) was used. The difference significance among treatment means was tested via the Tukey HSD significance post hoc test ($p < 0.05$) at the assessments of disease severity. Student's *t*-test for independent means ($p < 0.05$) was used to test the difference significance between treatments at yield and pesticide concentration assessments. The SPSS Statistics software (IBM SPSS Statistics V20, Chicago, IL, USA) was used to perform the analysis.

The following assessments were carried out: disease infestation and pest attack rate, amount of grape yield, and analysis of pesticide residues in grapes and wine. We analyzed the infestation rate of three fungi and the attack rate of three pests. The studied fungi were downy mildew (DM) (*Plasmopara viticola* Berk. and M.A. Curtis), powdery mildew (PM) (*Erysiphe necator* Schwein.), and gray mold (GM) (*Botrytis cinerea* Pers. = *Botryotinia fuckeliana* (de Bary)). The analyzed pests were spotted wing drosophila *Drosophila suzukii* Matsumura, European grapevine moth *Lobesia botrana* Denis and Schiffermüller, and mite *Panonychus ulmi* Koch. Diseases and pest attack rate analysis were performed according to EPPO (European Plant Protection Organisation) standards by direct visual scouting of infestation/attack rate on 200 randomly chosen leaves or grape clusters per plot four times per season. Not all obtained data during seasonal assessments are presented in this manuscript. The followed EPPO standards were: PP1/4(4) (*E. necator*), PP1/11(3) (*Eupoecilia ambiguella* and *L. botrana*), PP1/17(3) (*B. fuckeliana* on grapevine); PP1/31(3) (*P. viticola*), PP1/133(2) (Tetranychid mites in vineyards), and PP1/281(1) (*D. suzukii*) [20]. Only data from the last disease infestation evaluations directly prior to harvest are presented in this manuscript.

Two spray programs were tested, which were composed to control all major diseases and pests that usually appear in the area of the experimental vineyards. The first, based on the applications of synthetic chemical pesticides throughout the whole season, was called the IP program, and the second was based on chemical synthetic pesticides applied during the first part of the season and on biological and low-risk preparations during the second part of the season. Some biostimulants were added to relieve plant stress. It was named the 0-pesticide residue program (ZPR). Spray programs are presented in Tables 1–4. We also had smaller, randomly scattered plots that were not treated with plant protection products (control plots). The main aim of the trial was to test the possibility of reducing the amount of applied conventional pesticides by 20–25% without compromising grape yield and financial results. Secondly, we wanted to test as many different active substances as possible, regardless of their toxicological properties (classified as less or more hazardous for the environment or human health), to see the final transfer rate of residues to wine. We wanted to obtain as much information as possible about where we can or can not reach the target of all residues in wine being below 0.001 mg kg^{-1}. We tested the IP spray programs winegrowers in Slovenia practically implement. We wanted to reach target 1 from the "From Field to Fork" strategy, i.e., a reduction of applied chemical pesticide amount per ha per year. The seasonal amount of pesticide a.s. at IP Pinot Gris spray program was 31.34 kg ha^{-1} and 26.77 kg ha^{-1} at ZPR (-14.58%). Amounts of a.s. (kg ha^{-1}) for

Sauvignon, Rebula, and Merlot spray programs were (IP 33.71 vs. 24.03 ZPR (−28.72%)), (IP 26.61 vs. 21.00 ZPR (−21.01%)) and (IP 35.37 vs. 28.24 ZPR (−20.15%)) respectively. Yield determination was performed by hand harvesting 50 vines, randomly chosen in the middle row of each plot. At harvest, parts of the grapes attacked by diseases or pests (e.g., gray mold) were removed from bunches, so we weighed only completely healthy bunches. For simple financial result estimation, we calculated the value of grapes and the cost of the spray program, considering only the cost of preparations and not the cost of application since the number of applications was practically the same in both spraying programs. We assumed that the price for a kilogram of grapes is the same for IP and ZPR as long as the quality parameters of the grapes are comparable. Information about prices of preparations (VAT included) was obtained from several local cooperatives that sell plant protection products. We took the average price for big packages (5–10 kg, L). Information on grape prices was obtained from local wineries.

Table 1. Spray program for the Pinot Gris vineyard in the 2021 season at integrated (IP) and 0-pesticide residue (ZPR) grape protection systems. Preparation was applied if marked with X.

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
16 May	Kumulus [1]	Sulfur (80%)	8	X	X
9 May	Kumulus [1]	Sulfur (80%)	6	X	X
	Wetcit [2]	Alcohol ethoxylate (8.15% *w*/*w*)	0.2	X	X
21 May	Delan pro [1]	Dithianon (12.5%) + Al-fosetyl (56.12%)	3	X	X
	Sercadis plus [1]	Difenconazole (5%) + Fluxapyroxad (7.5%)	0.15	X	X
	Vitanica SI [3]	Algae extract with Si and micronutrients	2		X
	Plantonic [18]	*Salix* + *Urtica* plant extract	4		X
28 May	Delan pro [1]	Dithianon (12.5%) + Al-fosetyl (56.12%)	3	X	X
	Vivando [1]	Metrafenone (50%)	0.2	X	X
	Vitanica SI [3]	Algae extract with Si and microelements	2	X	X
3 June	Cabrio Top [1]	Metiram (55%) + Pyraclostrobin (5%)	2	X	X
	Kumulus [1]	Sulfur (80%)	2	X	X
	Basfoliar Force [3]	Algae extract + Mn + Zn	2	X	
	Basfoliar Active [3]	Algae extract + NPK	2		X
13 June	Cabrio Top [1]	Metiram (55%) + Pyraclostrobin (5%)	2	X	X
	Kumulus [1]	Sulfur (80%)	2	X	X
	Collis [1]	Boscalid (20%) + Kresoxim-methyl (10%)	0.4	X	X
25 June	Cabrio Top [1]	Metiram (55%) + Pyraclostrobin (5%)	2	X	X
	Kumulus [1]	Sulfur (80%)	3	X	X
	Basfoliar Active [3]	Algae extract + NPK	3	X	
	Orvego [1]	Ametoctradin (30%) + Dimetomorph (22.5%)	0.8		X
	Sivanto prime [4]	Flupyradifurone (20%)	0.5		X
8 July	Orvego [1]	Ametoctradin (30%) + Dimetomorph (22.5%)	0.8	X	
	Collis [1]	Boscalid (20%) + Kresoxim-m. (10%)	0.4	X	
	Basfoliar Force [3]	Algae extract + Mn + Zn	2.5	X	X
	Sivanto prime [4]	Flupyradifurone (20%)	0.5	X	
	Kumulus [1]	Sulfur (80%)	3		X
24 July	Cabrio Top [1]	Metiram (55%) + Pyraclostrobin (5%)	2	X	
	Kumulus [1]	Sulfur (80%)	3	X	
	Basfoliar force [3]	Algae extract + Mn + Zn	2		X
	Wetcit [2]	Alcohol ethoxylate (8.15% *w*/*w*) + botanical oil	2		X

Table 1. *Cont.*

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
31 July	Vivando [1]	Metrafenone (50%)	0.2	X	
	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	8		X
	Wetcit [2]	Alcohol ethoxylate (8.15% *w*/*w*)	1		X
22 August	Kumulus [1]	Sulfur (80%)	3	X	
	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	8		X
	Wetcit [2]	Alcohol ethoxylate (8.15% *w*/*w*) + botanical oil	2		X
	Vitanica SI [3]	Algae extract with Si and microelements	3		X

Product producer: [1]—BASF Germany, [2]—Oro Agri USA, [3]—Compo Germany, [4]—BAYER Germany, [5]—Syngenta Switzerland, [6]—Idai Nature Spain, [7]—Corteva Bulgaria, [8]—Adama Belgium, [9]—Biofa Switzerland, [10]—Belchim Crop Protection Belgium, [11]—Tradecorp Spain, [12]—Novozymes Denmark, [13]—Intermag Poland, [14]—ISK Bioscience Belgium, [15]—K + S Germany, [16]—Sumito Chemical Agro Europe, [17]—Aspanger GmbH Austria, [18]—OGET GmbH Austria.

Table 2. Spray program for the Sauvignon vineyard in the 2021 season at integrated (IP) and 0-pesticide residue (ZPR) grape protection systems. Preparation was applied if marked with X.

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
16 April	Kumulus [1]	Sulfur (80%)	8	X	X
10 May	Thiovit jet [5]	Sulfur (80%)	6	X	X
	Folpan [8]	Folpet (80%)	0.7	X	X
18 May	Luna exper. [4]	Fluopyram (20%) + Tebuconazole (20%)	0.4	X	X
	Thiovit jet [5]	Sulfur (80%)	4	X	X
	Universalis [5]	Azoxystrobin (9.35%) + Folpet (50%)	2	X	X
28 May	Mikal pr. F [4]	Folpet (25%) + Iprovalicarb (4%) + Al-fosetyl (50%)	3	X	X
	Nativo [4]	Tebuconazole (50%) + trifloyxstrobin (25%)	0.16	X	X
5 June	Mikal pr. F [4]	Folpet (25%) + Iprovalicarb (4%) + Al-Fosetl (50%)	3	X	X
	Karathane gold [7]	Meptyldinocap (35%)	0.3	X	X
13 June	Mikal flash [4]	Folpet (25%) + Al-fosetyl (50%)	3	X	X
	Vivando [1]	Metrafenone (50%)	0.2	X	X
25 June	Orvego [1]	Ametoctradine (30%) + Dimetomorph (22.5%)	0.8	X	X
	Sercadis plus [1]	Difenconazole (5%) + Fluxapyroxad (7.5%)	0.15	X	X
	Sivanto prime [4]	Flupyradifurone (20%)	0.5		X
8 July	Thiovit jet [5]	Sulfur (80%)	3	X	
	Nativo [4]	Tebuconazole (50%) + trifloyxstrobin (25%)	0.16	X	
	Profiler [4]	Flupicolide (4.44%) + Al-fosetyl (66.67%)	3	X	
	Sivanto prime [4]	Flupyradifurone (20%)	0.5	X	
	Quitobasic [6]	Chitosan hydrochloride (5%)	3		X
	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	6		X
	Vegex beta [6]	Plant extract + essential oils	1.5		X
24 July	Thiovit jet [5]	Sulfur (80%)	2.5	X	
	Basfoliar force [3]	Algae extract + Mn + Zn	3		X
	Pergado F [5]	Mandipropamid (5%) + Folpet (40%)	2.5	X	
	Equibasic [6]	*Equisetum* extract	2		X

Table 2. *Cont.*

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
31 July	Thiovit jet [5]	Sulfur (80%)	2.5	X	
	Basfoliar force [3]	Algae extract + Mn + Zn	3	X	
	Quitobasic [6]	Chitosan hydrochloride (5%)	3		X
	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	6		X
	Vegex beta [6]	Plant extract + essential oils	1.5		X
7 August	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	4		X
	Wetcit [2]	Alcohol ethoxylate (8.15% w/w) + botanical oil	1		X
	Quitobasic [6]	Chitosan hydrochloride (5%)	2		X

Product producer: [1]—BASF Germany, [2]—Oro Agri USA, [3]—Compo Germany, [4]—BAYER Germany, [5]—Syngenta Switzerland, [6]—Idai Nature Spain, [7]—Corteva Bulgaria, [8]—Adama Belgium, [9]—Biofa Switzerland, [10]—Belchim Crop Protection Belgium, [11]—Tradecorp Spain, [12]—Novozymes Denmark, [13]—Intermag Poland, [14]—ISK Bioscience Belgium, [15]—K + S Germany, [16]—Sumito Chemical Agro Europe, [17]—Aspanger GmbH Austria, [18]—OGET GmbH Austria.

Table 3. Spray program for the Rebula vineyard in the 2021 season at integrated (IP) and 0-pesticide residue (ZPR) grape protection system. Preparation was applied if marked with X.

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
16 April	Kumulus [1]	Sulfur (80%)	8	X	X
11 May	Thiovit jet [5]	Sulfur (80%)	6	X	X
	Delan pro [1]	Dithianon (12.5%) + Al-fosetyl (56.12%)	3	X	X
21 May	Karathane gold [7]	Meptyldinocap (35%)	0.5	X	X
	Universalis [5]	Azoyxstrobin (9.35%) + Folpet (50%)	1.5	X	X
27 May	Ampexio [5]	Mandipropamid (25%) + Zoxamide (2%)	0.5	X	X
	Dynali [5]	Ciflufenamid (3%) + Difenconazole (6%)	2.5	X	X
3 June	Karathane gold [7]	Meptyldinocap (35%)	0.5	X	X
	Ridomil gold [5]	Metalaxyl-m (3.88%) + Mancozeb (64%)	2.5	X	X
13 June	Ampexio [5]	Mandipropamid (25%) + Zoxamide (24%)	0.5	X	X
	Dynali [5]	Ciflufenamid (3%) + Difenconazole (6%)	0.65	X	X
	Delfan plus [11]	Amino acid-based foliar fertilizer	1		X
25 June	Ridomil gold [5]	Metalaxyl-m (3.88%) + Mancozeb (64%)	2.5	X	X
	Topas 100 EC [5]	Penconazole (10%)	0.3	X	X
	Trafos K [11]	P_2O_5 (30% w/w) + K_2O (20% w/w)	2		X
	Sivanto prime [4]	Flupyradifurone (20%)	0.5		X
8 July	Trafos K [11]	P_2O_5 (30% w/w) + K_2O (20% w/w)	2.5	X	
	Thiovit jet [5]	Sulfur (80%)	3	X	
	Ampexio [5]	Mandipropamid (25%) + Zoxamide (24%)	0.5	X	
	Quitobasic [6]	Chitosan hydrochloride (5%)	3		X
9 July	Sivanto prime [4]	Flupyradifurone (20%)	0.5	X	
24 July	Pergado F [5]	Mandipropamid (5%) + Folpet (40%)	2.5	X	
	Topas 100 EC [5]	Penconazole (10%)	0.3	X	
	Quitobasic [6]	Chitosan hydrochloride (5%)	3		X
	Thiovit jet [5]	Sulfur (80%)	3		X
	Affirm [5]	Emamectin (0.95%)	1,5	X	X
31 July	Pergado F [5]	Mandipropamid (5%) + Folpet (40%)	2.5	X	
	Thiovit jet [5]	Sulfur (80%)	2.5	X	

Table 3. *Cont.*

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
31 August	Thiovit jet [5]	Sulfur (80%)	3	X	
	Equibasic [6]	*Equisetum* extract	3		X
7 September	Taegro [12]	*Bacillus amyloliquefaciens* strain FZB24 (13%)	0.375		X
	Quitobasic [6]	*Chitosan hydrochloride (5%)*	3		X

Product producer: [1]—BASF Germany, [2]—Oro Agri USA, [3]—Compo Germany, [4]—BAYER Germany, [5]—Syngenta Switzerland, [6]—Idai Nature Spain, [7]—Corteva Bulgaria, [8]—Adama Belgium, [9]—Biofa Switzerland, [10]—Belchim Crop Protection Belgium, [11]—Tradecorp Spain, [12]—Novozymes Denmark, [13]—Intermag Poland, [14]—ISK Bioscience Belgium, [15]—K + S Germany, [16]—Sumito Chemical Agro Europe, [17]—Aspanger GmbH Austria, [18]—OGET GmbH Austria.

Table 4. Spray program for the Merlot vineyard in the 2022 season at integrated (IP) and 0-pesticide residue (ZPR) grape protection system. Preparation was applied if marked with X.

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
18 April	Kumulus [1]	Sulfur (80%)	10	X	X
	Ovitex [10]	Paraffin oil (81.7%)	10	X	X
3 May	Thiovit jet [5]	Sulfur (80%)	6	X	X
10 May	Delan pro [1]	Dithianon (12.5%) + Al-fosetyl (56.12%)	3	X	X
	Talendo extra [7]	Proquinazide (16%) + Tetraconazole (8%)	0.25	X	X
20 May	Cymbal [10]	Cymoxanil (45%)	0.2	X	X
	Karathane gold [7]	Meptyldinocap (35%)	0.4	X	X
24 May	Mikrovit B [13]	Boron (11%)	1	X	X
	Phylgreen [11]	Algae extract (15% *w*/*w*)	1	X	X
31 May	Delan pro [1]	Dithianon (12.5%) + Al-fosetyl (56.12%)	3	X	X
	Vivando [1]	Metrafenone (50%)	0.2	X	X
11 June	Kusabi [14]	Pyriofenone (30%)	0.25	X	X
	Profiler [4]	Fluopicolide (4.44%) + Al-fosetyl (66.67%)	3	X	X
16 June	Delfan plus [11]	Amino acid-based fertilizer	1	X	
	Epso top [15]	MgO (16%) + SO_3 (32.5%)	3	X	
21 June	Ampexio [5]	Mandipropamid (25%) + Zoxamide (24%)	0.5		X
	Dynali [5]	Ciflufenamid (3%) + Difenconazole (6%)	2.5		X
25 June	Ampexio [5]	Mandipropamid (25%) + Zoxamide (24%)	0.5	X	
	Dynali [5]	Ciflufenamid (3%) + Difenconazole (6%)	2.5	X	
30 June	Collis [1]	Boscalid (20%) + Kresoxim-m. (10%)	0.4	X	
	Orvego [1]	Ametoctradin (30%) + Dimetomorph (22.5%)	0.8	X	
	Plantonic [18]	*Salix* + *Urtica* extract	4		X
	Quitobasic [6]	Chitosan hydrochloride (5%)	4		X
14 July	Prolectus [16]	Fenpyrazamine (30%)	1.2		
	Decis 2.5 EC [4]	Deltamethrin (2.5%)	0.5	X	X
	Aspanger [17]	Muscovite clay	6	X	X
	S-system [6]	SO_3 (32%) + Mn (1%) + Zn (1%) + polycarboxylic acid	2		X
31 July	Cabrio top [1]	Metiram (55%) + Pyraclostrobin (5%)	2	X	
	Kumulus [1]	Sulfur (80%)	3	X	
	Vitisan [9]	Potassium hydrogen carbonate (99.49%)	9		X
	Wetcit [2]	Alcohol ethoxylate (8.15% *w*/*w*) + botanical oil	0.8		X

Table 4. *Cont.*

Date	Commercial Name	Active Ingredient	Dosage (kg, L/ha)	IP	ZPR
3 August	Delfan plus [11]	Amino acid-based fertilizer	1		X
	Final K [11]	K_2O (46.5% *w*/*w*)	3		X
5 August	Vivando [1]	Metrafenone (50%)	0.2	X	
	Quitobasic [6]	Chitosan hydrochloride (5%)	4		X
14 August	Kumulus [1]	Sulfur (80%)	3	X	
	Laser 240 SC [7]	Spinosad (24%)	0.22		X
	Serenade ASO [4]	*Bacillus amyloliquefaciens* (1.396%)	4		X

Product producer: [1]—BASF Germany, [2]—Oro Agri USA, [3]—Compo Germany, [4]—BAYER Germany, [5]—Syngenta Switzerland, [6]—Idai Nature Spain, [7]—Corteva Bulgaria, [8]—Adama Belgium, [9]—Biofa Switzerland, [10]—Belchim Crop Protection Belgium, [11]—Tradecorp Spain, [12]—Novozymes Denmark, [13]—Intermag Poland, [14]—ISK Bioscience Belgium, [15]—K + S Germany, [16]—Sumito Chemical Agro Europe, [17]—Aspanger GmbH Austria, [18]—OGET GmbH Austria.

2.2. Trial Locations, Vineyard Characteristics, and Pesticide Application

The vineyards were located in the western part of Slovenia, called the Vipava valley district, with a mixed semi-Mediterranean and sub-alpine climate. The vineyard with the Sauvignon variety was located in Zavino (45°51′17.43″ N, 13°50′13.38″ E, WGS 84), the vineyards with the varieties Rebula and Pinot Gris were located in the village Draga (45°52′49.03″ N, 13°43′20.20″ E, WGS 84), and the vineyard with the Merlot vines was situated in Merljaki (45°53′12.07″ N, 13°38′50.74″ E, WGS 84). Some characteristics of vineyards are presented in Table 5. We chose older vineyards managed extensively with considerable disease pressure in past seasons and less frequent pesticide application. Pesticides were applied with standard vineyard axial fan cross-flow sprayer Zupan DT (Zupan sprayers, Slovenia) equipped with electrostatic support, which delivered 300 L of spray per ha using an Albuz ATR 80 nozzle operated at 12.2 bars. The spray droplet VMD_{50} value was 80 µm. The timing of pesticide application was adopted according to the advice of the local plant protection advisory and disease prognostic service.

Table 5. Characteristics of vineyards where the trials were performed.

Variety	Age (Years)	Planting Density	No. of Vines per ha	Training System	Max. GRV m^3/ha
Pinot Gris	15	0.9 m × 2.7 m	4100	Single Guyot	6500
Rebula	22	0.8 m × 2.6 m	4800	Short cordon	8300
Merlot	18	0.8 m × 2.4 m	5200	Short cordon	9000
Sauvignon	19	0.8 m × 2.7 m	4600	Single Guyot	7000

GRV—maximum grapevine row volume during the summer period.

2.3. Pesticide Residue Analysis

The pesticide residue determinations were performed in the internationally validated food analytics laboratory Wagner Lebensmittel analytic GmbH located in Lebring (Austria) using the QuEChERS (Quick, Easy, Cheap, Effective, Rugged, and Safe) extraction method, followed by ultra-high-performance liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) and gas chromatography with mass spectrometry (GC-MS/MS). The sample preparation was carried out according to the European standard EN 15662, "Foods of plant origin Multimethod for determining pesticide residues using GC- and LC-based analysis following acetonitrile extraction/partitioning and clean-up by dispersive SPE—Modular QuEChERS-method" [21]. The pesticides were extracted with acetonitrile, followed by a dispersive cleaning step. We delivered samples of grapes (5 kg) for laboratory analysis within 24 h after harvest. Before the analysis, samples were kept in cooling boxes at 2 °C. The same procedures were applied to the wine samples, amounting to 0.5 L each. The limit of quantification of pesticides was 0.003 mg kg^{-1}, and the limit of detection was

0.001 mg kg^{-1} for grapes and wine. The analysis was performed in four repetitions for each treatment.

In the case of the active substances where the average residue concentration was at a level of 0.001 mg kg^{-1} or higher, we also calculated the degree of reduction in the concentration of pesticide residues. In cases where the average residue concentration at ZPR and IP was equal to or higher than 0.001 mg kg^{-1}, the following formula was used: pesticide concentration reduction rate (%) = 100 − ((concentration ZPR/concentration IP) × 100). In cases where the average concentration at IP was above 0.001 mg kg^{-1} and at ZPR below 0.001 mg kg^{-1}, we assessed the theoretical reduction of the concentration of residues according to the following formula: approximate minimum pesticide concentration reduction rate (%) = 100 − ((0.0009/concentration IP) × 100). A theoretical estimate of the degree of reduction was thus obtained, and the calculated value was marked with the $\simeq$ symbol, which means that the estimated value asymptotically approaches some approximation of the minimal residue concentration reduction degree.

2.4. Grape Juice Production, Analysis, and Winemaking Procedure

From each plot, 300–450 grape clusters were chosen randomly from 100 grapevines in the middle row of plots to obtain a random sample weighing 50 kg. Must was prepared in four repetitions. Prior to pressing, the grapes were not destemmed. They were crushed, and the grape juice was sulfited immediately after the grape pressing (5 g hL^{-1}). For the grape pressing, a small stainless-steel basket press was used (Obst/Berren Spindel-Korb-Presse V20, Fischer Germany). Before starting the fermentation, the fresh juice was analyzed for sugar content (total soluble solids TSS; °Oe) using a digital refractometer (ATAGO 4487 PAL-87S; Atago Inc., Bellewue, WA, USA) with an automatic temperature compensation (ATC). Total titratable acids content (total acidity TA; g L^{-1}) was determined using a titration method by application of the standard base and color indicator bromothymol blue [22]. Fermentation and vinification were performed in miniature tanks. For all wine samples, the vinification process was the same. After the grape pressing, the grape juice was clarified for 24 h and was later decanted and then fermented for two weeks at a temperature of around 18 °C by adding dry yeast. For the fermentation, the dry yeast (*Saccharomyces cerevisiae* Meyen ex E.C. Hansen) strain ZYMAFLORE® X5 Laffort (France) was used (20 g hL^{-1}). After the finished fermentation, fresh wine was decanted from lees and transferred to new tanks, where it was aged and clarified for 3 months. Finning during the aging was not performed. In January 2022 and 2023 (Merlot), the clarified wine was filtered, and samples were taken for pesticide residue analysis. Before the pesticide analysis, the filtration of the wine samples was performed via a Hettich® ROTOFIX 320A centrifuge (Hettich GmbH, Tuttlingen, Germany) at 4000 RPM for 8 min.

3. Results

3.1. Weather Conditions

According to Koppen's climate classification, the climate features at all research locations belong to the climate type Cfa (a humid subtropical climate characterized by hot and humid summers and cool to mild winters). These climates normally lie between latitudes of 25° and 40° and are located poleward from adjacent tropical climates. It is also characterized as a warm temperate climate in some climate classifications.

Figures 1 and 2 show the climatic charts obtained from the meteorological station Vipolže (for the year 2021) and from the meteorological station Miren (for the year 2022). The stations are located close to the experimental vineyards.

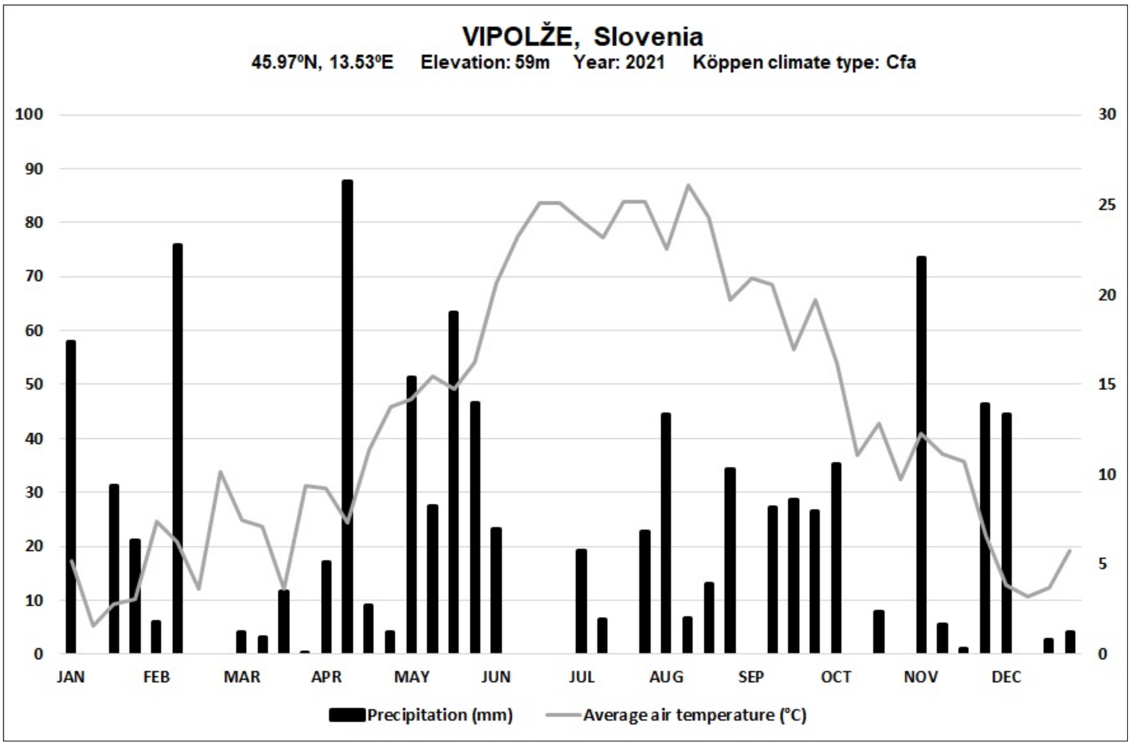

Figure 1. The climatic diagram shows the annual rainfall and air temperature regime. The bars represent the average weekly precipitation (mm), and the line is the average weekly air temperature (°C) at the meteorological station Vipolže (Slovenia) in 2021.

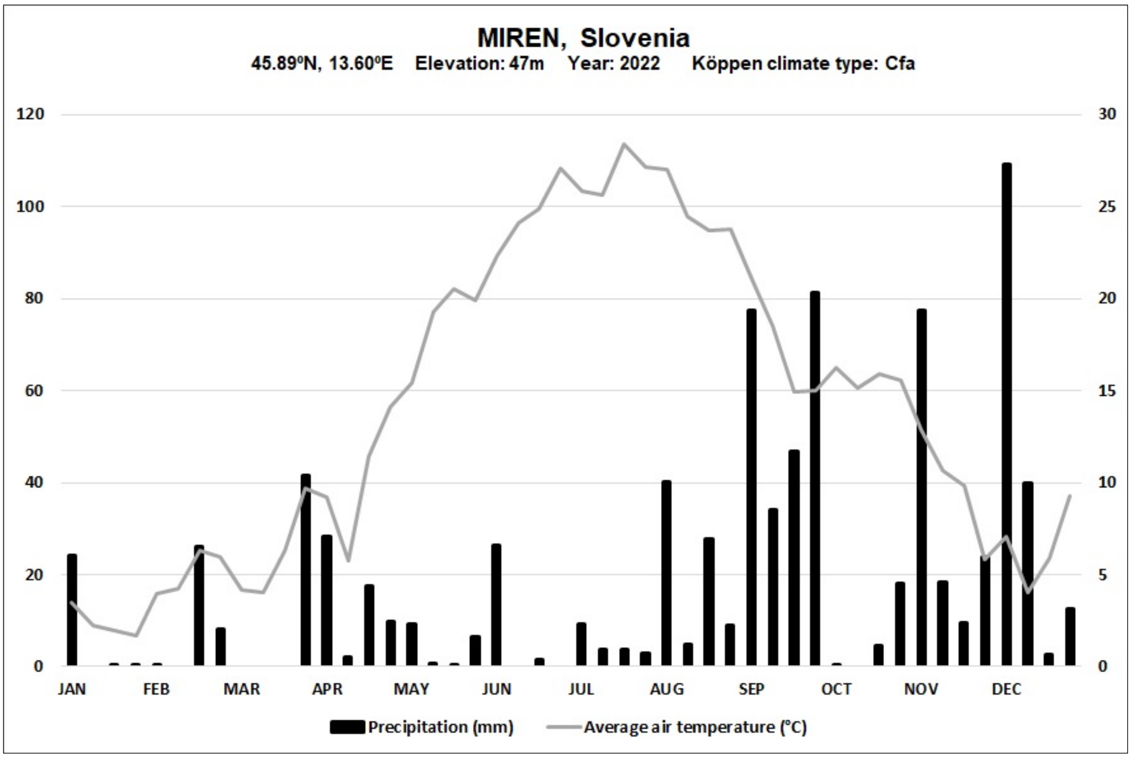

Figure 2. The climatic diagram shows the annual rainfall and air temperature regime. The bars represent average weekly precipitation (mm), and the line is the average weekly air temperature (°C) at the meteorological station Miren (Slovenia) in 2022.

The spring growing period in 2021 was unusually wet, with a low-temperature period from the end of February to the beginning of March (Figure 1). The second lower-temperature period occurred at the end of April and the beginning of May. The first part of May was moderately dry. These conditions caused a delayed flowering period and also delayed primary infections by downy and powdery mildew. The drought in 2021 started in the third week of June and lasted almost until the end of August. Rains in mid-August and September created optimal conditions for the development of gray mold and powdery mildew (Figure 1).

At the beginning of the growing period in 2022, the weather conditions were less suitable for grape and disease development. There were periods of lower temperatures during the end of April and the beginning of May. The first part of May was cold and moderately dry (Figure 2). The grapevine developed slowly, and flowering started with a slight delay. The temperatures in the first two-thirds of June were suitable for grape development. The rainfall enabled a proper supply of water until the last week of June, after which a long drought period started. During the first part of June, conditions for infections with downy mildew were very suitable. During the summer, the plants were exposed to drought until the harvest. During the second part of summer, there was some rain but not enough to completely stabilize the physiological conditions in the grape plants. The rain occurring at the end of August enabled the development of powdery mildew and gray mold (Figure 2).

3.2. Disease Infestation Rate and Pest Attack Rate at Harvest

The pest attack rate was very low, so the pest attack rate data are not presented. Small populations of the following pests were detected: *D. suzukii*, *L. botrana,* and *P. ulmi*. We think that pests had no significant influence on the amount of yield and disease development. The data on disease infestation rates assessed by visual scouting (% infested area) a day before harvest are presented in Table 6. The infestation rate of downy mildew (DM) (*P. viticola*), powdery mildew (PM) (*E. necator*), and gray mold (GM) (*B. cinerea*) at the control nontreated plots on Rebula grapes was moderate (DM 13.85%, PM 12.05%, GM 16.18%). The differences in infestation rates between ZPR and IP programs were not statistically significant in any of the studied diseases. The ZPR program caused a minor increase in infestation rate on grapes only at PM (IP 2.11% vs. 2.93% ZPR) and GM (IP 6.30% vs. 6.76% ZPR). In the Pinot Gris vineyard, the control plots infestation rate was a little higher, especially at DM (21.83% on grapes). PM attack rate in the control grapes was 14.22%, and the GM infestation rate was 11.56%. Differences in attack rates on grapes were noticed (at DM IP 1.89% vs. 4.22% ZPR; at PM IP 5.10% vs. 5.23% ZPR, at GM IP 4.88% vs. ZPR 6.42%) but were not statistically significant. The DM and PM infestation rates were equally severe on leaves and grapes in the Sauvignon vineyard (see Table 6). The GM attack rate at the Sauvignon control plot was 11.18%. The differences between ZPR and IP were small and statistically non-significant. The highest difference was noticed at GM (IP 3.30% vs. ZPR 6.76%). In the Merlot vineyard in 2022, the weather conditions were suitable for disease development. The DM control plots infestation rate on the grapes was over 60%. PM and GM infections were at a lower level but were present in a significant amount of bunches. The differences between IP and ZPR plots were not statistically different for any of the studied diseases (see Table 6). Results for all four varieties demonstrate a particular increase in disease infestation rate due to the ZPR implementation, but in general, the rate of increase is not statistically significant. The population of pests was small and did not contribute significantly to disease development or yield loss.

Table 6. Disease infestation rates (% infested area ± SE) at harvest for two grape protection systems (ZPR—0-pesticide residue protection; IP—integrated protection) in four grape varieties.

Grape Variety	Variant	*Plasmopara viticola* DM Leaf	*Plasmopara viticola* DM Grapes	*Uncinula necator* PM Leaf	*Uncinula necator* PM Grapes	*Botrytis cinerea* GM Grapes
Rebula	ZPR	0.25 ± 0.09 b	1.89 ± 0.17 b	2.45 ± 0.67 b	2.93 ± 0.36 b	6.76 ± 1.04 b
	IP	0.46 ± 0.08 b	2.10 ± 0.20 b	2.89 ± 0.49 b	2.11 ± 0.57 b	6.30 ± 0.95 b
	Control	20.85 ± 1.76 a	13.85 ± 1.93 a	32.60 ± 3.99 a	12.05 ± 2.31 a	16.18 ± 2.71 a
Pinot Gris	ZPR	7.51 ± 1.06 b	4.22 ± 0.88 b	5.78 ± 0.77 b	5.23 ± 0.84 b	6.42 ± 0.84 a
	IP	3.12 ± 0.88 b	1.89 ± 0.07 b	5.64 ± 0.71 b	5.10 ± 0.44 b	4.88 ± 1.02 a
	Control	33.68 ± 3.23 a	21.83 ± 3.15 a	18.25 ± 2.73 a	14.22 ± 1.19 a	11.56 ± 2.95 a
Sauvignon	ZPR	3.56 ± 0.88 b	1.90 ± 0.46 b	4.83 ± 0.81 b	4.89 ± 0.89 b	6.76 ± 1.42 ab
	IP	2.45 ± 0.29 b	2.10 ± 0.40 b	4.00 ± 1.32 b	3.90 ± 0.42 b	3.30 ± 0.81 b
	Control	23.6 ± 4.58 a	20.0 ± 1.88 a	23.55 ± 1.73 a	17.55 ± 4.92 a	11.18 ± 1.27 a
Merlot	ZPR	9.03 ± 0.80 b	6.32 ± 0.47 b	1.26 ± 0.22 b	1.99 ± 0.11 b	1.05 ± 0.16 b
	IP	6.62 ± 1.02 b	5.1 ± 0.86 b	0.92 ± 0.44 b	1.58 ± 0.24 b	0.76 ± 0.16 b
	Control	78.97 ± 3.09 a	61.0 ± 3.16 a	8.74 ± 0.48 a	7.13 ± 0.24 a	3.63 ± 0.52 a

Means marked with the same letters within the same parameters and grape variety are not significantly different according to the Tukey HSD test ($p < 0.05$).

3.3. Results of Yield and Financial Loss Analysis

The results of the yield assessments are presented in Table 7. In the Rebula variety, the differences in the average amount of yield (9636 kg ha^{-1} IP vs. 9269 kg ha^{-1} ZPR), TSS (88.50 °Oe IP vs. 87.33 °Oe ZPR), and in total acidity TA (7.45 gL^{-1} IP vs. 8.00 g L^{-1} ZPR) were not statistically significant. The average yield loss caused by the implementation of ZPR amounted to 367 kg ha^{-1}, and the financial loss was EUR 326 ha^{-1}. Similar results were obtained in Pinot Gris, in which differences in the average amount of yield (6295 kg ha^{-1} IP vs. 6236 kg ha^{-1} ZRP), TSS (84.60 °Oe IP vs. 84.80 °Oe ZRP), and total acidity TA (10.08 g L^{-1} IP vs. 10.05 g L^{-1} ZRP) were also not statistically significant. The implementation of the ZPR concept caused a non-significant loss of yield, amounting to 59 kg ha^{-1}, and a financial loss of EUR 78 ha^{-1}. In the Sauvignon variety, the ZPR concept did not reduce the average yield significantly (10181 kg ha^{-1} IP vs. 9772 kg ha^{-1} ZPR; −410 kg ha^{-1} loss). The reduction in average TSS content (104.6 °Oe IP vs. 91.8 °Oe ZRP) and the increase in TA (8.00 g L^{-1} IP vs. 10.22 g L^{-1} ZPR) were significant. The implementation of the ZPR practice decreased the grape quality. The financial loss in Sauvignon, due to the performance of ZPR, amounted to EUR 267 ha^{-1}. The average yield of Merlot grapes in 2022 was high because the vine development conditions were suitable despite the drought. The ZPR implementation did not significantly reduce the amount of yield (22,754 kg ha^{-1} IP vs. 22,548 kg ha^{-1} ZRP) or grape quality. The average TSS content (96.25 °Oe IP vs. 96.63 °Oe ZPR) and TA of grapes (5.19 g L^{-1} IP vs. 5.53 g L^{-1} ZPR) were similar. Because of the higher yield and higher costs of the spray program, the nominal financial loss in Merlot EUR 437 ha^{-1} was higher than in the other three varieties in season 2021.

3.4. Pesticide Residues in Grapes

Results about the concentration of pesticide residues in grapes at harvest are presented in Tables 8–11. 13 active substances were applied during the 2021 season in the Rebula vineyard (see Table 8). On average, 8.0 a.s. with a concentration above the 0.001 mg kg^{-1} limit were found in IP and 7.0 in the ZPR grapes. In 3 of the detected a.s. (cyflufenamid, folpet and mandipropamid), the concentration was significantly lower in ZPR grapes than in IP grapes. Concentration reduction rates ranged from 24% to 90%. The concentrations of azoxystrobin, meptyldinocap, difenconazole, and penconazol fell under the 0.001 mg kg^{-1} level (marked with <0.001 ND). It is interesting that no fungicide penconazol at ZPR was detected, despite the fact that it was applied quite late in the season. With the ZPR system, only two-thirds of the a.s. were at a level below 0.01 mg kg^{-1}, and with the IP system, only three a.s. residues were below that level. The basic concept of 0.0-residue has not been fully achieved, i.e., all a.s. residues in grape shells being below a concentration level of 0.01 mg kg^{-1}. Al-fosetyl, flupyradifuron, and cyflufenamid were over the limit of 0.01 mg kg^{-1}.

Table 7. Yield and must parameters (mean ± SE) (TSS—total soluble solids, TA—total acidity) for two grape protection systems (ZPR—0-pesticide residue protection; IP—integrated protection) in four grape varieties.

Variant	Healthy Grapes kg/ha	TSS Oe°	TA g/L	Value of Grapes (*VG*) EUR/ha	Cost of Spray Program EUR/ha (*CS*)	Financial Loss EUR/ha (*VG* IP–*VG* ZPR) + (*CS* ZPR–*CS* IP)
Rebula; harvest 28 September 2021; price of 1 kg of grape EUR 0.65						
ZPR	9269 ± 235 a	87.3 ± 1.37 a	8.00 ± 0.26 a	6025 ± 153 a	808	239 + 87 = 326
IP	9636 ± 295 a	88.5 ± 0.56 a	7.45 ± 0.23 a	6264 ± 192 a	721	/
Sauvignon; harvest 21September 2021; price of 1 kg of grape EUR 0.70						
ZPR	9772 ± 189 a	91.8 ± 2.30 b	10.22 ± 0.22 a	6840 ± 132 a	743	287–20 = 267
IP	10,181 ± 272 a	104.6 ± 1.28 a	8.00 ± 0.2 b	7127 ± 190 a	763	/
Pinot Gris; harvest 9 September 2021; price of 1 kg of grape EUR 0.70						
ZPR	6236 ± 299 a	84.8 ± 2.10 a	10.05 ± 0.25 a	4366 ± 210 a	771	41 + 37 = 78
IP	6295 ± 231 a	84.6 ± 2.23 a	10.08 ± 0.18 a	4407 ± 162 a	734	/
Merlot; harvest 3 October 2022; price of 1 kg of grape EUR 0.65						
ZPR	22,548 ± 1173 a	96.63 ± 1.22 a	5.53 ± 0.14 a	14656 ± 763 a	2024	134 + 303 = 437
IP	22,754 ± 1596 a	96.25 ± 0.75 a	5.19 ± 0.09 a	14790 ± 1038 a	1721	/

Means marked with the same letters within the same parameters and grape variety are not significantly different according to the independent-sample t-test ($p < 0.05$).

Table 8. Average concentration (mean ± SE) of pesticide residues in Rebula grapes. A result of <0.001 ND means that a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR mg/kg	IP mg/kg	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	<0.001 ND	/
Al-fosetyl	<0.001 ND	<0.001 ND	/
Al-fosetyl + metabolites	0.7663 ± 0.067 a	1.327 ± 0.289 a	42.25
Phosphonic acid	0.5667 ± 0.050 a	0.9833 ± 0.210 a	42.36
Ciflufenamid	0.028 ± 0.001 b	0.039 ± 0.003 a	28.20
Difenconazole	<0.001 ND	<0.001 ND	/
Emamectin	<0.003	<0.003	/
Fludioxonil	0.0085 ± 0.00454 a	0.0157 ± 0.00067 a	45.85
Azoxystrobin	<0.001 ND	<0.001 ND	/
Flupyradifurone	0.0222 ± 0.016 a	0.0393 ± 0.009 a	43.51
Folpet	0.009 ± 0.002 b	0.095 ± 0.015 a	90.52
Mandipropamid	0.003 ± 0.0004 b	0.0122 ± 0.002 a	75.41
Meptyldinocap	<0.001 ND	<0.001 ND	/
Metalaxyl-m	0.0033 ± 0.001 a	0.0049 ± 0.0002 a	32.65
Penconazole	<0.001 ND	0.008 ± 0.001	≃88.75
Zoxamide	0.0044 ± 0.0003 a	0.0058 ± 0.0008 a	24.13
AN of found a.s. > 0.01 mg/kg	3.00 ± 0.58 b	4.67 ± 0.33 a	35.76
AN of found a.s. > 0.001 mg/kg	7.00 ± 0.00 a	8.00 ± 0.00 a	12.50

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

Table 9. Average concentration (mean ± SE) of pesticide residues in Pinot Gris grapes. A result of <0.001 ND means that a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR mg/kg	IP mg/kg	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	0.01127 ± 0.0024	≃92.01
Al-fosetyl	<0.001 ND	<0.001 ND	/
Al-fosetyl + metabolites	0.009 ± 0.003 a	0.011 ± 0.009 a	18.18
Phosphonic acid	0.003 ± 0.001 a	0.007 ± 0.002 a	57.14
Ametoctradin	0.00833 ± 0.0019 b	0.0179 ± 0.0087 a	53.46
Boscalid	0.0034 ± 0.0007 b	0.0607 ± 0.01 a	94.39
Difenconazole	<0.001 ND	<0.001 ND	/
Dimetomorph	0.0066 ± 0.001 b	0.01273 ± 0.003 a	48.15
Dithianon	<0.001 ND	<0.001 ND	/
Flupyradifurone	0.00333 ± 0.0006 a	0.00503 ± 0.001 a	33.79
Fluxapyroxad	<0.003	<0.003	/
Kresoxim-methyl	<0.001 ND	<0.001 ND	/
Metrafenone	<0.001 ND	0.061 ± 0.007	≃98.52
Pyraclostrobin	0.0058 ± 0.0004 b	0.01967 ± 0.004 a	70.51
AN of found a.s. > 0.01 mg/kg	0.33 ± 0.33 b	5.67 ± 0.33 a	94.17
AN of found a.s. > 0.001 mg/kg	7.00 ± 0.00 b	9.00 ± 0.00 a	22.22

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

Table 10. Average concentration (mean ± SE) of pesticide residues in Sauvignon grapes. A result of <0.001 ND means that a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
Al-fosetyl	0.019 ± 0.011 a	0.038 ± 0.017 a	50.00
Al-fosetyl + metabolites	2.100 ± 0.176 a	2.900 ± 0.223 a	27.58
Phosphonic acid	0.750 ± 0.033 a	0.900 ± 0.080 a	16.60
Ametoctradin	<0.003	0.0086 ± 0.002	/
Boscalid	<0.003	0.003 ± 0.003	/
Azoxystrobin	<0.001 ND	<0.001 ND	/
Difenconazole	<0.001 ND	<0.001 ND	/
Dimetomorph	<0.003	<0.003	/
Fluopyram	<0.003	<0.003	/
Fluopicolide	<0.003	<0.003	/
Flupyradifurone	<0.003	<0.003	/
Fluxapyroxad	<0.003	<0.003	/
Folpet	0.006 ± 0.002 b	0.018 ± 0.004 a	66.66
Iprovalicarb	<0.001 ND	<0.003	/
Mandipropamid	<0.003	0.029 ± 0.004	/
Metrafenone	<0.001 ND	<0.001 ND	/
Tebuconazole	<0.001 ND	0.011 ± 0.002	≃91.81
Zoxamide	0.0054 ± 0.0016 a	0.0084 ± 0.0043 a	35.71
Trifloxystrobin	<0.001 ND	0.009 ± 0.0006 a	≃90.00
AN of found a.s. > 0.01 mg/kg	1.33 ± 0.38 b	4.33 ± 0.38 a	69.28
AN of found a.s. > 0.001 mg/kg	7.33 ± 0.88 b	10.33 ± 0.88 a	29.04

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

Table 11. Average concentration (mean ± SE) of pesticide residues in Merlot grapes. A result of <0.001 ND means that a.s. was not detected at level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	0.0057 ± 0.0009	≃84.21
Al-fosetyl	<0.001 ND	<0.001 ND	/
Al-fosetyl + metabolites	4.400 ± 2.570 b	13.730 ± 2.160 a	67.95
Phosphonic acid	5.810 ± 2.610 a	10.230 ± 1.610 a	43.20
Ametoctradin	<0.001 ND	0.180 ± 0.036	≃99.50
Boscalid	<0.001 ND	0.011 ± 0.003	≃91.81
Cyflufenamid	0.010 ± 0.004 a	0.030 ± 0.014 a	66.66
Cymoxanil	<0.001 ND	<0.001 ND	/
Delatamethrin	<0.001 ND	<0.001 ND	/
Difenconazole	0.015 ± 0.006 a	0.041 ± 0.019 a	63.41
Dimetomorph	<0.001 ND	0.050 ± 0.015 a	≃98.20
Dithianon	0.002 ± 0.001 b	0.006 ± 0.001 a	66.66
Fenpyrazamine	<0.001 ND	0.011 ± 0.004 a	≃91.81
Fluopicolide	0.015 ± 0.002 a	0.025 ± 0.007 a	40.00
Kresoxim-methyl	<0.001 ND	<0.001 ND	/
Mandipropamid	<0.003	0.024 ± 0.0078	/
Meptyldinocap	<0.001 ND	<0.001 ND	/
Metrafenone	<0.001 ND	0.012 ± 0.002	≃92.50
Pyraclostrobin	<0.001 ND	0.032 ± 0.009	≃97.18
Pyriofenone	<0.003	0.004 ± 0.0005	/
Proquinazide	<0.001 ND	<0.001 ND	/
Zoxamide	0.027 ± 0.0100 a	0.040 ± 0.0130 a	32.50
Spinosad	<0.001 ND	<0.001 ND	/
AN of found a.s. > 0.01 mg/kg	4.25 ± 1.03 b	9.75 ± 0.48 a	56.41
AN of found a.s. > 0.001 mg/kg	6.75 ± 0.48 b	15.00 ± 0.00 a	55.00

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

The analysis results of the Pinot Gris grapes are presented in Tables 9 and 12; active substances were applied during the 2021 season. On average, 7.00 a.s. at a level higher than 0.001 mg/kg were found in ZPR grapes and 9.00 a.s. in IP grapes. The concentration of difenconazole, metrafenon, ditianon, metiram, and kresoxim-methyl fell to such a low level that there was no detection (below 0.001 mg kg^{-1}; marked with <0.001 ND). At 5 a.s., the ZPR system resulted in a decrease in residue concentration (metiram, ametoctradin, boscalid, dimethomorph, metrafenone, and pyraclostrobin). In grapes from the ZPR plots, practically all residues were below the level of 0.01 mg kg^{-1}, and in the IP system, only five a.s. residues were below this level. The basic concept of ZPR has been achieved in the ZPR grapes, i.e., all residues were below 0.01 mg kg^{-1}. Different levels of degradation speed among different a.s. were noticed. Flupyradifuron degraded faster than we expected. Metrophenone disintegrated quickly. Despite its use at the end of July, the concentration was low (0.0061 mg kg^{-1} in IP). Amethoctradine and dimethomorph degraded slowly. Metiram was degraded at a moderate speed. The same applies to fluxapiroxad.

The analysis results of Sauvignon grapes are presented in Table 10. The spraying program for the Sauvignon variety was very intensive, and we found many residues of a.s. We applied 16 different a.s. In the IP grapes, 10.33 residues above the limit of 0.001 mg/kg were found on average, of which two residues were at a level above 0.01 mg kg^{-1}. In the ZPR grapes, 7.33 residues above 0.001 mg kg^{-1} were found on average, of which 1 residue (Al-fosetyl) was above 0.01 mg kg^{-1}. We did not reach the 0.0-residue goal completely because there were some residues found above the 0.01 mg kg^{-1} level. Residues were generally at a very low level. An extensive reduction of concentration was achieved, especially for the substances fluopyram, flupyradifuron, folpet, and fluopicolid. Five theoretically fairly persistent substances were not found at a level higher than 0.001 mg kg^{-1} (metrafenone, azoxystrobin, difenconazole, tebuconazole, and trifloxystrobin).

Table 12. Average concentration (mean ± SE) of pesticide residues in Rebula wine. A result of <0.001 ND means that a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	<0.001 ND	/
Al-fosetyl	0.008 ± 0.003 b	0.150 ± 0.130 a	94.66
Al-fosetyl + metabolites	3.300 ± 1.270 a	5.200 ± 0.400 a	36.53
Phosphonic acid	2.450 ± 0.950 a	4.250 ± 0.530 a	42.35
Azoxystrobin	<0.001 ND	0.011 ± 0.010	≃91.81
Cyflufenamid	<0.001 ND	<0.003	/
Difenconazole	<0.001 ND	<0.001 ND	/
Emamectin	<0.001 ND	<0.001 ND	/
Flupyradifurone	<0.003	<0.003	18.18
Folpet	<0.001 ND	0.004 ± 0.001	≃77.50
Mandipropamid	<0.001 ND	0.005 ± 0.002	≃82.00
Meptyldinocap	<0.001 ND	<0.001 ND	/
Metalaxyl-M	<0.003	<0.003	/
Penconazole	<0.001 ND	<0.001 ND	/
Zoxamide	<0.001 ND	<0.001 ND	/
AN of found a.s. > 0.001 mg/kg	1.50 ± 0.58 b	4.25 ± 0.96 a	64.70

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

The results of the Merlot grape analysis from season 2022 are presented in Table 11. The beginning of the 2022 season was rainy, and fungicides were therefore applied frequently. We applied many different a.s. to obtain much data on a.s. dissipation rates. A total of 21 different a.s. were applied. In the IP program, 15 were detected, on average, at levels higher than 0.001 mg kg^{-1}, and in the ZPR, 6.75 a.s. were detected. The ZPR program reduced the number of detected substances significantly. Implementing the ZPR program reduced the concentration of the following a.s.: metiram, Al-fosetyl, ametoctradin, boscalid, dithianon, difenconazole, dimethomorph, metrafenone, piraclostrobin, and pyriofenone. Reduction rates were in range between 30% and 90% (see Table 11). The goal to have all residues at a level lower than 0.01 mg kg^{-1} in ZPR was not achieved, but a decrease from 9.75 a.s. found on average at IP to 4.25 a.s. found in ZPR grapes was significant.

3.5. Pesticide Residues in Wine

The results of the residue analysis in wine are presented in Tables 12–15. In the Rebula wine from the ZPR plots, only Al-fosetyl metabolites, flupyradifurone, and metalaxyl-M were found at a level higher than 0.001 mg kg^{-1} (see Table 12). In the IP wine, residues of azokxystrobin, Al-fosetly, cyflufenamid, flupyradifurone, folpet, mandipropamid, and metalxyl-M were found. In the IP wine, 4.25 a.s. with a concentration over 0.001 mg kg^{-1} and 1.5 a.s. at ZPR were found on average. The average number of found a.s. over the level 0.001 mg kg^{-1} was 64.7% reduced at ZPR. With the ZPR system in the Rebula plots, the goal of all residues being below 0.001 mg kg^{-1} was almost achieved but was not reached completely. The substances flupyradifuron and Al-fosetyl were used a little too late in the season. In one of the four repetitions in ZPR, the goal of all a.s. being at a level lower than 0.001 mg kg^{-1} was reached.

Table 13. Average concentration (mean ± SE) of pesticide residues in Sauvignon wine. Result < 0.001 ND means a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	<0.001 ND	/
Al-fosetyl	0.033 ± 0.016 b	0.910 ± 0.438 a	96.33
Al-fosetyl + metabolites	2.420 ± 0.810 b	4.930 ± 0.357 a	50.81
Phosphonic acid	1.730 ± 0.598 b	4.000 ± 0.280 a	56.69
Ametoctradin	<0.001 ND	<0.003	≃77.50
Azoxystrobin	<0.001 ND	<0.001 ND	/
Difenconazole	<0.001 ND	<0.001 ND	/
Dimetomorph	<0.001 ND	0.004 ± 0.001	≃77.50
Fluopyram	<0.001 ND	<0.003	≃55.00
Fluopicolide	<0.001 ND	<0.003	≃59.09
Flupyradinefurone	<0.001 ND	<0.001 ND	/
Fluxapyroxad	<0.001 ND	<0.003	/
Folpet	<0.001 ND	0.008 ± 0.0006	≃88.75
Iprovalicarb	<0.001 ND	<0.003	/
Mandipropamid	<0.001 ND	<0.003	/
Metrafenone	<0.001 ND	<0.001 ND	/
Tebuconazole	<0.001 ND	0.011 ± 0.001	≃91.81
Trifloxystrobin	<0.001 ND	<0.001 ND	/
AN of found a.s. > 0.001 mg/kg	1.00 ± 0.00 b	7.50 ± 1.23 a	86.67

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN—average number of found active substances.

Table 14. Average concentration (mean ± SE) of pesticide residues in Pinot Gris wine. Result < 0.001 ND means a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	<0.001 ND	/
Al-fosetyl	0.079 ± 0.030 a	0.134 ± 0.016 a	41.04
Al-fosetyl + metabolites	10.600 ± 2.220 b	62.500 ± 20.362 a	83.04
Phosphonic acid	7.720 ± 1.712 b	38.650 ± 13.818 a	80.02
Ametoctradin	<0.003	0.005 ± 0.001	/
Boscalid	<0.001 ND	0.004 ± 0.002	≃77.50
Difenconazole	<0.001 ND	<0.001 ND	/
Dimetomorph	<0.003	0.003 ± 0.0003	/
Dithianon	<0.001 ND	<0.001 ND	/
Flupyradifurone	<0.003	<0.003	/
Fluxapyroxad	<0.001 ND	<0.001 ND	/
Kresoxim-methyl	<0.001 ND	<0.001 ND	/
Metrafenon	<0.001 ND	<0.001 ND	/
Pyraclostrobin	<0.001 ND	<0.001 ND	/
AN of found a.s. > 0.001 mg/kg	3.00 ± 0.71 a	4.50 ± 0.50 a	33.33

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

Table 15. Average concentration (mean ± SE) of pesticide residues in Merlot wine. A result of <0.001 ND means that a.s. was not detected at a level higher than 0.001 mg kg^{-1}. /—concentration reduction rate and significance of difference between IP (integrated) and ZPR (0-pesticide residue) means cannot be calculated. Pesticide concentration reduction rate (%) = 100 − ((ZPR/IP) × 100) (see explanation in Section 2.4).

Active Substance	ZPR (mg/kg)	IP (mg/kg)	% Reduction Rate
∑ Dithiocarbamates	<0.001 ND	<0.001 ND	/
Al-fosetyl	0.00325 ± 0.003 b	0.0210 ± 0,0025 a	84.52
Al-fosetyl + metabolites	1.475 ± 0.871 b	8.625 ± 0,427 a	82.85
Phosphonic acid	1.100 ± 0.647 b	6.500 ± 0.303 a	83.07
Ametoctradin	<0.001 ND	0.0582 ± 0.024	≃98.45
Boscalid	<0.001 ND	<0.003	/
Cyflufenamid	<0.001 ND	<0.001 ND	/
Cymoxanil	<0.001 ND	<0.001 ND	/
Delatamethrin	<0.001 ND	<0.001 ND	/
Difenconazole	<0.001 ND	<0.001 ND	/
Dimetomorph	<0.001 ND	<0.003	/
Dithianon	<0.001 ND	<0.001 ND	
Fenpyrazamine	<0.001 ND	<0.003	/
Fluopicolide	<0.003	<0.003	/
Kresoxim-methyl	<0.001 ND	<0.001 ND	/
Mandipropamid	<0.003	<0.003	/
Meptyldinocap	<0.001 ND	<0.001 ND	/
Metrafenone	<0.001 ND	<0.003	/
Pyraclostrobin	<0.001 ND	<0.003	/
Pyriofenone	<0.001 ND	<0.001 ND	/
Proquinazide	<0.001 ND	<0.001 ND	/
Zoxamide	<0.001 ND	<0.003	/
Spinosad	<0.001 ND	<0.001 ND	/
AN of found a.s. > 0.001 mg/kg	2.25 ± 0.25 b	9.75 ± 0.25 a	76.92

Means marked with the same letters at a specific a.s. do not differ significantly according to the independent-samples *t*-test ($p < 0.05$). AN is the average number of found active substances.

The results for the Sauvignon wine are presented in Table 13. In the Sauvignon wine from the ZPR managed plots, only Al-fosetyl metabolites were found. If we did not use Al-fosetyl, we would produce wine practically without pesticide residues and reach the 0-pesticide residue requirements. In the IP Sauvignon wine, 7.5 residues were found at levels higher than 0.001 mg kg^{-1} and 1 a.s. in ZPR on average. The average number of found a.s. over the level 0.001 mg kg^{-1} was reduced by 86.67% at ZPR. Here, we can see a clear difference between the results in the IP and ZPR concepts. The only a.s. found in ZPR was Al-fosetyl.

The results for Pinot Gris are presented in Table 14. In the Pinot wine from the ZPR plots, four residues were found (Al-fosetyl, ametoctradin, dimethomorph, and flupyradifurone). The goal of 0-pesticide residue requirements was not reached. In the IP Pinot wine, 4.5 a.s. were found with concentration over 0.001 mg kg^{-1}, and in ZPR wine, 3.0 a.s. on average. In Pinot we had the worst results of all trials. The average number of found a.s. over the level 0.001 mg kg^{-1} was reduced by only by 33.33% in ZPR. Maybe the reason for that was the grapes of the Pinot being harvested earlier than the grapes of the other tested varieties. The available residue deterioration time was shorter than in other varieties.

The results for the Merlot wine are presented in Table 15. In the Merlot plots, we applied many a.s., and therein lies the reason why many residues were found at a moderate concentration level. In the IP wine, we found 9.75 residues, and in ZPR, 2.25 residues were above the level of 0.001 mg kg^{-1} on average. We did not reach the ZPR goal, but the difference between IP and ZPR was statistically significant. In ZPR wine, we found only residues of Al-fosetyl, fluopicolide, and mandipropamid at a level between 0.003 and 0.001 mg kg^{-1}. We detected only 3 a.s. out of 21 applied. This is a suitable result; we almost reached the goal of ZPR. It looks as though the mentioned three substances have quite a high grape-to-wine transfer rate.

4. Discussion

4.1. Efficacy of Disease and Pest Control

The downy mildew disease pressure in the 2021 season was moderate, and in 2022, high. Despite the reduction in the number of conventional pesticide applications and of the cumulative dose of pesticides, of a.s. per ha per season for approx. 20–25% and the supplementation of chemical pesticides with alternative products, we provided a high level of protection for the grapevine. Only a statistically non-significant increase in disease infestation rate in all three studied diseases was noticed. The differences in infestation rates at IP and ZPR plots were mostly not significant. Some studies demonstrate the consequences of different levels of pesticide reduction on the efficacy of grapevine pest and disease control [23–31]. We cannot compare mentioned studies dealing with the development of new production methods with our research directly because we focused only on the alteration of the spray program as the only measure to reach a higher level of sustainability of grape production. In other studies, they studied the broader spectrum of vineyard management strategies, plus pesticide reduction. We think the 0-pesticide residue approach fits in with the new developments of IPM, enabling a more sustainable integrated production. The efficacy we achieved with ZPR in our trials is close to the level of standard integrated spray programs with incorporated alternative plant protection products, as reported by [14,24,26–28].

The comparison results between the IP and ZPR systems also depend on how well and intensive the IP spray program is. If we have a highly efficient IP spray program, the difference to ZPR will be bigger than if we compare less efficient IP spray programs to ZPR. Disease pressure has a very significant influence. When the disease pressure is moderate, more favorable results for ZPR are obtained. Considering short-term results, it seems that the ZPR protection system is equally efficient as standard IP. Some grape growers in the region where the trials were performed executed IP protection trials with a significant reduction in the number of pesticide applications per season for a couple of years. Their approach was to start spraying as late as possible and to cancel the last 2–3 sprays before harvest. By doing this, they reduced the annual dose of applied pesticide a.s. per ha for approximately 30%. The described practice resulted in a significant increase in infestation rates of *Phomopsis viticola* (Sacc.) Sacc., *Elsinoë ampelina* Shear, *Guignardia bidwellii* (Ellis) Viala and Ravaz, and sour bunch rot (combined yeast and bacterial infection) (oral information provided by growers). The same problems arose in growing PIWI-resistant grape varieties in systems with any application of pesticides (oral information provided by growers). Considering this information, the important question accompanying the introduction of ZPR is, what are the long-term consequences of a significant chemical pesticide use reduction rate for the health status and fitness of the vineyards, also considering climate change and the introduction of new diseases and pests? In the short term, it looks like ZPR holds a population of harmful organisms at an acceptable level, but we have to be aware of the serious threats in grape growing, such as phytoplasma diseases (Flavescence dorée) [32], rickettsia caused by Pierce's decline disease (*Xylella fastidiosa* Wells et al.) [33], and trunk diseases from the ESCA complex [34]. These diseases, if not held at a low population level, can completely destroy vineyards. In the literature, we can mostly find results of pesticide reduction studies lasting 2–3 years in integrated production [4,35] or studies about conversions to organic production [24,25]. Studies that last long and analyze long time scale dynamics of grapevine pests and diseases are rare, and it is therefore not possible to predict the consequences of long-term ZPR system usage. Long-term studies are needed. Pragmatically speaking, we could say that if organic vineyards sustain the pressure of diseases, then the 0-pesticide residue vineyards with reduced pesticide usage will also sustain. The long-term consequences are also related to the availability of efficient alternative plant protection products. If these are available and we start to grow more resistant grape varieties, then there is no fear of a large-scale increase in disease and pest populations.

4.2. Yield

The trials demonstrated that the implementation of the ZPR concept causes a small yield reduction between 2% and 5% due to the reduced disease and pest control efficiency. In one of the four trials, the quality of must was slightly reduced, but in three of four, it was not. We expect that the ZPR wine has a comparable sensorics quality to the IP wine. In the literature, many sources are available on the comparisons between integrated and organic grape production. Reports are also available on the newly developed low-input integrated grape production with significantly reduced intensity of pesticide use. Our ZPR-tested protection system can be compared with such low-input production trials. One of the latest publications on low-input grape growing was published by Perria et al. in 2022 [35]. They tested the "Green Grapes" concept. The significant reduction of the pesticide concept was feasible only in low or moderate disease pressure conditions. The overall results of the three-year study indicated that disease management protocols based solely or predominantly on the use of alternative and resistance-inducing substances do not appear to ensure effective protection against diseases in disease-susceptible varieties. The trials have confirmed that we need highly efficient control at the beginning of the season and that the intensity of pesticide use can possibly be significantly reduced in the second part of the season. The conclusions in these other studies resemble the results of our research. The other two publications that are comparable with our results were published by Pertot et al. in 2017 [1] and Fouillet et al. in 2022 [4]. They studied new strategies for a grapevine cropping system redesign and found out that cropping system redesign entails drastic changes in the vineyards; new, less-susceptible grape varieties and new non-chemical plant protection products with higher levels of efficacy than the existing ones would have to be used since most of the existing alternative solutions are only partially effective. This means that pest and disease pressure is reduced, but pests are not eradicated to a level where we could guarantee avoiding economically relevant yield losses. IPM strategies were mentioned similarly to ZPR but were not considered as 0-pesticide residue production.

4.3. Financial Loss

We were not able to find any scientific reports on the feasibility of the ZPR system. The ZPR system is in its early stages of development. Some wine producer websites, for example, vitisphere.com or decanter.com, have indicated the possibility that 0-pesticide residue wines could be sold for a 10–15% higher price than standard wines from integrated production. They also posted that the level of pesticide residues in ZPR wines is comparable to wines from organic production and think that the quality of ZPR wines is comparable to or of higher quality than wines from organic production. In the case of wines selling at a 10% higher price than standard conventional IP wines, grape growers could very likely compensate for a smaller yield reduction (2–3%) and a 5% increase in pest and disease control costs. Some studies show that growers are very reluctant to accept the risks involved in introducing new cropping systems [36]. We did the simple compensation calculation for our four trials considering the obtained yields, pressing efficacy of 75% (grape/must ratio), and a price of EUR 4.5 per 1 L of bottled IP wine. The results indicate that an equal financial result at IP and ZPR production is reached if the ZPR Rebula wine is sold at a 3.95% higher price, the Pinot wine at a 0.94% higher price, the Sauvignon wine at a 4.19% higher price and the Merlot at a 0.90% higher price. We believe that such an increase in price can be realized by innovative marketing. The professionally performed ZPR concept seems to be feasible. It could be especially feasible if supported with subsidies issued for reducing pesticide use. Research shows that by using advanced prognostic models to predict the need for spraying and by using improved application techniques, it is possible to reduce pesticide use by as much as

40% and production costs by up to 20% [36,37]. If we combine the ZPR concept and the mentioned technical support systems, then we can improve the economics of ZPR cultivation and probably further reduce pesticide residues in grapes.

4.4. Level of Residue Reduction in Grapes and Wine

Many factors influence pesticide dissipation dynamics from application to harvest (DR) and the transfer rate from grapes to wine (TR) during the winemaking processes. In several scientific publications, much data on DR and TR are available and can serve as tools for decisions on the latest time periods of specific preparation applications in ZPR. Factors that significantly impact DR are: weather, method and timing of pesticide application, pesticide formulation, and chemical properties of pesticide [7–9,12]. Factors that significantly impact the TR are: chemical and physical properties of pesticide (p.e. water solubility and pK_{ow} value (octanol-water partition coefficient), grape pressing technique, methods of wine clearing and filtration, and many others [10,12,13,38–45]. It was proven several times that TR of specific a.s. are lower in red wines than in white wines. The maceration step in the preparation of red wines has a significant impact on residue dissipation/transfer. In this manuscript, we do not present data on the DR and TR we obtained. We tested more than 25 active substances. In half of them, the results are similar to the data obtained by researchers in the abovementioned publications, and in the other half, the differences were quite big (more than $\pm$30%). This means that the data on DR and TR are quite variable, and in order to provide suitable advice to grape growers, local trials need to be carried out for several seasons. The growers should systematically collect data on weather, the timing of pesticide application, and vinification processes, so they can gain the needed experience for planning ZPR spray program usage. It is not an easy task since studies show that growers are very reluctant to implement novelties [37,38]. Any long-term behavioral change in plant protection requires efforts from many stakeholders [37–39].

The goal of our trials was to produce grapes with residues lower than 0.01 mg kg^{-1} and wine with residues lower than 0.001 mg kg^{-1}. The lower concentration of residues in ZPR grapes is a consequence of several factors: on the one hand, prolonged PHI, and on the other hand, changes in residue dissipation kinetics. The range of available alternative plant protection preparations is very wide, and they have different chemical and physical effects on the deposit of pesticides on the surface of vine organs and also on the physiological processes inside the plant tissues [46]. That means that the choice of alternative products for spraying in the second half of the growing season can cause very different impacts on pesticide dissipation kinetics. Many studies are needed to understand the effects of chitosan, laminarins, carbonates, algae and plant extracts, clay minerals, silicon polymers, and many others [47,48]. Some alternative products significantly alter the pH value of plant surfaces, and others act as natural detergents. Humectants increase the penetration of pesticides, plant resins, and silicon polymers and prolong residue deposit stability. The described processes cause a great variability of results and make giving suitable advice very difficult. This means that we need to provide much education for the growers and advisors.

Growing PIWI (in German Pilzwiderstandsfähige Rebsorten) varieties would fit perfectly into the ZPR concept and would make it easier to implement. Grape growers need suitable support in at least two directions. They need information about the dissipation kinetics and grape-to-wine transfer rates of all pesticide substances we use in the vineyard. A decision support system of adopted prolonged pre-harvest waiting intervals (PHI) needs to be developed, so the growers can plan the last possible period of application of a specific pesticide a.s. to reach residue concentrations lower than 0.001 mg kg^{-1}. With many a.s., the PHIs need to be prolonged for at least 2–3 weeks.

The first step of ZPR implementation should be to provide simple, concise information on a.s. that have a fast DR and low TR. As a result of our research, we estimate that a.s. with a TR lower than 10% are usually not found in wine at concentrations higher than

0.001 mg kg^{-1} if we respect the PHI on the pesticide label. Such a.s. are: deltamethrin, emmamectin, azoxystrobin, cyflufenamid, difenconazole, penconazol, krezoxim-methyl, folpet, fluxapyroxad, zooxamid, spinosad, and metalaxyl-M. We have to pay attention to the following a.s. with a TR higher than 20%, which will appear in wine in concentrations higher than 0.001 mg kg^{-1} if the PHI stated on the product label is followed: fluopyram, Al-fosetyl, boscalid, cyprodinil, fludixonil, pyrimethanil, dimethomorph, ametoctradin, tebuconazol, fluopicolid, mandipropamid, and flupyradifurone. As mentioned a.s., we need a significant prolongation of the PHI stated on the pesticide label. Special attention needs to be paid to Al-fosetyl. Our advice is not to use Al-fosetyl in a ZPR system. Residues are easily found in wine despite it being used just early in the season.

Some applications are already available on websites that offer growers calculations of pesticide residue concentrations in wine according to the date of pesticide application and vinification method type. When growers enter the data about the pesticide application dates, they receive information about the expected concentration of pesticide residues in grapes and wine. With such applications, growers can quite precisely determine which preparations they can or cannot use in order to achieve the goal of having all pesticide residues below 0.001 mg kg^{-1}. An example of a freely available smartphone application is available on the website [49].

The second condition for implementing ZPR is a suitable market availability of alternative plant protection preparations from the low-risk substance category and biological pesticides at a sufficiently low competitive price. If the prices of alternative preparations are high, the cost of alternative spray programs could be too high compared to the cost of a standard IP spray program. In such cases, the feasibility of a 0-residue approach decreases. Help in the form of subsidies for the purchase of alternative products is always welcome.

5. Conclusions

Our research aimed to test the ZPR concept's executability and feasibility. The results obtained in the four trials demonstrate that reaching the goal of all residues in wine being at a concentration level lower than 0.001 mg kg^{-1} is not easily achieved when growing disease-susceptible varieties that need to be sprayed frequently. We would have had to restrict the application of chemical pesticides more than we did. ZPR provided suitable diseases control, and yield reduction was not statistically significant. We conducted only four experiments, and from the obtained results, it is not possible to conclude that ZPR offers completely comparable financial results to standard integrated IPM-steered cultivation.

It is necessary to perform a significant number of experiments in order to create a comprehensive opinion on the applicability of the ZPR approach and to provide growers with technical guidance, i.e., provide them rules for the preparation of spray programs based on a.s. dissipation rate data and grape-to-wine residue transfer rate data.

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