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Biological manifestations of three apple cultivars and degree of attack by apple scab and powdery mildew

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Abstract: The study aims to investigate the phenological and reproductive characteristics of three apple cultivars (Melrose, Mutsu, and Florina) and to predict the development of apple scab and powdery mildew using the RIMpro disease and pest prediction model based on meteorological data from a Meteobot weather station. The study was conducted during the period 2021-2024. The trees are in full fruiting, grafted onto MM 106 rootstock, and planted at a distance of 4.5 × 3.0 m. The plantation was maintained using standard technology. The beginning of flowering (BBCH 61) in the studied cultivars was with an interval of 3 days. Mutsu was the most productive cultivar, followed by Florina and Melrose. The damage caused by the economically essential diseases apple scab (*Venturia inaequalis*) and powdery mildew (*Podosphaera leucotricha*) was determined. Mutsu was found to have the highest degree and percentage of apple scab, and Florina was the most susceptible to powdery mildew of the three cultivars studied. Using data from the Meteobot meteorological station and the associated Rimpro forecasting model, fungicide spraying can be reduced to achieve healthier fruit production.

Key words: yield; flowering; *Venturia inaequalis*; *Podosphaera leucotricha*; RIMpro

INTRODUCTION

Modern breeding programs focus on creating cultivars with improved fruit quality, resistance to diseases, pests, and abiotic stress factors, early fruiting, and high productivity (Laurens, 1999; Wicklund et al., 2021; Mamalova, 2021). Recently, apple scab-resistant cultivars were recommended, which allow for a significant reduction in the use of chemical preparations, and in some cases even without fungicide treatment, which also leads to better economic results (Farooqui & Amin Dalal, 2005; Inderbitzin et al., 2019; Höfer et al., 2021; Boboeva, 2023).

Economically, the most important apple diseases are apple scab (*Venturia inaequalis*) (Cooke) Wint, and powdery mildew (*Podosphaera leucotricha*) (Ellis and Everh.) E. S. Salmon. The most widely grown cultivars are highly susceptible to these diseases, and losses can compromise yields unless intensive control is applied (Borovinova, 1994; MacHardy, 1996). In recent years, work has been done on creating and refining predictive models for diseases and pests, aiming to establish the most appropriate times to combat them (Arsevska et al., 2016; Zhelev, 2018). Various prediction models take into account the conditions on which the emergence and development of a given disease or pest depend (Kim et al., 2005; Rossi et al., 2007). Climate change is a crucial factor that underscores the importance of forecasting models. A key aspect of these processes is not only the average levels of precipitation or temperature, but also the occurrence of extreme weather events, such as periods of heavy rainfall followed by drought during atypical times. Precipitation

promotes the development of many diseases in cultivated plants (Zhelev, 2018).

Main strategies for effectively managing apple scab include the use of resistant cultivars, tolerant rootstock, and effective control of primary and secondary infection through the use of an integrated crop management system, biological control, and the use of biotechnological approaches that improve the yield and quality of apple production (Kaymak et al., 2016).

Mitigating yield losses in apple production through the cultivation of varieties with enhanced resistance to apple scab and powdery mildew can significantly benefit both regional and national economies. The implementation of resistant cultivars will reduce pesticide use in apple production, which will both decrease production costs and protect human health and the environment (Delate et al., 2008).

The aim of this study was to evaluate the phonological and reproductive characteristics of three apple cultivars, as well as to predict the development of apple scab and powdery mildew using a disease and pest prediction model.

MATERIAL AND METHODS

The study was conducted in the experimental field of the Institute of Agriculture - Kyustendil during the period 2021 – 2024, with three apple cultivars (Florina, Melrose and Mutsu). Trees were grafted onto MM 106 rootstock and planted in the spring of 2009 at a distance of 4.5 × 3.0 m. Florina was used as the control. Each cultivar was represented by ten trees and each tree was counted as a separate replication. The trees were in a period of full fruiting and were grown using a standard technology. The soil is Chromic Luvisols, slightly sandy-loamy with a neutral reaction. The soil surface in the inter-rows was maintained with regular mowing of the grass with a mulcher, and the row strips were treated once with a total herbicide. Phenological phases were recorded annually according to the BBCH scale (Meier, 2001) - beginning of flowering (BBCH 61), full flowering (BBCH 65), end of flowering (BBCH 69), fruit ripening (BBCH 87), and average fruit yield per tree (kg). The degree of attack by apple scab and powdery mildew was determined on 5 trees of each cultivar by examining 25 leaves, leaf rosettes, and fruits, respectively.

The first visual reading was of the leaf rosettes to establish primary infection - spring reading. The next reading of the leaves was carried out in July (summer reading) to establish secondary infections, and the third reading was performed in the fall - 15-20 days after the end of the last treatment, for a final assessment of the development of the disease. The fruits were inspected at the time of harvest. The leaves and fruits were divided into categories /scores/. The attack rate was calculated by the formula of Townsend and Heuberger, 1967 (Kremer and Unterstenhofer, 1967).

The leaves and fruits were categorized according to the following scoring scale:

0 - no symptoms; 1 - 1–10%; 2 - 10–25%; 3 - 25–50%; 4 - 50–75%; 5 - 75–100% infection.

Plant protection against the main diseases in different years was carried out with a different number of fungicide treatments - 7 in 2021, 6 in 2022, 4 in 2023, and 7 in 2024 using the preparations permitted for the respective disease. During the studied period, contact copper-containing fungicides were used in the “Mouse-ear stage” phenophase (BBCH 54), and from “End of flowering” (BBCH 69) to “Fruit about 80% final size” (BBCH 78), systemic products. During the growing season of 2022 and 2023, contact action sulfur preparations were applied to the Florina cultivar.

In parallel with the visual method, the predictive model of the Dutch company RIMpro was used to predict the development of the relevant apple diseases based on data from the Meteobot meteorological station. The RIMpro model provides various types of information useful for issuing warnings related to apple scab management, such as infection periods, their relative severity, and the estimated time of symptom appearance. It uses meteorological data provided by the Meteobot station (air temperature (°C), leaf wetness duration (hours), and rainfall (mm), which is located 300 m from the studied cultivars.

The data were statistically processed using analysis of variance (ANOVA), and the significance of differences between mean values was determined by Duncan's test $p \leq 0.05$.

RESULTS AND DISCUSSION

For the flowering of fruit trees the average daily temperatures and relative humidity of the air are essential. Under the conditions of the Kyustendil region, flowering usually begins in early April and ends in the first days of May, with significant differences observed between individual years. Thermal conditions in the Kyustendil region during the study years were assessed through temperature sums during the potential growing season (Figure 1).

The last two years were warm, with 2024 having the highest temperature sums during the entire period. From observations on the flowering phenophases, it was found that during the research period, the beginning of flowering in the studied cultivars began earlier by 10-15 days in 2024, compared to the previous two years, which is a result of the extremely high air temperatures in winter and early spring.

On average for the period, the "beginning of flowering" phenophase (BBCH 61) begins earliest in Florina and the interval of 1 to 3 days in the other two cultivars (Table 1). The "end of flowering" phase (BBCH 69) was registered between April 26 and 30, i.e., the flowering duration for the individual cultivars was 11 -13 days.

Data on the productive manifestations of the trees showed some variation in average yields (Table 2).

In 2023, yields were significantly reduced compared to the other two years, which is a result of unfavorable weather conditions in the spring

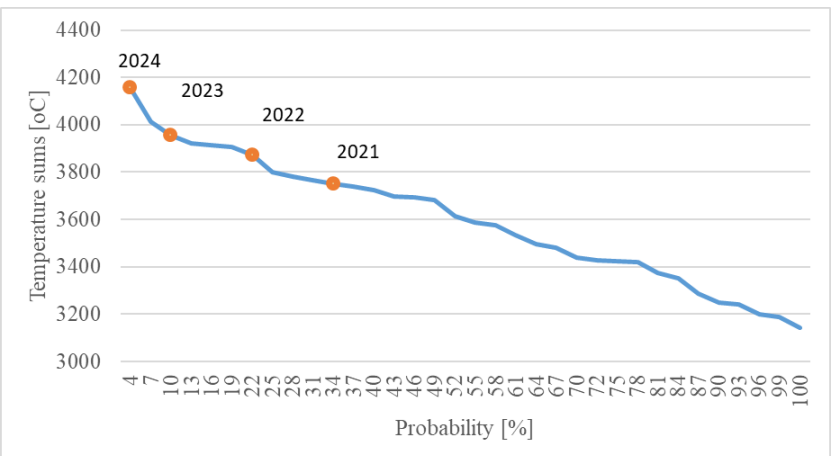

Figure 1. Active temperatures during the potential growing season

Table. 1. Phenological phase of apple cultivars on average for 2022-2024

Cultivar	Flowering phases:			Ripening of fruit (BBCH 87)
	Beginning (BBCH 61)	Full (BBCH 65)	End (BBCH 69)	
Melrose	19.04	21.04	30.04	01.10
Mutsu	17.04	20.04	29.04	30.09
Florina	16.04	19.04	26.04	28.09

during flowering (low average daily temperatures and rainy weather), which led to the impossibility of effective pollination (Figure 2). The highest total 4-year yield was obtained from the Mutsu

Table 2. Average yield of apple cultivars (kg/tree) for 2021-2024

Cultivar	2021	2022	2023	2024	Cumulative (2021-2024)
Melrose	16.3 ab	18.1 ab	2.3 b	21.5 a	58.2 b
Mutsu	15.9 b	22.3 a	3.0 b	23.5 a	64.7 a
Florina (c)	19.4 a	17.0 b	5.0 a	17.5 b	58.9 b

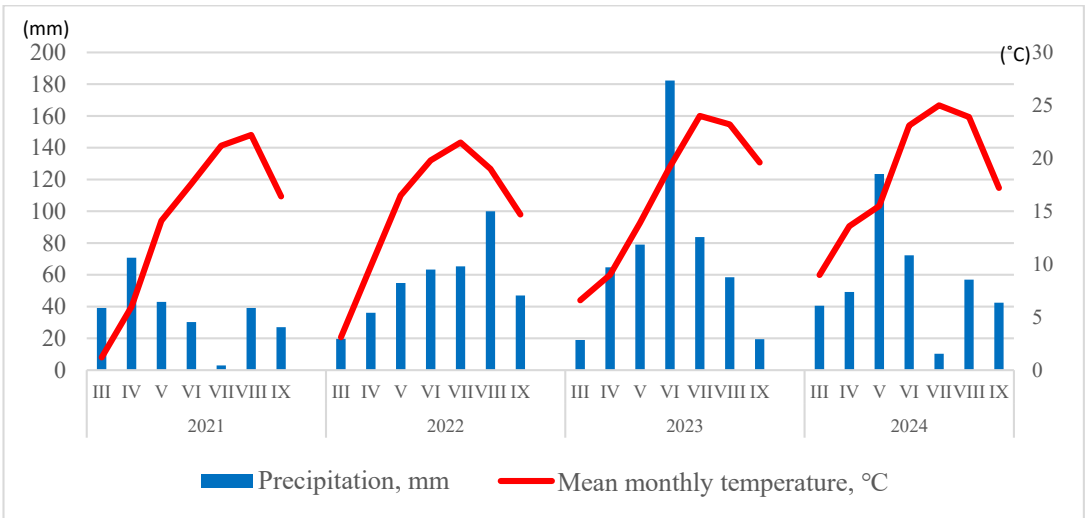

Figure 2. Precipitation amount (mm) and average monthly temperatures (°C) for the period March – September 2021-2024

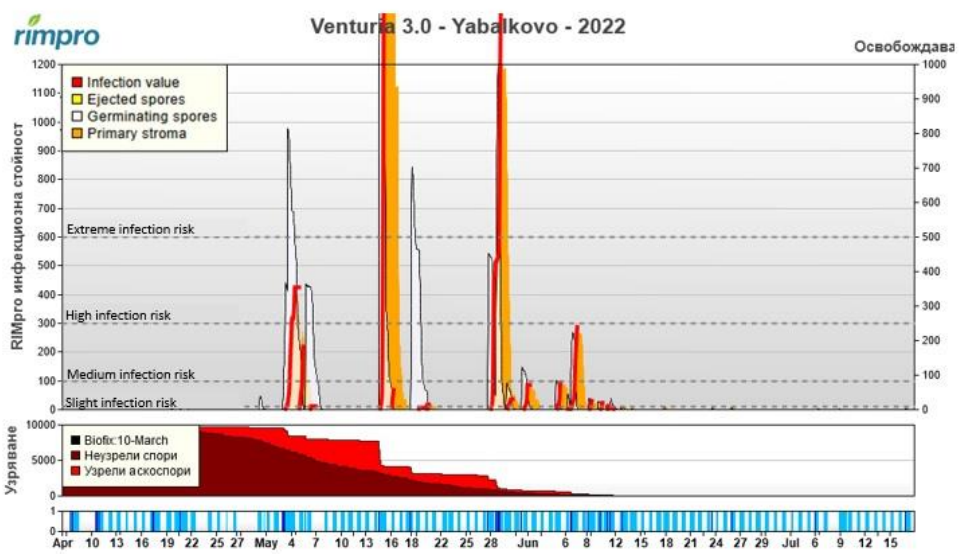

Figure 3. Data from a prediction model for the causative agent of apple scab in 2022

trees. No differences in yields were found between the other two cultivars.

During the study period, the predictive model used for apple scab registered a high and extreme infectious risk in the second and third ten days of April (Figures 3, 4, 5).

During this period, apples are in different phenophases of development - BBCH (59-60) in 2022, BBCH (51-54) in 2023 and BBCH (61-65) in 2024, respectively. During extreme infectious risk, the release of over 2000 - 3000 ascospores was recorded which, in the presence of moisture, caused infection of the leaves. During the period 2022-2024, extreme infectious risk was also observed in May, when there was a higher amount of precipitation. Of the four years of study, 2023 is characterized by the most frequent and the highest amount of precipitation in the months from March to September (Figure 2).

In individual years, the highest percentage of leaves attacked by apple scab in the Mutsu and Melrose cultivates was recorded in 2024 (93.0 and

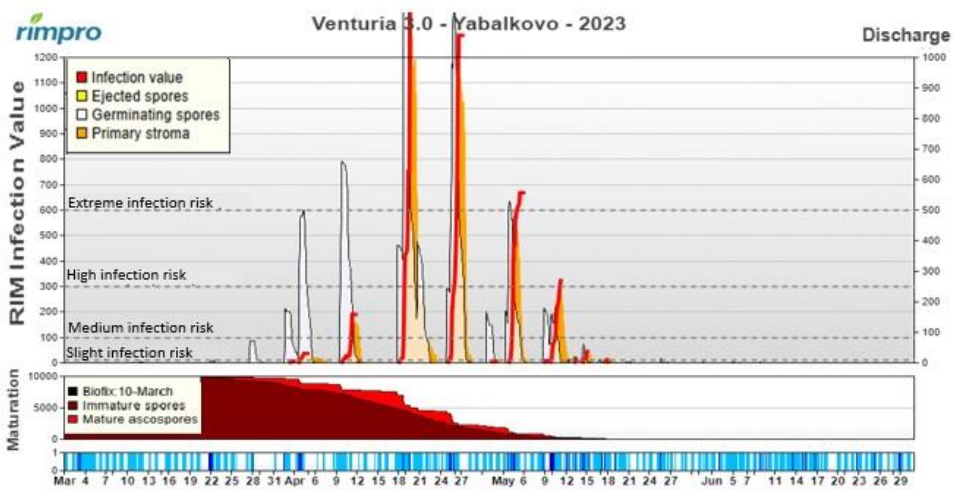

Figure 4. Data from a prediction model for the causative agent of apple scab in 2023

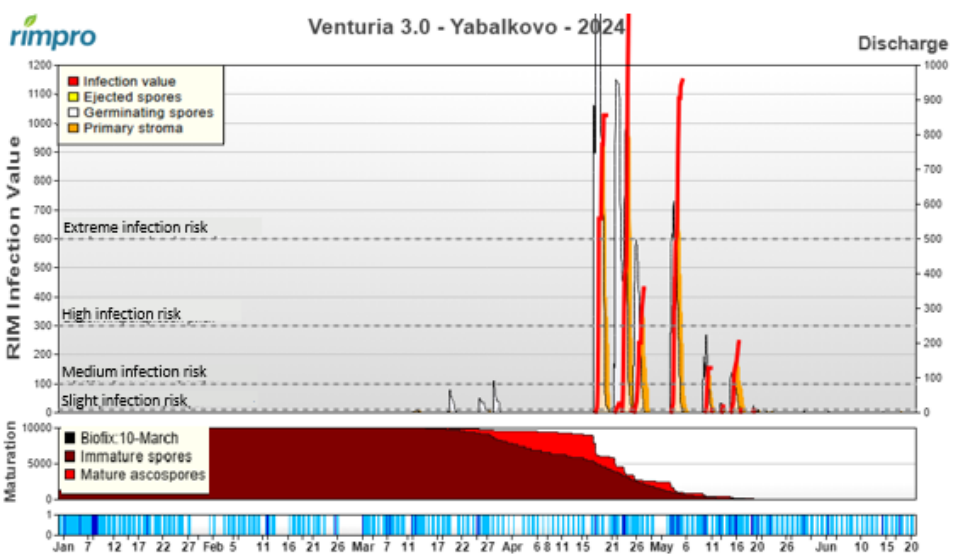

Figure 5. Data from a prediction model for the causative agent of apple scab in 2024

82.6%, respectively), and the lowest in 2022 (48.0 and 41.6%). The percentage of fruits attacked in both cultivates was higher in 2023 (63.1 and 100%), and the lowest in 2022 (9.6% for the Melrose and 26.6% for Mutsu) (Table 3). On average for the period, the highest percentage of leaves and fruits attacked by apple scab was found in Mutsu (77.2% leaves and 70.9% fruits attacked, respectively). Of the two scab-susceptible cultivars, Mutsu showed greater susceptibility than Melrose during the study period (Table 3).

On average for the period, the degree of apple scab attack in Mutsu and Melrose was as follows: on leaf rosettes 17.5 and 11.2%, on leaves – 28.4 and 23.8%, and on fruits 19.4 and 7.4% (Table 4).

The highest percentage of leaves damaged by powdery mildew was also recorded in 2023 and reached 77.3% on average for the three cultivars, and they were least attacked in 2021 (12.5%). In individual years, the percentage of damaged leaves was the lowest in 2021 for the Mutsu cultivar (2.2%), and the highest in 2023, reaching 71.2%. In Melrose, the damaged leaves were 4.2% for 2021 and 74.4% for 2023, respectively. In the scab-resistant cultivar Florina, the damage was 31% in 2021 and 86.8% in 2024. On average for the studied period, Florina had the highest damage percentage - 67.5%, followed by Melrose (50.4%) and Mutsu (43.5%) (Table 5). The information on the resistance/susceptibility of fruit ge-

Table 3. Percentage of leaves and fruits damaged by apple scab in three apple cultivars in 2021 - 2024

Cultivar	(*Venturia inaequalis*), percent damaged:									
	leaves					fruits				
	2021	2022	2023	2024	Average	2021	2022	2023	2024	Average
Melrose	73.6	48	81.2	82,6	71.4	13.2	9.6	63.1	61.3	36.8
Mutsu	89	41.6	85.3	93	77.2	72.1	26.6	100	84.7	70.9
Florina	-	-	-	-	-	-	-	-	-	-

Table 4. Degree attack (%) of apple scab (*V. inaequalis*) in three apple cultivars in 2021 - 2024

Cultivar	Degree attack, %														
	leaf rossettes					leaves					fruits				
	2021	2022	2023	2024	Average	2021	2022	2023	2024	Average	2021	2022	2023	2024	Average
Melrose	8.6	4.9	14.2	17	11.2	20.5	12.1	27.5	35.2	23.8	2.6	1.9	12.6	12.4	7.4
Mutsu	22.6	4.8	17.9	24.5	17.5	33.3	9.8	32.1	38.5	28.4	15	5.3	26	31.2	19.4
Florina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 5. Percentage of damaged leaves and degree attack, % of powdery mildew (*P. leucotriha*)) in three apple cultivars in 2021 - 2024

Cultivar	Percentage of leaves damaged					Degree attack, %				
	2021	2022	2023	2024	Average	2021	2022	2023	2024	Average
Melrose	4.2	52,8	74.4	70.2	50.4	0.8 b	12.9 b	25.1 b	17.9 a	14.2 b
Mutsu	2.2	44.8	71.2	55.6	43.5	0.4 b	11.0 c	25.7 b	14.8 a	13.0 c
Florina (c)	31	65.8	86.2	86.8	67.5	6.7 a	19.6 a	32 a	35.2 b	23.4 a

netic resources towards economically important diseases is important for breeding and for planting traditional cultivars (Höfer et al., 2021).

The average leaf powdery mildew attack rate for the period for Mutsu was 13%, for Melrose – 14.2%, and for Florina, it was 23.4%. In all years of the study, the attack rate for the Florina had the highest values among the three tested cultivars. The lowest value was in 2021 - 6.7%, and the highest in 2024 - 35.2%. The differences between the cultivars in all years and the averaged data for the period have been statistically proven (Table 5).

The earlier completion of treatments in 2023 (in early July) against powdery mildew, as well as the rainfall that fell afterward - 76.8 mm in July and 58.5 mm in August, created favorable conditions for the higher percentage of apple scab and powdery mildew infection (Figure 2). In a similar study, Chatzidimopoulos et al. (2020) recommend checking fruit for infection in humid areas during late summer, and if necessary, additional spraying should be done.

CONCLUSIONS

The results of this study showed that the tested apple cultivars have high productive potential and are well adapted to the local agro-ecological conditions. The used predictive software model for diseases and pests RIMpro allows, by predicting the time of occurrence of a given infection, to apply more effective chemical protection. This reduces the costs of agricultural producers, and the resulting production is healthier due to the reduced number of chemical treatments. Data from the Meteobot meteorological station (temperature, precipitation, etc.) can be provided to farmers in the area to determine the most appropriate times for treatment against apple scab.

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