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Original Research

The Impact of Abiotic and Biotic Factors on the Productivity of the Apple Cultivars *(Malus domestica)*

Vahid Avdiu, Gezim Hodolli*, Bedri Dragusha, Kaltrina Bunjaku

Faculty of Agriculture & Veterinary, University of Pristina "Hasan Prishtina", St. "George Bush", 10000, Prishtine, Kosovo

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Abstract

This research paper presents the results of a field trial performed in the eight-year orchard with the apple cultivar (*Malus doestica*): 'Fuji', 'William's Pride' and 'Pink Lady', on the rootstock M9. The experiment as a randomized block system included 18 apple trees (9 for each cultivar). Each plant was monitored and examined some bio-morphological parameters. At the same time monitoring and examining some abiotic factors (frozen, drought, hail wind) and biotic factors (pests, diseases, birds) through agrologic stations and sampling. By the results obtained we found that: abiotic factors we have identified drought damage caused by high temperatures and radiation, lack of rainfall and wind, while from biotic factors damage is caused by diseases, pests and birds. According to apple cultivars, the 'Fuji' cultivar suffered the greatest damage to productivity from two factors, abiotic (49.74% failure to achieve optimal fruit mass and 17% superficial burning of fruits) and biotic (56.24% birds, 9.93 scab and 4.33 others). 'Pink Lady' is damaged from biotic factor (43.17% failure to achieve optimal fruit mass and 36% superficial burning of fruits, 3.64% Cracking of fruits, and 1.64% fruit fall) whereas from biotic factors damage (19.2% birds, 23.8% scab, 10.07% codling moth and 4.8% apple sawfly). While 'William's Pride' has suffered the least damage (36.68% failure to achieve optimal fruit mass and 4.66% other physical damage) and biotic factor (12.4% fruit rot, 9.4% powdery mildew, 5.4% birds, 29% codling moth, 2.7% apple sawfly).

Keywords: abiotic, biotic, 'Fuji', 'William's Pride', 'Pink Lady'

Introduction

Natural conditions in Kosovo, especially in some regions, are very favorable for apple cultivation, although climate change in recent years is making this product more and more challenging.

In recent years, the cultivation and production of apple is declined due to abiotic stresses associated with climate change. Environmental factors are more influential on growth and quality of fruits. They are mainly responsible for abiotic stresses (heat, cold, salinity and drought) induced to the plants, and affect

*e-mail: gezim.hodolli@uni-pr.edu

apple fruit development productivity and quality. There are certain mechanisms behind the stress tolerance caused by these environmental factors [1]. The apple genetic resources available can be exploited to breed varieties resistant against diverse abiotic stresses, which can help expand the cultivation area of the apples [1, 2]. In addition to factors that farmers can control to some extent, such as soil moisture or structure, according to [3] among all climatic factors, the temperature seems to be the most important factor in the apple crop productivity. He added that the role of spring frosts, hail, summer drought, and spring rain in reducing productivity and fruit quality cannot be ignored.

According Vitasse [4], during analyzed long-term temperature data from the period 1975-2016 in 50 locations in Switzerland and used different phenological models calibrated with long-term series of the flowering and leaf-out timing of two fruit trees (apple and cherry) to test whether the risk of frost damage has increased during this period.

Among abiotic stresses, drought is the most important limiting factor for plants, causing great crop loss in fields and fruit plantations. About 40% of all crop losses reported by participants to the USDA-FSA between 2013 and 2016 were caused by drought, water stress is the most important cause for crop loss, and future climatic conditions are likely to include growth of the frequency and duration of drought [5]. Droughts are characterised by a decrease in precipitation over a lengthy period, such as a season or a year, and can occur in virtually all climatic zones, including both high and low rainfall locations [6]. Drought has the greatest impact on plant morphology, physiology, and biochemistry [7]. Drought tolerance of the apple cultivars, through analyzing several fluorescence parameters was different by genotype-dependent [8]. Effects of drought stress on plants depended on rootstocks, severity and duration of drought stress. Stomatal conductance was remarkably affected by drought stress [9]. The strong correlation exists between stomata conductance with soil moisture, soil and leaf temperature[10].

Main factors by which different environmental conditions (e.g., temperature, light, flood, and drought), and management practices (pruning, thinning, girdling, sheltering, water aspersion, irrigation, and fertilization) influence frost sensitivity and frost exposure of trees [11].

Sunburn is a physiological disorder of apples and other fruit species caused by excess solar radiation. Damage occurs in practically all growing regions of the world, causing severe crop loss every year. Direct factors required for induction of the three currently known types of sunburn (i.e., sunburn necrosis, sunburn browning, and photooxidative sunburn) include excess radiant heating and/or exposure to excess sunlight [12]. Apple cultivars different in their susceptibility to sun damage, which is evidenced, in part, by the timing of symptom development and severity [13].

Climate change-induced losses to production can occur directly or indirectly, including via the distributions and impacts of plant pathogens [14].

The maintenance of the beneficial plant microbiome to control plant pathogens is an emerging concept of disease management, and necessitates a clear understanding of these microbial communities and the environmental factors that affect their diversity and compositional structure. Growing season is the most significant factor affecting fungal community structure and diversity of apple fruit, suggesting that future microbiome studies should take place for multiple growing seasons to better represent the host-microbiome of perennial crops under different environmental conditions [15].

The pest incidence was negatively influenced by evening relative humidity, mean relative humidity and bright sunshine, whereas other weather parameters did not influence the incidence of apple [16].

Apple scab *(Venturia inaequalis)* is one of the diseases that mostly occurs in apples, leaves, flowers, fruits, and seedlings. The degree of apple-scab infection differed depending on the climatic conditions and more precisely on the frequency and amount of precipitation combined with the average daily air temperatures. There are also varying susceptible degrees between apple cultivars in relation to scab, as well as to powdery mildew [17].

Apple scab and powdery mildew are diseases with devastating impact in apple reduction, which can result in decreased fruit quality and yield. Moreover, ever foliar infection can lead to premature defoliation and reduced tree vigor, which in turn may restrict or prevent formation of fruit buds for the next year [18].

Apple powdery mildew (Podosphaera leucotricha) is one of the most important diseases in apples caused by Podosphaera leucotricha and is present in all countries that cultivate apple culture. The pathogen can attack shoots, buds, and fruits that significantly reduce the quality of the fruit [19].

Over 50 species of insects and spiders can cause damage to apple orchards, a number of them regularly cause damage and are quite disturbing to farmers. Different types of pests can attack the root system, shoots, leaves, and fruits. Those pests that directly attack fruits are the biggest concern in apple production. The most serious damage to apple fruit occurs throughout the growing season, from the time the fruit begins to develop until the harvesting process [20].

Different types of aphids feed on apple leaves, shots, and yang fruits. Some produce a white material, in the form of cotton or wax that is easily seen. Others cause twisted leaves. Although the damage seems dramatic, it usually has minor consequences for the health of the trees or the quality of the fruit [20]. However, when the spread is very large, the damage can be as serious as the direct ones (damage to leaves, shoots, and fruits) but also indirect as a vector of diseases and viruses.

Codling moth (Carpocapsa pomonela) is the most harmful insect species of the Tortricidae family that causes economic damage to apple production worldwide [21].

As the trend of climatic changes that have appeared in recent years is also influencing fruit harvests, this study aims to evaluate several metrological parameters under the effect of biotic and abiotic changes in the growth of various apple cultivars.

Material and Methods

The study was conducted in 2019, in a 7-year-old apple orchard, in the didactic farm of the Faculty of Agriculture and Veterinary, University of Pristina. Planting distances were 3.5 x 1 m. The research included three cultivars of the apple, 'William's Pride', 'Pink Lady', and 'Fuji' on the rootstock M9. They have been in high demand among farmers and consumers in recent years because of the higher quality.

The experiment consists of 54 plants, separated into two groups, including three different the apple cultivars. In the first group of plants (In total, 27 plants were tested, with 9 plants from each cultivar) were not applied agro technical measures were applied; while in the second group were applied agro technical measures (fertilizing, irrigation, and protection from diseases and pests).

Meteorological data (air temperature, dew point, vapor pressure deficit VPD, relative humidity, precipitation, leaf wetness, active radiation, wind direction, wind speed, soil temperature, air pressure) and prognoses of some apple pests (aphids, codling moth crpocapsa pomonela) and diseases (fire blight *erwinia amylovora*, scab *venturia inaequalis* powdery mildew *podosphaera leucotricha*), were provided from Faculty of Agriculture and Veterinary Agrological Station, which is inside of the didactic farm where this experiment were realized.

From the beginning of vegetation in all plants included in the experiment were carefully monitored and examined:

Bio-morphological parameters were described in line with Descriptors list for the apple (*Malus*) [22]. Dynamic of flowering: the beginning of bloom (20% of flowers bloomed), Full bloom (75% of flowers bloomed), and end of bloom (95% of flowers bloomed). Every two days exanimated 100 clusters of flowers were to calculate the percentage of bloom. Morphologic parameters of the tree: plant height (m), plant width (m), trunk cross-section area (TCSA) (cm^2). Inflorescence: Number of flowers per plant (all flowers in all plants examined). Fruits: number of fruits settings (all fruits in all plants examined), the mass of fruits (g), BRIX, and total acids content (%)

Apple cultivars do not have similar resistance related to diseases Table 1. The metrics (Air temperature and leaf whiteness) were gathered for each hour from the Agrologic station's data. The classification model were based in hours of wetness from the beginning of rain given by W.D. Mills as Modified separately by A.L. Jones [23] and Stansvard [24].

Abiotic factors: Drought damage caused by high temperatures and radiation, lack of rainfall and wind, manifested as (superficial burning of fruits, cracking of fruits, failure to achieve optimal fruit mass, fruit fall), Late spring frozen – Minimal temperatures, Hail, Wind.

Damage caused has been identified in fruits. Damage recording was performed based on observations, relevant measurements, and software used for these purposes. Damaged fruits are considered damaged if the wound on the fruit surface is >5 mm in size [25]. The statistical data were processed by JMP 2010 software (Table 4).

Results and Discussion

The abiotic and biotic factors in apples, as well as the interaction between them, have an essential impact on the success or failure of apple cultivation. These factors individually or as a combination can affect all organs of the plant and all stages of its development. Abiotic factors are vital for the development of apples, the success of which depends on the optimal values of these factors. While in biotic factors we are dealing with the competition of apples with other organisms within a certain living environment, which also depends the success of the development of apples. Some of them can be harmful, some competitors and some supporters.

Table 1. Disease Susceptibility of Common Apple Cultivars [29].

The apple Cultivar	Apple Scab (*Venturia inequalis*)	Fire Blight (*Erwinia amylovora)*	Juniper Rusts* (*Gymnosporangium juniperi- virginianae)*	Powdery Mildew (*Podosphera leucotryha)*
'William's Pride'	VR	R	VR	R
'Pink Lady'	VS	VS	R	R
'Fuji'	S	VS	R-VS	R

VR-Very Resistant VS-Very Susceptible R-Resistant S-Susceptible MR-Moderately Resistant MS-Moderately Susceptible N/A-Data not available

Table 2. Average meteorological data in 2019 (Faculty of Agriculture and Veterinary, Agrological Station –IPKO).

Month	Air temperature [ºC]			Relative humidity [%]	Precipitation [mm]
	Average	Max.	Min.	Average	Total
January	-2.42	9.72	-14.6	91.26	21.60
February	2.71	15.99	-9.55	75.22	8.40
March	8.45	22.43	-4.86	55.76	10.00
April	11.64	26.29	-0.06	64.78	48.60
May	13.44	25.03	2.15	73.42	51.00
June	20.73	32.78	9.5	73.47	66.4
July	21.29	35.41	6.66	67.22	66.6
August	22.87	36.64	9.01	59.17	11.0
September	17.69	33.47	1.21	66.4	31.8
October	13.44	28.09	0.95	69.18	4.8
November	10.16	21.72	-0.19	85.24	61.0
December	2.57	13.54	-9.94	89.16	28.6
					Sum 409.8

Table 3. Dynamics of flowering time as apple cultivars, comparing temperatures (2019).

Cultivar	Time of blooming			Number of days	Temperature [ºC]			Precipitation [mm]
	Beginning	Full	End		Min	Max	Average	
‘William’s Pride’	05.04.2019	12.04.2019	18.04.2019	15	-0.1	26.3	11.58	47.2
‘Pink Lady’	12.04.2019	21.04.2019	30.04.2019	19				
‘Fuji’	14.04.2019	23.04.2019	30.04.2019	17				

Table 4. Several bio-morphological characteristics of three different apple varieties’ of eight-year old trees (2019).

Cultivar	Plant height [m]	Plant width [m]	Trunk cross section area TSCA [cm^2]	No. of flower [plant]	No. of fruits setting [plant]	%. of fruits setting [plant]	Mass of fruit [g]	BRIX %	Total acids [%]
‘William’s Pride’	2.92^a	1.25^a	26.10^a	1184^a	137^a	13.30^a	103.7^a	10.1^c	6.39^a
‘Pink Lady’	2.90^a	1.16^a	21.59^b	523^c	69^b	11.65^a	89.7^b	13.5^b	5.60^a
‘Fuji’	2.82^a	1.22^a	24.71^a	939^b	114^a	12.29^a	84.9^b	14.9^a	3.20^c
Compare means	q*				Alpha				
Tukey-Kramer HSD	2.49729				0.05				

$^{a, b, c}$ - levels not connected by the same letters are significantly different; q* – confidence quartile; alpha – significant parameter

During the period of 2019, we have managed to identify some damage from abiotic and biotic factors. We have also found that the behavior of apple cultivars towards these factors has been different.

Flowering is a very important biological phase that is related to the genetic basis, but in this process environmental factors also have an influence. Considering the time when flowering occurs (April) suggests that this stage is very endangered by environmental factors such as late spring frosts as well as the emergence of various diseases and pests. From the data presented in Table 2 and Table 3 it can be seen that fortunately the flowering phase of the apple was not accompanied by late spring frosts. But there has been a lot of rain that has created conditions for the emergence of diseases. It is also noted that the time and duration of the flowering period were different for each apple cultivar.

Analyzing the bio-morphological data (Table 4) we notice that the three cultivars have plants of similar size, with a difference to the Pink Lady cultivar that has the smallest TCSA which is also reflected in the smallest number of flowers and fruits per plant.

High temperatures, high radiation, and lack of precipitation manifested in the form of drought (Table 2), manifested in the critical stages of fruit development have caused quite high damage (Table 5). These damages are observed in the three cultivars analyzed. The greatest damage was evidenced by the failure to achieve optimal fruit size according to genetic potential, where the most pronounced is in the Fuji cultivar then Pink Lady, and smaller in William's Pride.

Significant damage has also been identified in the superficial burning of fruits where the most pronounced

Table 5. Abiotic factors damages to the apple cultivars

Cultivar	Non-agro technique measures		With agro technique measures		Drought damage				Wind
	Fruit mass [g]	Productivity [kg/plant]	Fruit mass [g]	Productivity [kg/plant]	Superficial burning of fruits [%]	Cracking of fruits [%]	Failure to achieve optimal fruit		Fruit fall [%]
							Mass [%]	Productivity [%]	
'William's Pride'	103.7	14.22	163,79	27.61	0.99	2.06	36,68	48.50	1.61
'Pink Lady'	89.7	6.35	157,86	12.94	36	3.64	43,17	50.93	1.34
'Fuji'	84.9	9.58	168,93	22.85	17	/	49,74	58.07	/

Table 6. Infections caused by scab were assessed based on air temperature and leaf moisture, for the months of April through October 2019.

Apple scab				
Month	Dates	Average Temperature [ºC]	Leafe wetness [hours]	Classification
April	09.04.2019	9.4	18	Moderate infection
	10.04.2019	10	15	Moderate infection
	15-16.04.2019	9.4	17	Moderate infection
May	05.05.2019	12.6	17	Moderate infection
	27.05.2019	17.2	11	Low infection
June	2.06.2019	14.9	17	Moderate infection
	03.06.2019	14.6	13	Low infection
	05.06.2019	16.6	20	High infection
	17-18.06.2019	20	16	Moderate infection
	20-21.06.2019	21	20	High infection
July	10.07.2019	15.6	22	High infection
	14.07.2019	16.8	13	Moderate infection
	29.07.2019	19.09	18	High infection
August	03-04.08.2019	20.9	16	Moderate infection
September	07.09.2019	21.6	14	Moderate infection
	09.09.2019	23.4	13	Moderate infection
	23-24.09.2019	15.05	23	High infection
	25.09.2019	19.2	9	Low infection
	27.09.2019	18.2	13	Moderate infection
October	04.10.2019	10.8	16	Low infection

Table 7. Biotic factors damages to the apple cultivars.

Cultivar	Total damage of fruits %	Participation in damage					
		Scab [%]	Powdery mildew [%]	Fruit rot [%]	Codling moth [%]	Apple sawfly [%]	Birds [%]
‘William’s Pride’	37.5	/	9.40	12.4	2.9	2.7	5.4
‘Pink Lady’	63.4	23.8	/	/	10.07	4.8	19.2
‘Fuji’	70.67	9.93	0.46	/	0.69	3.18	56.24

have been in the ‘Pink Lady’ cultivar then in ‘Fuji’ and very little in ‘William’s Pride’. Relative damage to ‘Pink Lady’ and ‘William’s Pride’ cultivars has been identified as fruit cracking and premature fruit falling by the wind.

Biotic factors have had a high impact on fruit damage in the three apple cultivars. The ‘Fuji’ cultivar suffered the most damage than ‘Pink Lady’ and less ‘William’s Pride’. These damages have been caused mainly by diseases (scab, powdery mildew, fruit rot), pests (codling moth, apple sawfly), and birds.

Ascosporous of scab, cause the primary infection in the spring during wet weather at a temperature of 6-26ºC. At a temperature of 6ºC the germination of ascospores is slow, the leaves should be wet within 28 hours, at a temperature of 10ºC this period is shortened to 14 hours, and at an optimum temperature of 18-24ºC this process lasts only 9 hours [26]. Conditions and occurrence of scabs during vegetation are reflected in Table 6.

In the spring powdery mildew infections occur when the relative humidity (RH) is greater than 70% and when (10- the temperature stays between 25ºC). Unlike other leaf diseases, leaf witness is not a requirement for the development of infection [18].

The response to temperature (13-28ºC) was non-linear, with the optimum c. 22ºC. In contrast, there was no detectable trend in the response of colony growth to vapor pressure deficit (1.6-10.4 mmHg). The results suggest that the rate of development of young colonies depends more on temperature than on moisture stress [27].

Optimal conditions for the presentation of powdery mildew occurred on 06.06.2019. At this time the germination of organs (conidia) started, the average daily temperature was 18.57ºC while the air humidity was 83.6%. Conditions for the appearance of infection continued during June and July.

During May, the average air temperature was 13.4ºC, the maximum 25ºC, and the lowest 2.15ºC. The relative humidity of the air was 73% of the 51 mm of rainfall. Also, the temperatures during June and July have been favorable for the apple worm development cycle.

The behavior of apple cultivars towards these biotic factors has been different (Table 7). William’s Pride has been mostly damaged by fruit rot then by powdery mildew then by birds. Pink Lady has suffered the highest damage from scabs then from birds then codling moth and apple sawfly, while there has been no damage from powdery mildew and fruit rot. While Fuji the greatest damage was caused by birds, then by scab, then by apple sawflies, while the damage by powdery mildew and codling moth was too small. The economic harm of birds has received relatively little attention compared to other agricultural pests. However, for many farmers, the impacts can be large and management costly [28].

Conclusions

Abiotic and biotic factors have a significant effect on the productivity of three apple cultivars. It has been discovered that apple cultivars’ responses to these factors non consistent. In addition, all three cultivars differed in terms of fruit weight and yield. In several situations, when non-agro technical methods were used, significant losses were observed. Drought impacts caused significant losses in fruit weight and yield.

The ‘William’s Pride’ cultivar has suffered the least damage from both abiotic and biotic factors when compared to the other two cultivars. This might be related to the genetic characteristics of ‘William’s Pride,’ which includes early ripening (late July), a longer time till fruit ripen, and an acidic flavor that birds may find less attractive.

The ‘Pink Lady’ cultivar has experienced significant abiotic damage, with superficial burning of fruits and an inability to produce an ideal weight of the fruit. Scabs, birds, and codling moths were the most prevalent biotic agents. This is connected to the genetic background, since late ripening (late October) has caused it more exposed to the August-October dry season and susceptible to apple scab.

The ‘Fuji’ cultivar has been the most heavily harmed by both abiotic and biotic factors. Substantial damage has resulted from inability to reach ideal fruit weight and yield, as well as from superficial fruit burning. Birds and scab have caused the greatest harm among biotic agents. The high sugar content in the fruit may have attracted many birds due to the fact that this cultivar has been so exposed to damage, late ripening (late October), and longer exposure to the dry period.

This study demonstrates the interaction and effect of biotic and abiotic factors in apple culture. It indirectly warns of the consequences of climate change, which have already begun to manifest and may intensify in the future.

Conflict of Interest

The authors declare no conflict of interest.

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