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Estimation of economic loss due to postharvest diseases of apple (cv. Idared) during four seasons

Procjena ekonomskog gubitka zbog skladišnih bolesti jabuka (cv.Idared) u četiri sezone

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ABSTRACT

A study was conducted over 2004/05, 2007/08, 2008/09 and 2009/10 in order to determine the significance and development of apple postharvest diseases during three months of storage. Fungicides were not applied during the last month of the growing season, and fruit were stored at storage room without temperature regulation. The incidence of postharvest diseases varied from 1.2 to 9.1% in different months and seasons, with the mean incidence of 1.9, 8.1, 2.9 and 3.8% in 2004/05, 2007/08, 2008/09 and 2009/10, respectively. Brown rot (*Monilinia fructigena*) was the dominant postharvest disease in all assessment periods, occurring on 0.5 to 7.7 % of fruit, with the mean incidence of 3.06 % in all seasons. Bitter rot (*Colletotrichum* spp.), gray mould (*Botrytis cinerea*) and blue mould (*Penicillium expansum*) were the other common diseases, recorded on average 0.48, 0.32 and 0.27% of fruit. Economic loss was estimated on the basis of disease incidence and the average price of apple according to the Market Information System in Agriculture database. If wholesale market prices were taken as a reference, average loss in different months of storage ranged from 5.16 to 52.78 € per ton of fruit. Mean estimated loss per ton of fruit and month of storage was 8.49 € in 2004/05, 46.02 € in 2007/08, 29.48 € in 2008/09, and 21.43 € in 2009/10. Using the open market place prices for calculation, average loss in different months of storage varied from 9.60 to 81.90 € per ton, and the mean estimated loss per tone of fruit and month of storage was 14.15, 69.58, 27.08 and 33.11 € in 2004/05, 2007/08, 2008/09 and 2009/10, respectively.

Key words: apple, economic loss, postharvest diseases.

SAŽETAK

U sezonama 2004/05, 2007/08, 2008/09 i 2009/10 provedeno je istraživanje razvoja i ekonomskevažnosti skladišnih bolesti jabuke tijekom tri mjeseca skladištenja. Fungicidi nisu korišteni u mjesecu prije berbe, a plodovi su čuvani u skladištu bez regulacije temperature. Učestalost skladišnih bolesti kretala se od 1,2 do 9,1 % u različitim mjesecima i sezonama, s prosječnim intenzitetom od 1,9; 8,1; 2,9 i 3,8 % u 2004/05., 2007/08., 2008/09. i 2009/10. Smeđa trulež (*Monilinia fructigena*) bila je dominantna skladišna bolest u svim očitavanjima. Javljala se na 0,5 do 7,7 % plodova, s prosječnim intenzitetom od 3,06 % računajući sve sezone. Gorka trulež (*Colletotrichum* spp.), siva plijesan (*Botrytis cinerea*) i plava plijesan (*Penicillium expansum*) bile su ostale češće bolesti, a zabilježene su na prosječno 0,48; 0,32 i 0,27 % plodova računajući sve sezone. Ekonomski gubici su izračunati na osnovi učestalosti skladišnih bolesti i prosječnih cijena jabuke prema Tržišnom informacijskom sustavu u poljoprivredi (TISUP). Pri izračunu s veleprodajnim cijenama, prosječni gubici u različitim mjesecima skladištenja kretali su se između 5,16 do 52,78 € po toni plodova. Prosječni izračunati gubitak po toni i mjesecu skladištenja iznosio je 8,49 € u 2004/05., 46,02 € u 2007/08., 29,48 € u 2008/09. i 21,43 € u 2009/10. Pri izračunu s malo-prodajnim cijenama, prosečni gubici u različitim mjesecima skladištenja kretali su se između 9,60 i 81,90 € po toni, a prosječni gubici po toni i mjesecu skladištenja bili su 14,15; 69,58; 27,08 i 33,11 € u 2004/05., 2007/08., 2008/09. i 2009/10.

Ključne riječi: jabuka, ekonomska šteta, skladišne bolesti.

INTRODUCTION

Apple (*Malus domestica* Borkh.) is the most important fruit species in Croatia. In recent years, the Croatian government and local authorities have stimulated and financially supported establishment of new apple orchards and apple storage facilities. This resulted in significant increment of small (1-5 ha) modern family orchards, which are either independent or associated in regional cooperatives. A significant number of independent small producers are selling their apples in local market places or in local stores. Most of the apples produced in such orchards are being sold during the first few months after harvest, and are stored in storage rooms without temperature regulation. In the case of cooperatives, apples are stored in modern CA facilities or in conventional storage.

No matter the storage type, various postharvest diseases regularly occur on stored apple fruit (Snowdon, 1990). Most of such diseases are caused by fungi and can cause losses which range from very low to considerable. Different management strategies are currently used or developed for reduction of postharvest apple diseases, from biological control (Janisiewicz and Korsten, 2002; Wilson et al., 1991) or physical treatments (Fallik, 2004), to chemical control (Spotts et al., 2002). As fungicide treatments after the harvest are not allowed in Europe, chemical treatments intended for reducing postharvest losses are conducted with short waiting period fungicides before the harvest.

Many small apple producers in Croatia have adopted the practice to treat their orchards four to three weeks before harvest with captan, or two to one week before harvest with boscalid and pyraclostrobin. Advised by extension service experts or pesticide traders, many producers consider such treatments as economically justifiable and effective in reducing disease incidence during the storage. However, certain producers leave out such treatments from disease control schedule, claiming these are not necessary and justifiable if there is no need for late apple scab (*Venturia inaequalis* (Cooke) G. Winter) control. Considering the average price of fungicides and additional expenses, the estimated cost of a treatment intended for reducing postharvest diseases could be about 130 to 200 € ha^{-1}. As there is a lack of data showing what could be the real loss in apple production caused by postharvest diseases, it is hard to evaluate economic justifiability of late fungicide treatment for storage diseases control.

The objectives of this study were to determine the causal agents of apple postharvest diseases, to compare disease incidence in different seasons, and to estimate economic losses during the first three months of storage on the basis of yield loss and market prices of apple.

MATERIAL AND METHODS

Experimental orchard, fruits and storage

The experimental apple orchard was situated near Ivanić-Grad in Northern Croatia. It was established in 1993 with the cultivar Idared on M 9 rootstock. The study was conducted in the 2004/05, 2007/08, 2008/09 and 2009/10 seasons. The number of fungicide treatments was variable depending on the season, and is stated in Table 1. During the 2007/08 season, hail severely damaged the orchard and only seven treatments were conducted, as it was decided that further investment in production would not be justifiable. Fungicides used were copper, captan, mancozeb, metiram, folpet, dodine, fenarimol, cyprodinil, difenoconazole, tebuconazole, kresoxim-methyl and trifloxystrobin, applied in different schedules, combinations and dose rates. All fungicide treatments were targeted to apple scab control. The last treatment in all seasons except in 2007/08 was conducted approximately one month before the harvest, except for 2007/08, when it was performed three months before the harvest.

Table 1. Postharvest diseases of apple fruits (cv. Idared) and disease incidence (%) recorded each month during three months of storage in seasons 2004/05, 2007/08, 2008/09 and 2009/10.

Tablica 1. Skladišne bolesti i učestalost skladišnih bolesti (%) na plodovima jabuke (cv. Idared) zabilježene svakog mjeseca tijekom tromjesečnog razdoblja skladištenja u sezonama 2004/05., 2007/08., 2008/09. i 2009/10.

Season	2004/2005				2007/2008				2008/2009				2009/2010				
No. of fungicide treatments	11				7				13				11				
Months of storage	1	2	3	x̄	1	2	3	x̄	1	2	3	x̄	1	2	3	x̄	
Diseases (%)																	Average (%)
Monilinia fructigena	0.7	0.5	1.8	1.0	6.5	6.9	7.7	7.03	1.9	2.1	2.4	2.13	1.1	2.1	3.0	2.07	3.06
Penicillium expansum	0.2	0.3	1.1	0.53	0.3	0.2	0.4	0.3	0.1	0.1	0.2	0.13	-	0.1	0.2	0.1	0.27
Botrytis cinerea	0.2	0.2	0.3	0.23	0.5	0.5	0.6	0.53	0.2	0.3	0.2	0.23	0.2	0.3	0.3	0.27	0.32
Colletotrichum spp.	-	0.1	-	0.03	0.1	0.1	0.3	0.17	0.2	0.3	0.5	0.33	0.3	1.1	2.8	1.4	0.48
Fusarium spp.	0.1	0.1	-	0.07	-	-	-	-	-	-	0.1	0.03	-	-	0.3	0.1	0.05
Phomopsis mali	-	0.1	-	0.03	-	-	-	-	-	-	-	-	-	-	0.2	0.07	0.03
Alternaria sp.	-	-	-	-	-	-	-	-	-	-	0.1	0.03	-	0.1	0.1	0.07	0.03
Botryosphaeria sp.	-	-	-	-	-	-	-	-	0.1	-	-	0.03	-	-	-	-	0.01
Neofabrea alba	-	-	-	-	-	-	0.1	0.03	-	-	-	-	-	-	0.1	0.03	0.02
Total (month, %)	1.2	1.3	3.2	1.9	7.4	7.7	9.1	8.1	2.5	2.8	3.5	2.9	1.6	2.7	7.0	3.8	
Mean (season, %)	1.9				8.1				2.9				3.8				
Mean (all seasons, %)	4.2																

For each season in which the study was performed, fruit were collected during harvest in wooden boxes. A number of randomly selected boxes filled with fruits was transferred to a storage room without temperature regulation, where it was left for three months. Three disease assessments were done during this storage period.

Disease assessment and identification

Postharvest diseases were assessed 30 days after harvest, and two more in 30-day periods. One thousand randomly selected fruit were examined for the presence of fungal diseases. Fruit with symptoms of scab (*V. inaequalis*) or powdery mildew (*Podosphaera leucotricha* (Ellis & Everh.) E.S. Salmon) were not taken into account, if such fruit was found. The causal agents of postharvest diseases were determined according to the symptoms when sporulation was clearly visible on fruit, following the descriptions of Rosenberger (1997a; 1997b; 1997c), Sutton (1997), Jones (1997) and Snowdon (1990). In some cases, the morphology of fungal structures on symptomatic apple tissue was examined in the laboratory using stereomicroscope and microscope. If sporulating structures had not developed on fruit, symptomatic fruit parts were placed in a moist chamber for several days, and fungi were identified when sporulation occurred. If only sterile mycelium appeared after moist chamber incubation, a piece of mycelium was placed on potato-dextrose agar (PDA) and incubated at 20 °C in 12/12 h photoperiod. After incubation, fungi were identified according to the morphology and sporulation in culture.

Disease incidence and economic loss estimation

Disease incidence was calculated on the basis of a number of symptomatic fruit out of the total number of fruit examined, and was expressed as a percentage. A chi-square test of independence was performed to test the eventual relationship between season and the average incidence of diseases found.

Economic loss was estimated on the basis of disease incidence, average fruit weight, and average monthly prices of apple fruit on Croatian market using the TISUP database (Market Information System in Agriculture). One hundred randomly selected fruit from each experimental season were weighted to obtain average fruit weight. To calculate the number of fruit in one ton, 1000 was divided by average fruit weight (in kg):

No. of fruits in one ton (NFT) = 1000 / average fruit weight (AFW).

The number of diseased fruit in one ton was calculated by multiplying the number of fruits per ton with disease incidence. Fruit loss in kg per ton was obtained by multiplying fruit loss per tone by average fruit weight (AFW).

Finally, economic loss was calculated by multiplying fruit weight loss per one tone with the average price of one kg of apple:

Fruit loss per one tone (FLT) = NFT x disease incidence (%);

Fruit weight loss per one tone (FWL) = FLT x AFW;

Economic loss per one ton (ELT) = FWL x average price of apple (per one kg).

Average wholesale market prices and average open market place prices were used (€ kg^{-1}, cv. Idared) according to the Market Information System in Agriculture data, taken for the periods when assessments were done. Average economic losses were estimated for each month, all months in one season, and all months in all seasons. Estimation was done for all diseases together.

RESULTS

Brown rot, caused by *Monilinia fructigena* Honey, was the dominant postharvest disease in all assessment periods. It was detected on stored fruit in range from 0.5 to even 7.7 % in monthly assessments, with the mean incidence of 3.06 % taking into account all years (Table 1). Season 2007/08 is significantly contributing to the average values of brown rot incidence, as the occurrence of postharvest diseases in this season was high. It must be considered that 2007/08 was a specific experimental season, in which hail damage occurred and standard disease management practice was not performed as in other years. If 2007/08 data is left out, mean monthly brown rot incidence would be 1.7 %. Other diseases found in most of the assessment periods and in all seasons were gray mould (*Botrytis cinerea* Pers.), blue mould (*Penicillium expansum* Link) and bitter rot (*Colletotrichum* spp.). The mean incidence of these diseases together was 1.07 % taking into account all seasons. Diseases caused by *Fusarium* spp., *Phomopsis mali* Roberts, *Alternaria* spp., *Botryosphaeria* spp. and *Neofabraea alba* (E.J. Guthrie) Verkley were detected in very low incidence and were found only on a few fruits in certain seasons.

Changes in disease incidence in different months of storage and changes in postharvest pathogens' population structure in different seasons are evident. Total disease incidence was regularly lower during the first month of storage, and regularly highest during the third, last month of storage. Disease incidence in 2004/05 during the third month (3.2 %) was 2.5-fold higher than average incidence during the first two months of storage (1.3 %). In 2009/10, disease incidence during the third month (7.0 %) was 3.2-fold higher than the average

Table 2. **Economic loss (€) per tone of apple fruits caused by postharvest diseases during three months of storage in seasons 2004/05, 2007/08, 2008/09 and 2009/10, estimated on the basis of average wholesale market and open market place prices.**

Tablica 2. **Novčani gubitak (€) po toni jabuka uzrokovan skladišnim bolestima tijekom tri mjeseca skladištenja u sezonama 2004/05., 2007/08., 2008/09. i 2009/10., izračunat na temelju prosječnih cijena na veletržnicama i tržnicama.**

Season3	2004/2005			2007/2008			2008/2009			2009/2010		
Month of storage	1.	2.	3.	1.	2.	3.	1.	2.	3.	1.	2.	3.
Price of apple[a] (€/kg)	0.43	0.43	0.46	0.58	0.55	0.58	0.68	0.63	0.68	0.58	0.56	0.57
Loss/t (€)	5.16	5.59	14.72	42.92	42.35	52.78	17.00	17.64	23.80	9.28	15.12	39.90
Mean loss/month/t (€)	8.49			46.02			29.48			21.43		
Mean loss/all months/t (€)	26.36											
Price of apple[b] (€/kg)	0.80	0.78	0.71	0.84	0.84	0.90	0.92	0.93	0.92	0.89	0.87	0.88
Loss/t (€)	9.60	10.14	22.72	62.16	64.68	81.90	23.00	26.04	32.20	14.24	23.49	61.60
Mean loss/month/t (€)	14.15			69.58			27.08			33.11		
Mean loss/all months/t (€)	35.98											

[a] - Mean wholesale market price, cv. Idared, according to TISUP (Market Information System in Agriculture).
[b] - Mean open market place price, cv. Idared, according to TISUP (Market Information System in Agriculture).

one during the first two months (2.2 %). In 2007/08 and 2008/09 seasons, such increase was not this high (Table 1). Changes in particular diseases occurrence among different seasons are prominent in cases of *P. expansum* and *Colletotrichum* spp. (Table 1). Blue mould (*P. expansum*) occurrence decreased from 2004/05 to 2009/10. On the other hand, an increase in bitter rot (*Colletotrichum* spp.) occurrence is notable. Bitter rot was found on only one fruit during the 2004/05, and during 2007/08 and 2008/09 its occurrence increased. In 2009/10, *Colletotrichum* spp. was found on 42 out of the 3000 fruit examined (average 1.4 %) and its incidence among all diseases was second to *M. fructigena*. Unlike *P. expansum* and *Colletotrichum* spp., the incidence of gray mould (*B. cinerea*) was more or less constant, with relatively small variations in different years.

The chi-square value for disease incidence among different seasons was 572, higher than 36.415 (X^2 0.05 for 24 df). This result confirms there is a relationship between postharvest disease incidence and a season.

Economic losses estimated for one-month storage periods ranged from 5.16 to 52.78 € per one ton of apple fruit, considering the wholesale market price (Table 2). Average value loss for all seasons was 26.36 € t^{-1} for month of storage. If open market place price was taken as a reference value, estimated monthly loss ranged from 9.60 to 81.90 € t^{-1}, and average loss in all seasons was 35.98 € t^{-1} for month of storage. As with disease incidence, economic losses were highest in 2007/08 season. Without data from this specific year, mean loss value for one month would be 19.8 € t^{-1} considering the wholesale market prices, or 24.78 € t^{-1} considering the open market place prices (Table 2).

DISCUSSION

Beside high efficacy and ecological acceptability, economic justifiability is one of the fundamental postulates of modern disease control and integrated pest management. It is not easy to impartially estimate losses caused by plant diseases in terms of money loss, as a number of economic factors can affect such estimations. This study shows how productivity (yield), product attributes (average fruit weight) or economic factors (price changes, year and sales type) can influence the loss value. It is obvious that factors like the period of storage, the price of storage, or regional alterations in apple price can also have an influence on economic loss estimation. If the results of this study are taken as a reference point for decision regarding late season (one or two weeks before the harvest) fungicide treatment aimed to reduce postharvest diseases, some calculations could be done. For example, if the theoretical production would be 30 t ha^{-1} and all production would be stored, an average loss caused by postharvest diseases in 2004/05 would be 255 € for one ha production. In 2009/10, such loss would be 643 €, in 2008/09 it would amount 885 €, while in 2007/08 it would reach even 1381 €. These estimations are taken for the wholesale market price. If apples are sold directly by producers and open market place price is considered, loss values would be higher. Such calculations indicate the economic justifiability of postharvest disease management with the late season fungicide treatment. Of course, it must be considered that the fungicide can not be 100 % effective in postharvest disease control, and the efficacy of such treatments should be related to economic justifiability calculations.

Brown rot (*M. fructigena*) was showed to be the most important postharvest disease in this study. Incidence of brown rot was considerably high in 2007/08, and the specificity of this experimental season shows the potential of this disease to cause relatively high postharvest yield loss. It can be presumed that the hail damage contributed to the *M. fructigena* development and inoculum increase, but the reduced number of fungicide treatments performed in this season seems to be more important. The significance of brown rot in apple production with a reduced number of fungicide treatments was shown in the study of Holb (2008). In an organic apple orchard, preharvest brown rot incidence was 19.8-24.5 %, compared to 4.3-6.6 % in an integrated orchard (Holb, 2008). Jones (1997) stated that *Monilinia* spp. rarely causes economic losses of apple. However, the results of this study show that brown rot can be an economically important apple disease. Mean postharvest brown rot incidence (without 2007/08) of 1.7 % recorded in this study is very similar to average 1.5-2.0 % postharvest incidence of brown rot recorded on Cox's Orange and James Grieve cultivars in the Netherlands (van Leeuwen et al., 2000).

In all the seasons, blue mould (*P. expansum*), gray mould (*B. cinerea*) and bitter rot (*Colletotrichum* spp.) were detected in lower percentage compared to brown rot. Rosenberger (1997b) refers to blue mould (*Penicillium* spp.) as the most important postharvest disease of apple. In this study, blue mould incidence was second to brown rot only in 2004/05 season. In 2007/08, blue mold incidence was lower than both brown rot and gray mould. In 2008/09 and 2009/10 seasons, blue mould was the fourth disease considering the number of fruits affected, with more fruits found decayed by brown rot, bitter rot and gray mould.

An increase of *Colletotrichum* spp. among postharvest pathogens' incidence from 2004/05 to 2009/10 was evident in this study, but it is hard to appoint which factors might have contributed to such increase. General agricultural practice, pest management, and storage conditions have not significantly changed over the experimental seasons. Fungicide application schedule and fungicides used were very similar, with an exception of 2007/2008 season. As so, an increase in *Colletotrichum* spp. on stored fruits could be attributed to possible inoculum level increment or climatic variations among years. Peres et al. (2005) stated that *Colletotrichum acutatum*, common causal agent of apple postharvest rot, is widespread in apple orchards, probably living as an epiphyte on plant tissue. In Croatia, three different *Colletotrichum* species were found to cause bitter rot of apple (Ivić et al., 2013), and the significance of this disease is generally increasing (Šubić, 2013).

The results of this study show the significance of apple postharvest diseases and their potential to cause relatively substantial yield loss. In a certain way, such results can be viewed as a warrant for further development of chemical, biological or physical treatments aiming to reduce losses caused by postharvest diseases of apple.

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