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EFFECTS OF *Phyllocoptruta oleivora* (ASHMEAD) ON FRUIT YIELD, QUALITY AND ECONOMIC VALUE IN CITRUS PRODUCTION

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Abstract: Citrus, which represents important species cultivated such as orange, tangerine, lemon, grapefruit and bitter orange and is one of the most important species in the field of fruit growing, is a fruit species with high economic value cultivated in the world and in Türkiye. However, there are diseases, pests and weed species that have negative effects on the yield, quality and economic value of citrus during the production process. The pest *Phyllocoptruta oleivora* (Ashmead) or citrus rust mite (CRM) causes great losses in terms of yield, quality and economic value in citrus fruits grown intensively in Türkiye and its surroundings as well as all over the world. In this study, the effects of CRM pest on the yield, quality and economic value of citrus fruits were investigated in citrus production. In the study where the literature review method was used, the data set consists of articles, bulletins, journals belonging to scientific studies on the subject; publications of academic institutions and organizations; studies of experts on the subject; studies, published information and documents conducted by public and private institutions and organizations with authority on the subject; and information obtained from units operating in the field and involved in the agricultural production process. According to the study findings, CRM damages the leaves and fruits of citrus fruits, reduces tree productivity by 30% and fruit productivity by 2.6-65%. Physical quality characteristics of fruit reduce fruit volume (weight, length, and diameter) by 12.5-25% and increase rind thickness by 13.95-23.81. Fruit chemical quality characteristics reduce fruit juice by 22.68-32.69%, Brix/Acid value by 9.22-27.56; increase Brix value by 4.23-16.36 and acid value by 14.66-80.82. CRM reduces the market value of citrus fruits by impairing the quality of 87% of the total marketable fruit. Damages caused by CRM affect tree productivity (30%), fruit productivity (15%), the quality of total marketable fruits by 87%, thus causing losses in market value and finally, causing a cost of $ 47 per acre in pest control, thus causing losses in total economic value of the fruit. As a result, CRM causes a decrease in fruit yield, fruit quality and fruit economic value in citrus. According to the study findings, prevention of this pest will increase the economic benefit from agricultural production.

Keywords: Citrus, Citrus rut mite, Product yield, Product quality, Product economic value

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1. Introduction

Citrus fruits, which are members of the *Aurantroideae* subfamily of the *Rutaceae* family and are one of the most produced fruits in the world and Türkiye, create significant added value to the world and Türkiye economy in terms of meeting the nutritional needs of people and the raw material needs of agriculture-related industries, as well as the employment it creates. (Turgutoğlu et al., 2023). As the most cultivated fruit species in more than 130 countries in the world (Gill et al., 2023), citrus fruits are a very important agricultural product for the world and Turkish economy due to their high nutritional, market and economic added value and being the main raw material of many industrial branches (Greenhalgh, 2023).

The varieties of citrus fruits with high economic value such as orange, tangerine, lemon and grapefruit, which are the most commercially produced in the world and in Türkiye (Oral and Akpınar, 2015), there are also varieties with less commercial importance compared to other varieties such as bitter orange, kumquat, citron, shaddock and bergamot (Aygören, 2023).

Citrus fruits, which are an important part of healthy and balanced diets, may vary depending on the variety; contain dietary fiber, pectins, essential oils, minerals, approximately 75-90% water, 6-9% sugar (Santiago et al., 2020). Citrus fruits are consumed daily as fresh fruit and a significant portion, approximately 80%, is used as raw material in the food industry, and approximately 40 million tons of organic waste is generated in these productions and consumption processes (Khan et al., 2021). These wastes, especially the fruit peel, seeds and fruit juice wastes that constitute 50% of the fresh weight and are rich in valuable compounds (Santiago et al., 2020), are re-evaluated and have created a new recycling industry branch and market that produces economic added value as raw material or consumer goods for sectors such as chemistry, medicine and cosmetics (Khan et al., 2021).

According to FAO (2022) data for 2022, a total of 76,410,037.46 tons of orange production and a total of 44,179,830.73 tons of tangerine production were realized in the world (Table 1).

When ten-year orange production data in the world are examined, it is seen that orange production increased with the increase in productivity per unit area on approximately the same area until 2018, and it followed a stable course between 2018-2022, whereas tangerine production and production areas have been following an increasing course since 2017 (Table 1). According to FAO (2022) data for 2022 in Türkiye, a total of 1,322,000.00 t of orange production was carried out in an area of 49,536.00 hectares, and a total of 1,865,000.00 t of tangerine production was carried out in an area of 67,854.00 hectares (Table 2).

In recent years, while a decrease has been observed in orange production areas and quantities in Türkiye, a continuous increase has been observed in tangerine production areas and quantities (Table 2). In the world, two other citrus varieties that have significant economic value in commercial terms, lemon and grapefruit, produced 21,529,604.13 tons of lemon and 9,761,754.88 tons of grapefruit in 2022 (Table 3).

In the last decade, a continuous increase has been observed in the production areas and quantities of lemon and grapefruit in the world. In Türkiye, 1,323,000.00 t of lemon and 198,000.00 t of grapefruit were produced in 2022 (Table 4).

As in the world, in Türkiye, a continuous increase in lemon production areas and production has been observed in the last decade, while a general decrease in grapefruit production areas and quantity has been observed (Table 4).

The transformation of resources consumed in the production of citrus fruits and other production processes into products that will obtain the highest benefit, the preservation of these products and their evaluation by processing them as waste and redirecting them to the production process are sustainable activities in the agricultural production process in terms of protecting, improving and developing the existence of nature, humans and other living beings.

There are pests, diseases and weeds (Gonçalves, 2018; Soares et al., 2021) that cause significant damage to the citrus tree and fruit, causing product loss and major economic losses in the citrus production processes (Gonçalves et al., 2018; Jaouad et al, 2020).

Table 1. Total orange and tangerine production area, productivity and quantity in the world (FAOSTAT, 2022)

Years	Oranges			Tangerines, mandarins, clementines		
	Area harvested (ha)	Yield (g ha^{-1})	Production (t)	Area harvested (ha)	Yield (g ha^{-1})	Production (t)
2013	4,121,615.00	177,663.00	73,225,907.61	29,106,411.19	121,287.00	29,106,411.19
2014	4,183,444.00	173,359.00	72,523,714.97	31,275,648.83	130,776.00	31,275,648.83
2015	4,040,461.00	180,147.00	72,787,538.68	33,384,549.49	131,266.00	33,384,549.49
2016	3,987,898.00	183,668.00	73,244,874.27	32,436,221.04	129,217.00	32,436,221.04
2017	3,937,959.00	186,983.00	73,632,991.46	32,947,192.61	129,713.00	32,947,192.61
2018	3,855,676.00	190,566.00	73,476,061.68	34,484,495.96	128,652.00	34,484,495.96
2019	3,946,378.00	193,387.00	76,317,766.17	38,972,615.66	128,782.00	38,972,615.66
2020	3,971,167.00	193,089.00	76,678,733.66	39,227,438.50	129,453.00	39,227,438.50
2021	3,979,466.00	191,775.00	76,316,327.95	42,431,495.76	133,162.00	42,431,495.76
2022	3,976,571.00	192,151.00	76,410,037.46	44,179,830.73	132,121.00	44,179,830.73

Table 2. Total orange and tangerine production area, productivity and quantity in Türkiye (FAOSTAT, 2022)

Years	Oranges			Tangerines, mandarins, clementines		
	Area harvested (ha)	Yield (g ha^{-1})	Production (t)	Area harvested (ha)	Yield (g ha^{-1})	Production (t)
2013	54,759.00	325,290.00	1,781,258.00	38,693.00	243,513.00	942,226.00
2014	54,653.00	325,632.00	1,779,675.00	41,745.00	250,784.00	1,046,899.00
2015	54,298.00	334,598.00	1,816,798.00	43,506.00	265,794.00	1,156,365.00
2016	52,696.00	351,070.00	1,850,000.00	46,569.00	287,109.00	1,337,037.00
2017	51,340.00	379,821.00	1,950,000.00	50,699.00	305,818.00	1,550,469.00
2018	50,806.00	373,972.00	1,900,000.00	51,590.00	319,829.00	1,650,000.00
2019	75,112.00	226,329.00	1,700,000.00	53,554.00	261,418.00	1,400,000.00
2020	46,012.00	289,919.00	1,333,975.00	59,834.00	265,005.00	1,585,629.00
2021	48,177.00	361,583.00	1,742,000.00	60,720.00	299,572.00	1,819,000.00
2022	49,536.00	266,877.00	1,322,000.00	67,854.00	274,855.00	1,865,000.00

Table 3. Total lemon and grapefruit production area, productivity and quantity in the world (FAOSTAT, 2022)

Years	Lemons and limes			Pomelos and grapefruits		
	Area harvested (ha)	Yield (g ha^{-1})	Production (t)	Area harvested (ha)	Yield (g ha^{-1})	Production (t)
2013	1,001,265.00	154,041.00	15,423,634.13	322,213.00	263,579.00	8,492,832.66
2014	1,021,825.00	155,824.00	15,922,457.71	320,295.00	259,805.00	8,321,447.59
2015	1,061,057.00	160,069.00	16,984,227.57	356,483.00	249,196.00	8,883,428.36
2016	1,060,967.00	160,888.00	17,069,662.83	363,883.00	247,299.00	8,998,809.65
2017	1,106,884.00	157,521.00	17,435,737.19	348,016.00	249,260.00	8,674,638.92
2018	1,168,226.00	166,515.00	19,452,694.13	385,247.00	234,669.00	9,040,560.76
2019	1,254,892.00	157,544.00	19,770,009.38	371,621.00	255,396.00	9,491,035.44
2020	1,287,477.00	159,347.00	20,515,518.01	375,999.00	254,264.00	9,560,290.12
2021	1,349,775.00	159,632.00	21,546,659.85	381,703.00	254,176.00	9,701,955.92
2022	1,334,255.00	161,360.00	21,529,604.13	393,704.00	247,947.00	9,761,754.88

Table 4. Total lemon and grapefruit production area, productivity and quantity in Türkiye (FAOSTAT, 2022)

Years	Lemons and limes			Pomelos and grapefruits		
	Area Harvested (ha)	Yield (g ha^{-1})	Production (t)	Area Harvested (ha)	Yield (g ha^{-1})	Production (t)
2013	27,425.00	264,825.00	726,283.00	6,420.00	356,385.00	228,799.00
2014	27,665.00	262,147.00	725,230.00	6,388.00	359,353.00	229,555.00
2015	28,570.00	262,706.00	750,550.00	6,348.00	393,864.00	250,025.00
2016	30,033.00	283,222.00	850,600.00	6,155.00	411,243.00	253,120.00
2017	32,428.00	310,575.00	1,007,133.00	5,359.00	485,165.00	260,000.00
2018	35,911.00	306,313.00	1,100,000.00	5,182.00	482,439.00	250,000.00
2019	40,155.00	236,583.00	950,000.00	5,222.00	477,183.00	249,185.00
2020	46,935.00	253,226.00	1,188,517.00	5,052.00	471,124.00	238,012.00
2021	52,233.00	296,747.00	1,550,000.00	5,039.00	494,146.00	249,000.00
2022	55,246.00	239,474.00	1,323,000.00	4,982.00	397,431.00	198,000.00

One of the most important pests in citrus fruits is CRM which invades the branches, leaves and fruits of all kinds of citrus specie and causes significant damage to fruit yield, quality and economic value (Demard and Qureshi, 2020).

This study was carried out to investigate the effects of CRM on fruit quality traits (physical properties: weight, length, diameter and rind thickness; chemical properties: juice, Brix, acids and Brix/acid ratio) fruit yield and economic value in citrus fruits.

2. General Characteristics of CRM

CRM or silver rust mite was first reported on citrus in Florida in 1879 by entomologist William Harris Ashmead, who first discovered CRM (*Phyllocoptruta oleivora* Ashmead) on citrus and named it after him (Yothers and Mason, 1930). CRM has been found all over the world and is an important pest of citrus, especially in humid regions (McCoy and Lye, 1995), in many countries such as China, Brazil, America, Argentina, Australia, Egypt, and England (Demard and Qureshi, 2020).

CRM, which is thought to have first emerged in Southeast Asia, the homeland of citrus fruits, has the potential to reproduce in large numbers in a short time (; development from egg to egg in 7 days) under suitable growing conditions (Yothers and Mason, 1930; Hall and Simms, 2003; Demard and Qureshi, 2020), however, it has very few effective natural enemies to compensate for this (McCoy and Lye, 1995) and is difficult to detect visually because of its very small structure, posing a significant threat, especially to commercial citrus species (Ferragut et al., 2012).

The eggs of CRM, laid singly (20-30 per day during the summer season) (Beattie and Gellatley, 1983), have a smooth and transparent surface of yellow colour and are seen in groups without contact with each other in the pits on the surface of leaves and fruits (Knapp, 1994). The incubation period of CRM eggs, which is longer during the winter months when temperatures are low, is 3.01 days on average in May, June and July when temperatures are high, and they are found in very large numbers on citrus trees during these months and cause great damage by infecting green fruit (Yothers and Mason, 1930; Beattie and Gellatley, 1983; Sarada et al., 2018). Depending on the temperature, CRM can reproduce and develop very rapidly in the summer (7-10 days) as the temperature drops to a standstill in the winter months, with the reproduction rate and development time of the new generation (14 days or more) decreasing as the temperature drops (Yothers and Mason, 1930; Demard and Qureshi, 2020). Although CRM normally has a short lifespan of one week or less, up to three weeks (maximum 23 days), depending on conditions, it maintains its existence by reproducing very quickly in very large numbers and reaching adulthood in a short time (Sarada et al., 2018).

CRM, which varies in colour from lemon yellow to yellow, light brown or brown, depending on the presence or absence of fungal disease and the stage of life, is usually yellow in Florida (Burditt et al., 1963). Although CRM is not very active when it emerges from the egg as a larva at the end of the incubation period, it begins to eat the epithermal cells on the surface of leaves and fruits and undergoes metamorphosis twice until it becomes an adult (Qureshi et al., 2023). On citrus trees, CRM is very difficult to detect when they are few in number (Demard and Qureshi, 2020), but when they are very numerous (several hundreds), each mite appears as a speck of dust with a dusty or powdery texture on new and fresh leaves, fruits and small shoots (Yothers and Msaon, 1930; Plantix, 2024). CRM is sensitive to temperature, which is a climate-related event, and as temperatures increase, more favourable environments are created for CRM reproduction and development (Ullah et al., 2022). Reproduction and development do not occur at low temperatures, and they cannot survive at very low temperatures (Ullah et al., 2022). Drought has a similar effect on CRM as temperature, and they cannot survive in extreme drought (Beattie and Gellatley, 1983), CRM is less or not found at all on leaves and fruits exposed to sunlight than on leaves and fruits that do not see sunlight (Futch et al., 2021). Although most of the CRM is washed away during long rainy periods, it is protected in the lower parts of citrus trees and spreads to every part of the tree immediately after rain, so it is not affected by water (Yothers and Msaon, 1930; Sarada et al., 2018). CRM move by jumping, albeit to a limited extent (Li-juan et al., 2000), and it is estimated that they migrate from the upper surfaces of fruits and leaves during the day to the lower surfaces at night, thus protecting themselves from heavy rainfall (Knapp, 1994; Prochemica, 2020). CRM is spread by agricultural control tools, wind, rain splash, insects (ants and spiders, etc.) and birds (Li-juan et al., 2000; Sarada et al., 2018). The CRM is most active in the summer months of April, May, June and July compared to the rest of the year (Demard and Qureshi, 2020), and the citrus species it is most commonly seen and damaged during this period are lemon, grapefruit, orange and tangerine, respectively (Yothers and Msaon, 1930; Beattie and Gellatley, 1983; Sarada et al., 2018).

The fruit peel, which is a natural packaging, protects the fruit flesh from pests, balances the gas exchange of the fruit with the environment, prevents the loss of fruit water and is a determining factor in the shelf life of the fruit from harvest to the end of the marketing process (Petracek, 2002). CRM reside in the peel of citrus fruits and feed on the epidermal cells of the peel, preventing the fruit from breathing in a way.

Typical descriptions of damage caused by CRM on citrus fruit peel have been made. The spots caused by CRM on orange fruit peel are classified according to the severity of damage caused by CRM and the time of fruit ripening (Sarada et al., 2018); when CRM damage is mild, it is called “golden”; If the CRM effect is moderate, the fruit is “black russet” when it is unripe; when CRM is severe and does not spread to the entire peel, this CRM damage is called “russet” (Yothers and Msaon, 1930; Demard and Qureshi, 2020); this CRM damage is called shark ridge in early lemon and grapefruit fruits (Yothers and Msaon, 1930; Knapp, 1994; Bayer, 2024).

3. Effect of CRM on Fruit Yield

Fruit yield, which is considered a kind of reward for the producer in the agricultural production process, is a factor that determines the income to be obtained in return for the labour and production costs incurred during a production period. The amount of citrus fruit produced (kg) and the product price determined under market conditions are the components of the income function. Therefore, it is not enough for the market price to be high, but the production amount must also be high enough to provide income and additional profit. While the extent of the damage caused by CRM to citrus fruits varies according to the level of infection of the fruits by CRM and the type and variety characteristics of the citrus, the damage caused by CRM to citrus fruits reduces fruit yield (Robles-Acosta et al., 2019). Table 5 shows the fruit yield loss rate due to CRM damage in scientific studies on damage caused by CRM in citrus.

In their study examining the effect of CRM on the quality traits of orange fruits in Valencia orange variety under Adana climate conditions, Satar et al. (2020) reported the weight of heavily infected fruit was 67.78% lower than that of uninfected fruit in their study in which they classified the damage caused by CRM in the citrus Valencia orange fruit according to three different levels of infection (light, medium and high bronze) (Table 5). Imbachi et al. (2012) investigated the damage caused by *Polyphagotarsonemus latus* (Banks) and CRM on Valencia variety orange fruits and found the fruit weight value to be 199.00 g in CRM infected orange fruits and reported that damage caused by CRM in citrus cultivation reduced fruit yield by 30%. Kalaisekar et al. (2003) reported that the fruit weight of CRM-infected fruits was 25% lower in orange and 17% lower in lemon compared to uninfected fruits in their study examining the effect of CRM on citrus varieties Sathgudi orange and Rangpur lemon. In their study on CRM, van Brussel (1975) reported that damage caused by CRM in citrus cultivation in Suriname reduced fruit yield on Duncan grapefruit by 25%. In a study conducted by Yothers (1918) on the use of spray methods in pest control in citrus fruits, it was reported that CRM infected orange and grapefruit fruits were 12.50% smaller than healthy fruits, thus fruit yield decreased by 12.5%. In their studies examining effect of the EM (effective microorganisms) on soil, leaves, CRM populations, fruit quality and yield of orange trees in the Pera sweet orange variety, Paschoal et al. (1994) reported that fruit yield in CRM infected orange was reduced by 2.6%.

Table 5. Effect of CRM on citrus fruit weight

	CRM Uninfected Weight (kg)	CRM İnfected Fruit Weight (kg)	*Change Decrease (%)	Citrus Variety & Source of Data
Orange	193.40 g	67.78	65	Valensiya (Satar et al., 2020)
Citrus	-	-	30	Citrus (Imbachi et al., 2012)
Orange	184.80	138.70	25	Sathgudi (Kalaisekar et al., 2003)
Lemon	68.40	56.50	17	Rangpur (Kalaisekar et al., 2003)
Grapefruit	-	-	25	Duncan (van Brussel, 1975)
Orange	151.20	147.30	2.6	Pera (Paschoal et al., 1994)
Citrus	-	-	12.5	Citrus (Yothers and Msaon, 1930)

*= calculation of change rate % = (healthy fruit value - infected fruit value) / healthy fruit value * 100.

The reason why the effect of CRM was very low in the study of Paschoal et al. (1994) can be explained by the fact that the EM, they used in their study, reduced the effect of CRM or the EM population became dominant and reduced the level of infection of CRM.

4. Effect of CRM on Fruit Quality

In the study, the effects of CRM on the physical quality traits (fruit weight, fruit length, fruit diameter and rind thickness) and chemical quality traits (juice content, brix, total acid and brix/acid ratio) of citrus fruits were investigated.

4.1. Physical Quality Parameters in Citrus Fruits

In the Citrus, fruit weight is an important physical quality parameter in terms of commercial evaluation of the fruit as well as creating a preliminary idea about the physical and chemical components present in the fruit volume (Robles-Acosta et al., 2019; Ruiz-Camacho et al., 2023). Kalaisekar et al. (2003) observed that CRM uninfected fruit weight was 184.80 g and infected fruit weight was 138.70 g in Sathgudi orange variety and uninfected fruit weight was 68.40 g and infected fruit weight was 56.50 g in Rangpur lemon variety (The change rate decrease was 24.95% in orange and 17.40% in lemon: Calculation of change rate % = (healthy fruit value - infected fruit value)/healthy fruit value *100). Sarada et al. (2018) reported that CRM reduced fruit weight by 25% in Duncan grapefruit variety in Suriname. Imbachi et al. (2012) investigated the damage caused by *Polyphagotarsonemus latus* (Banks) and CRM on Valencia variety orange fruits and found the fruit weight value to be 199.00 g in CRM infected orange fruits and reported that there was no relationship between CRM and the weight value.

Fruit diameter and height are important physical quality parameters in determining fruit shape index in terms of marketing and customer preference in citrus fruit. CRM causes fruit to fall before ripening, deformity and shrinkage of fruit shape, thus reducing fruit yield and quality (Yang et al., 1994; Puspitarini and Endarto, 2021). Yang et al. (1994) studied the effects of CRM damage on orange fruit growth and abscission in Hamlin orange cultivar, and divided the fruit infected level into five categories (0-19, 20-39, 40-59, 60-79, 80-100) and determined the fruit diameter growth of CRM as percentage. Yang et al. (1994) reported that fruit diameter growth values in the least infected fruits were 2.6% and in the most infected fruits were 1.7% as of December 17, in their observations starting in January 1992. Satar et al. (2020) reported that the fruit diameter of Valencia orange cultivar was 69.84 mm in non-CRM infected fruits and 58.14 mm in CRM heavily infected fruits (Change rate decrease 16.75%). Kalaisekar et al. (2003) observed that fruit diameter in CRM uninfected orange and lemon fruits was 68.00 mm and 49 mm, respectively; and fruit diameter in CRM infected orange and lemon fruits was 57.00 mm and 40.00 mm, respectively (Change rate decrease 16.18% and 18.37%, respectively). Sarada et al. (2018) reported that damage caused by CRM can reduce fruit volume by 25%.

In citrus, fruit height is an important component of the fruit shape index in terms of marketing processes and customer preferences. Yothers (1918) reported in his study that orange and grapefruit fruits infected with CRM developed 12.50% less than in uninfected fruits. Kalaisekar et al. (2003) observed that the fruit length in CRM uninfected orange and lemon fruits was 66.00 mm and 47 mm, respectively; and in CRM infected orange and lemon fruits, the fruit length was 54.00 mm and 38.00 mm, respectively (Change rate decrease 18.18% and 19.35%, respectively). Satar et al. (2020) reported fruit height as 70.89 mm in CRM uninfected fruits and 59.19 mm in the most heavily infected fruits (Change rate decrease %16.50).

Peel thickness in citrus fruits is an important physical quality parameter in terms of the ripening, marketing processes and shelf life durability of the fruit. Peel thickness varies according to the citrus type and market needs, for example, thick peel is desired for fresh consumption and thin peel for juice. The peels of citrus fruits, which consist of 25% peel (Shan, 2016), have turned into a new industry branch (Shan, 2016) in the waste conversion process due to the important functional components they contain (essential oil, pectin, carotenoids, hesperidin and limonene) and are processed in the waste conversion process and used as raw materials for the chemical and pharmaceutical industries (Olife and Mohammed, 2021). CRM damages the fruit skin cells, disrupts the characteristic structure and colour of the fruit, prevents the development of the fruit, and thus can significantly reduce the marketability and economic value of the fruit (Cartwright and Browning, 1988; Chávez-Dulanto et al., 2018). Kalaisekar et al. (2003) reported the fruit peel thickness of Sathgudi orange variety as 4.30 mm in non-CRM infected fruits, 4.90 mm in heavily CRM infected fruits, and 2.10 mm and 2.60 mm in Rangpur lemon variety, respectively (Change rate increase 13.95% in orange and 23.81% in lemon).

In general, CRM feeds on the epidermal cells on the green branches, leaves and fruits of all varieties and species of citrus trees with its piercing & sucking mouth structures (Futch et al., 2021), causing these cells on the surface of fresh branches and leaves and in the peel of the fruits to lose their ability to photosynthesize (Afzal et al., 2021; Garrido et al., 2023; Roth-Nebelsick and Krause, 2023). CRM has negative effects on fruit volume (weight, height, diameter and rind thickness), one of these negative effects is that in citrus fruits infected with CRM, the water loss rate is 3 times higher than in non-infected fruits, depending on the fruit and environmental conditions, reported by Allen (1978) in a study on the Valencia orange variety. According to Imbachi et al (2012), this can cause a 30% decrease in plant fruit yield. According to scientific study data, CRM reduces the physical quality characteristics, weight, length, diameter and peel thickness, of citrus fruits that are moderately and heavily infected.

4.2. Chemical Quality Parameters in Citrus Fruits

Consumer preferences for juice, one of the intrinsic quality attributes of the citrus fruits, have strong economic importance in determining marketing processes (Rodríguez et al., 2016). Yang (2016) reported that the juice content in citrus fruits was between 40-45%, while EL-Gioushy et al. (2018) reported that the juice content of Washington Navel orange was between 41.99-44.99%. Kalaisekar et al. (2003) observed that the juice ratio in orange and lemon was 62.10 mL and 28.30 mL in CRM uninfected fruits and 41.80 mL and 20.10 mL in CRM infected fruits, respectively (Change rate decrease 32.69% in orange and 28.98% in lemon). Satar et al. (2020) reported the juice ratio of CRM in uninfected fruits of the Valencia orange variety as 49.96% and the juice ratio of the most heavily infected fruits as 38.63% (Change rate decrease %22.68).

Brix value is one of the fruit juice quality indicators used to evaluate fruit juice quality by determining the amount of water-soluble solids content as a measure of ripeness, flavour and sweetness level (Koubaa et al., 2018). Imbachi et al. (2012) observed that the Brix value was 9.70 and that CRM damaged the outer surface of the fruit, but according to the Pearson correlation test result (-0.29; 0.22), there was no significant relationship between the damage caused by CRM and the Brix values. Yothers and Mason (1930) determined the average Brix value of oranges in seven measurements taken at certain intervals from November 1 to December 30 as 10.64% in CRM-uninfected fruits and 11.09% in CRM-infected fruits (Change rate increase 4.23%). Paschoal et al. (1994) observed a Brix value of 10.70 in the control group and a Brix value of 11.30 in the EMPS (effective microorganisms applied to soil and to citrus trees) application where the CRM population was high (Change rate increase 5.60%). Kalaisekar et al. (2003) observed that the brix value in orange fruits without CRM was 11.00, in fruits with CRM infection the brix value was 12.80, and in lemon fruits it was 10.70 and 11.30, respectively (Change rate increase 16.36% in orange, 10.28% in lemon).

Acidity is an important fruit juice quality indicator (Kraus and Popek, 2013) used to determine the process from unripe fruit to full maturity and to determine fruit juice quality (Bartholomew and Sinclair, 1943). Satar et al. observed that the titratable acid value in orange fruits of the Valencia orange variety was 0.73% in CRM-infected fruits and 1.32% in CRM-infected fruits (Change rate increase 80.82). Yothers and Mason (1930) determined the average citric acid value in oranges as 1.16% in CRM-uninfected fruits and 1.33% in CRM-infected fruits (Change rate increase 14.66%). Paschoal et al. (1994) observed the citric acid value as 1.30% in the Pera sweet orange variety in CRM uninfected fruits (control group) and 1.20% in the EMPS application where the CRM population was highest (Change rate decrease 8.33%). Satar et al. and Yothers and Mason findings that CRM affects acidity values, acidity values in CRM infected fruits are higher than in CRM uninfected fruits. Contrary to these findings, Paschoal et al. (1994) observed that titratable acidity value (8.33%) was higher in CRM uninfected orange fruits than in CRM infected fruits.

Brix/acid ratio, one of the fruit juice quality indicators, is used to determine the balance between sweetness and sourness in fruit taste, as the sugar content increases and the acidity decreases as the fruit ripens, and to determine the degree of ripening of the orange fruit (Kaur et al., 2023). Yothers and Mason (1930) determined the average Brix/acid ratio value in oranges as 9.22% in CRM-uninfected fruits and 8.37% in CRM-infected fruits (Change rate decrease 9.22%). Satar et al. (2020) observed that the Brix/titratable acid value in the Valencia orange variety was 14.84% in CRM-uninfected fruits and 10.75% in CRM-infected fruits (Change rate decrease 27.56%). Kalaisekar et al. (2003) reported Brix/acid ratio values in CRM uninfected orange and lemon fruits as 12.79% and 11.38%, respectively; Brix/acid ratio values in CRM infected fruits as 16.20% and 13.56%, respectively (Change rate increase 26.66% in orange and 19.14% in lemon). Paschoal et al. (1994) observed that the brix/acid ratio value in the Pera sweet orange variety was 8.40% in the CRM-uninfected fruits (control group) and 9.70% in the EMPS application where the CRM population was the highest (Change rate increase 15.48%). While the Brix/acid ratio values of Yothers and Mason, Satar et al. confirmed the data in scientific studies on CRM (Knapp, 1994; Sarada et al., 2018; Robles-Acosta et al., 2019; Demard and Qureshi, 2020), on the contrary, Paschoal et al. observed that the Brix/acid ratio values were higher in CRM infected fruits. This difference can be explained by the EM used in the study of Paschoal et al. or by the change in the citrus variety characteristic, water-soluble solids content and acid values of the fruit juice depending on time during fruit ripening (Yang, 2016; Hussain et al., 2017).

According to scientific study data, CRM reduces the chemical quality characteristics of citrus fruits infected at moderate and heavy levels, respectively, by decreasing the juice value, increasing the Brix and acid values and decreasing the Brix/acidity ratio.

5. Effect of CRM on Fruit Economic Value

The economic value losses caused by CRM in citrus fruit production can be listed under three headings: damage to the citrus tree and fruit, market price, and control costs.

Firstly, yield loss in the tree and fruit; Imbachi et al. reported that the biggest effect of CRM on low fruit yield is the damage it causes to the fruit surface, and that production losses due to the damage it causes to the upper leaves may be approximately 30% due to the decrease in the photosynthetic capacity of the citrus tree. The studies conducted by Yothers and Mason (1930) and McCoy and Albrigo (1975), it was reported that CRM damages the epidermal cells in the fruit pod, prevents the physical and chemical development of the fruit and causes a decrease in the yield and quality of the product and causes significant economic losses. Excessive water loss in fruits heavily infected by CRM causes three times more water loss in CRM citrus fruits, the fruit peel cannot fulfil its function, the fruit volume and weight decrease; the acidity value and water-soluble solid amount increase in the fruit with reduced juice volume and all these effects are reflected in the aesthetic appearance of the fruit, as a result, the market value of the fruit whose aesthetic structure is damaged decreases (Robles-Acosta et al., 2019).

Secondly, loss in market value; the damage caused by CRM to the fruit peel reduces the fruit quality and therefore the market value of the fruit, and accordingly, it was determined that 13% of the citrus fruits grown in Florida during the 1915-16 growing season were first class, 41% second class and 46% third class (Yothers, 1918). Sarada et al. (2018) reported that CRM reduced fruit yield by 40% in Duncan grapefruit variety in Suriname. This rate is the amount of decrease in fruit weight caused by CRM by 25%, and 15% is the rate of fruit loss that falls to the ground before it is harvested due to CRM (van Brussel, 1975).

Finally, CRM control costs; Van Leeuwen et al. (2015) reported in their study analysing the global acaricide market that the market for combating mites was approximately 900 million € according to sales records of chemicals used to control mites in 2013. Childers (2011) compared the control methods used by producers with foliar spray programs containing HMO, especially in the control of CRM, and reported that the annual cost of chemical control of mites by citrus growers in Florida in the late 1990s was 171 million US dollars. In a study conducted by Pimentel (2002) on human population growth and biodiversity decline, it was reported that the annual import cost of pesticides used to control arthropod pests in the USA was approximately 20 billion dollars. According to 1977 data, the cost of controlling mites in citrus is $47 per acre. The total cost of control in Florida, United States, is approximately $40 million (Boyd, 1978).

As a result, CRM causes economic losses in citrus trees with moderate or severe infection by reducing tree productivity (30%), fruit yield (2-65%), market value (affecting the market value of 87% of the total fruit amount) and increasing production costs (costs incurred to control CRM are $47 per acre).

6. Conclusion

This literature review was conducted to investigate the effects of damages caused by CRM in citrus on fruit yield, fruit quality traits and economic value of the fruit. According to the findings of the scientific study, CRM reduces fruit yield by 2.6 - 65% depending on the level of infection and citrus variety. Similarly, it reduces fruit physical quality traits in the range of fruit volume (weight, length and diameter) by approximately 17.40 - 25.00% and increases rind thickness by 13.95 - 23.81%. In the chemical properties of fruits heavily infected with CRM, it was observed that fruit juice decreased by 22.68 - 32.69% and Brix/acid ratio by 9.22 - 27.56%, Brix value increased by 4.23 - 16.36% and acidity value increased by 14.66 - 80.82%. In citrus, the damages caused by CRM to citrus trees are 30% reduction in tree productivity, 40% reduction in fruit yield due to damages it causes to fruit (15% of fruit falling before ripening, 25% of damage to fruit at the harvest stage), 87% reduction in the quality of marketable fruit quantity and causing it to be sold at a lower market price, and finally, the cost of controlling CRM ($47 per acre) are the economic losses caused by CRM in the economic value of the fruit. Scientific studies support that CRM pest significantly affects fruit yield, fruit quality characteristics and fruit economic value in citrus cultivation. As a result, measures should be taken against CRM pest and more research should be done on this subject in order to reduce agricultural production losses and preserve its economic value.

Author Contributions

The percentages of the author contributions is presented below. The author reviewed and approved the final version of the manuscript.

	H.S.
C	100
D	100
S	100
DCP	100
DAI	100
L	100
W	100
CR	100
SR	100

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision.

Conflict of Interest

The author declare that there is no conflict of interest.

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