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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Determination of Viral Diseases in Tomato and Pepper Production Areas of Kırşehir Province, Türkiye

Türkiye'nin Kırşehir İli Domates ve Biber Üretim Alanlarında Görülen Viral Hastalıkların Belirlenmesi

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Abstract

An extensive survey study was conducted during the 2023 cultivation season to determine the prevalence of virus diseases in the Central, Kaman and Mucur districts of Kırşehir province where summer vegetable cultivation is intensively performed. During the field studies, leaf samples were collected from symptomatic plants in the cultivation areas. Leaf samples were taken from a total of 150 plants including 75 tomato and 75 pepper plants with symptoms such as yellowing (chlorosis), mild or severe mosaic, leaf deformation, blistering mosaic, vein-banding on leaves and stunting. They were tested for the presence of tobacco mosaic virus (TMV), cucumber mosaic virus (CMV), tomato mosaic virus (ToMV) and tomato spotted wilt virus (TSWV) using double antibody sandwich enzyme-linked immuno sorbent assay (DAS-ELISA) method. 122 of the 150 samples collected (81.3%), were found to be infected with various viruses and ToMV which was found as single or mixed infections, was the most common virus with 44.7% rate among these samples. ToMV was followed by TSWV with 41.3% infection rate, CMV with 16.7% and TMV with 16.0%, respectively. 18.7% of the samples taken from Kırşehir pepper and tomato cultivation areas, were determined to be infected with TSWV, 18.0% with ToMV and 10.0% with CMV in the single infections and no single infections of TMV. When the situation of mixed infections in tomato and pepper leaf samples is considered, TSWV+ToMV were detected in 14.0% of leaf samples, TMV+ToMV in 8.0%, TMV+TSWV in 3.3%, CMV+TMV in 2.7% as double infection and TMV+TSWV+ToMV in 2.7%, TMV+CMV+ToMV in 2.0% as triple infections. The most common virus in tomato leaf samples with a rate of 41.3% was ToMV, while TSWV in pepper leaf samples with 56.0%. TMV+TSWV+ToMV mixed infection caused the most damage (average damaged leaf area 88.8%) to the leaves of tomato plants. In pepper plants, the most severe disease was determined as TMV+CMV+ToMV mixed infection with mean 54.6% damaged leaf area. TSWV with 56.7% infection rate in Mucur, CMV with 41.0% in Kaman and ToMV with 77.8% in Central district were determined as the most common viruses. This study has the characteristics of the first research on the identification of viruses in tomato and pepper production areas of Kırşehir. It has emphasized the impact of ToMV and TSWV on cultivation by revealing the prevalence and diversity of viral diseases in tomato and pepper production areas in Kırşehir. Consequently, it is recommended that the use of resistant varieties, control of vectors, avoiding mono-culture production, reducing the use of infected seeds/seedlings and the application of integrated pest management for effective control of plant viruses in the region.

Keywords: Tomato, Pepper, DAS-ELISA, Vegetable viruses, Virus diseases

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Öz

Kırşehir ilinin yazlık sebze yetiştiriciliğinin yoğun olarak yapıldığı Merkez, Kaman ve Mucur ilçelerinde virüs hastalıklarının yaygınlığını belirlemek amacıyla 2023 üretim sezonu boyunca kapsamlı bir sörvey çalışması gerçekleştirilmiştir. Arazi çalışmaları sırasında üretim yapılan alanlardaki simptom gösteren bitkilerden yaprak örnekleri toplanmıştır. Bu kapsamda, yapraklarda sararma (kloroz), hafif veya şiddetli mozaik, yaprak şekil bozukluğu, kabarcıklı mozaik, damar bantlaşması ve bitkide cücelik gibi belirtiler gözlemlenen 75 domates ve 75 biber olmak üzere toplamda 150 bitkiden yaprak örneği alınmıştır. Bu yaprak örnekleri tobacco mosaic virus (TMV), cucumber mosaic virus (CMV), tomato mosaic virus (ToMV) ve tomato spotted wilt virus (TSWV) varlığını belirlemek amacıyla double antibody sandwich enzyme-linked immuno sorbent assay (DAS-ELISA) yöntemi kullanılarak test edilmiştir. Toplanan 150 örneğin 122'sinin (%81.3) çeşitli virüslerle enfekte olduğu tespit edilmiş ve bu örnekler arasında %44.7 oranında tekli veya karışık enfeksiyon şeklinde saptanan ToMV en yaygın virüs olarak belirlenmiştir. ToMV'yi sırasıyla %41.3 enfeksiyon oranıyla TSWV, %16.7 ile CMV ve %16.0 ile TMV takip etmiştir. Kırşehir biber ve domates üretim alanlarından alınan örneklerin %18.7' sinin TSWV, %18.0'ının ToMV ve %10.0'ının CMV ile tek başına enfekteli olduğu bulunmuştur. Ancak örneklerin hiçbirinde TMV'ye ait tekli enfeksiyonlara rastlanmamıştır. Domates ve biber bitkilerindeki karışık enfeksiyonların durumu değerlendirildiğinde, örneklerin %14.0'ında TSWV+ToMV, %8.0'ında TMV+ToMV, %3.3'ünde TMV+TSWV, %2.7'sinde CMV+TMV ikili enfeksiyonları ve %2.7'sinde TMV+TSWV+ToMV, son olarak %2.0'ında TMV+CMV+ToMV üçlü enfeksiyonları tespit edilmiştir. Domates yaprak örneklerinde en yaygın virüs %41.3 oranıyla ToMV olurken, biber yaprak örneklerinde ise %56.0 oranıyla TSWV, en yaygın virüs olarak tespit edilmiştir. Domates bitkilerinde yapraklara en fazla zarar veren enfeksiyon TMV+TSWV+ToMV karışık enfeksiyonu olmuştur. Bu enfeksiyonun neden olduğu hasarlı yaprak alanı ortalama %88.8 olarak ölçülmüştür. Biber bitkilerinde ise en şiddetli hastalık, ortalama %54.6 hasarlı yaprak alanı ile TMV+CMV+ToMV karışık enfeksiyonu olarak belirlenmiştir. Sonuçlar ilçelere göre değerlendirildiğinde, Mucur ilçesinde %56.7 enfeksiyon oranıyla TSWV, Kaman ilçesinde %41.0 oranıyla CMV ve Merkez ilçede %77.8 oranıyla ToMV en yaygın virüsler olarak belirlenmiştir. Bu çalışma, Kırşehir'in domates ve biber üretim alanlarındaki viral hastalıkların tanılanması açısından yapılan ilk araştırma niteliğindedir. Kırşehir'deki domates ve biber üretim alanlarında viral hastalıkların yaygınlığını ve çeşitliliğini ortaya koyarak, özellikle ToMV ve TSWV'nin üretim üzerindeki etkisini vurgulamıştır. Sonuç olarak, bölgede virüslerle etkin mücadele için dayanıklı çeşitlerin kullanımı, vektörlerin kontrolü, mono-kültür üretim şeklinin engellenmesi, enfekte tohum/fide kullanımının azaltılması ve entegre mücadele yöntemlerinin uygulanması önerilmektedir.

Anahtar Kelimeler: Domates, Biber, DAS-ELISA, Sebze virüsleri, Virüs hastalıkları

1. Introduction

Vegetables hold significant place in human nutrition not only due to their taste, aroma and unique flavors but also because of the essential nutrients, vitamins and minerals they provide. Rich in fiber, protein and various phytochemicals, vegetables play a vital role in also human health (Engindeniz, 2009). Therefore, vegetable production occupies a crucial position in global and Türkiye economies and contributing to the efficient economic utilization of agricultural lands (Engindeniz, 2009; Çelebi, 2019).

Located in a mild and subtropical climate zone, Türkiye ranks second after the USA in the world's ecologically rich countries. In our country, which has an important ecological diversity, approximately 50 different vegetable species that are subject to trade can be cultivated (Decoteau, 2000; Yanmaz et al., 2002), and more than 20 different species that are collected from the nature and consumed as vegetables without being cultivated grow in the ecology of our country (Abak et al., 2000). Tomato and pepper, belonging to the *Solanaceae* family, are annual cultivated plants that rank first among the vegetables whose fruits are eaten in our country (Günay, 1992; Yılmaz, 2014).

33.572.553 tons of vegetables were produced on 8.035.874 decares of area in Türkiye, as dated 2024. Within the total amount of vegetable production; 14.617.000 tons of tomatoes on 1.823.244 decares and 3.428.038 tons of pepper production on 855.076 decares have an important part. Tomato production was 8.111.400 tons of tomato for fresh market and 6.505.600 tons of industrial tomato; pepper production was 1.941.156 tons of industrial-Capia pepper; 933.090 tons of green pepper; 421.267 tons of bell pepper and 132.525 tons of Charleston pepper. Of the total vegetable production of 26.289 tons in Kırşehir province in 2024; 9.699 tons of tomatoes and 1.662 tons of peppers were produced (TurkStat, 2025).

Diseases caused by phytopathogens are among the essential factors that reduce yield and quality in tomato and pepper cultivation, which have an important role in both our country and Kırşehir province vegetable cultivation. Due to the lack of any chemical control against plant virus diseases, the challenge becomes difficult, and viruses cause significant yield losses. In the control of these viral diseases, which are a problem in agricultural areas, cultural methods should be applied, resistant varieties and healthy plant propagation material should be used, and an effective control of vectors should be carried out. Therefore, it is very important to use appropriate diagnostic methods and take necessary precautions in the control of viruses (Çulal Kılıç and Yardımcı, 2012).

Tobacco mosaic virus (TMV; *Tobamovirus tabaci*) and tomato mosaic virus (ToMV; *Tobamovirus tomatotessellati*), members of the genus *Tobamovirus* (*Virgaviridae* family) (Randa-Zelyüt et al., 2025), are among the most important viruses observed in tomato and pepper production areas. After tobacco, tomato plants are the most damaged vegetable species by TMV, and epidemics in which 100% of tomato plants are infected are frequently experienced. Depending on the growth period of the tomato plant and the time of infection, sometimes combined with poor quality of the remaining fruits, the yield loss caused by TMV can range from 18% to 50% (Mandahar, 2000; Marys et al., 2008). ToMV, one of the most widespread and destructive viruses affecting tomato production (Mrkvová et al., 2022), which can spread rapidly and cause serious damage to all susceptible tomato varieties (Pozharskiy et al., 2022), is responsible for up to 50% losses (Linn and Wricht, 1951). Since these two viruses have a very broad host range, these harmful effects are not limited to tomato plants, but are also responsible for serious yield losses, especially in pepper plants (Kumar et al., 2011; Lueloff and Hudelson, 2024).

Cucumber mosaic virus (CMV; *Cucumovirus CMV*) (*Bromoviridae*: *Cucumovirus*) is a viral disease agent that occurs worldwide and is regarded as very important in tropical and subtropical regions of the world. During the dry and hot spring months, the number and activity of aphids increases and infection rates approach 100% and plants may need to be uprooted and removed (Hooks and Fereres, 2006). Generally, losses due to CMV infections are between 10 and 20%, and in some cases, although the crop can still be harvested, the market value is reduced because the fruits obtained appear to be of poor quality (Palukaitis and García-Arenal, 2003).

Tomato spotted wilt virus (TSWV; *Orthotospovirus tomatomaculae*), which belongs to the genus *Orthotospovirus* of the family *Tospoviridae* (Tsompana et al., 2005) and causes more than 1 billion dollars loss in agricultural production every year (Griep et al., 2000), infects 1.090 dicotyledonous and monocotyledonous plant species belonging to 80 different families (Parrella et al., 2003). TSWV causes infection in numerous vegetables, fruits, ornamental plants and weeds in tropical and subtropical regions and its common hosts include tomato, pepper, tobacco, potato and lettuce (EPPO, 2021). In studies conducted worldwide, TSWV has been reported to

cause 75-100% yield loss in tomato plants (Gitaitis et al., 1998) and 40% in pepper plants (Gracia et al., 1999). TSWV, which is transmitted by thrips (Scholthof et al., 2011), is known to cause damage mainly on *Solanaceae* vegetables such as tomatoes and peppers (Soler et al., 1998).

The symptoms and severity of infections caused by ToMV, TMV, CMV, and TSWV — which are among the most significant viral pathogens affecting tomato and pepper crops — vary depending on several factors, including the host plant species, developmental stage and age of the plant, cultivar, time of infection, climatic conditions, and the specific viral strain involved (Soler et al., 1998). The general symptoms of these 4 viruses in tomato and pepper plants include chlorosis, mosaic, rugose, narrowing of leaf laminae (such as fern leaf symptoms), curling, deformations, necrotic spots and streaks, mottling and smaller than normal leaf blade development; plant stunting, chlorotic and necrotic ring spots on fruits (Abad et al, 2000; Mazourek et al., 2009; EPPO, 2021; Pozharskiy et al., 2022; Lueloff and Hudelson, 2024).

As can be recognized from the production data, tomato and pepper constitute the majority of vegetable production in Kırşehir province (TurkStat, 2025). Tomato and pepper cultivation is severely affected by TMV, ToMV, TSWV and CMV infections (Nikolić et al., 2018). There are many studies to determine the occurrence, prevalence and diseases caused by these 4 viruses in vegetable production areas in Türkiye (Güldür et al., 1995; Bostan and Dursun, 2002; Arlı-Sökmen and Şevik, 2006; Çelik et al., 2010; Şevik and Arlı-Sökmen, 2012; Paylan and Erkan, 2013; Yılmaz, 2014; Geyik, 2017; Özdağ and Sertkaya, 2017; Öncü, 2021; Deligöz et al., 2023), but there is no record of the situation in Kırşehir province where tomato and pepper production is increasing every year (TurkStat, 2025). Although virus-like symptoms were observed in the surveys conducted in tomato and pepper production areas, the absence of prior studies identifying the viruses causing these diseases was the primary reason for our research. This study aimed to identify the viral agents threatening tomato and pepper production in our province and to support the development of effective control programs. Tomato and pepper leaf samples collected from the districts of Kırşehir province (Mucur, Kaman, and Central districts) were tested for the most common viral agents -TMV, TSWV, ToMV, and CMV- using the DAS-ELISA method. As a result, the prevalence rates of these viral agents in Kırşehir's vegetable production areas were determined. This study has, for the first time, revealed the status and prevalence rates of these four viruses in Kırşehir's tomato and pepper production areas.

2. Materials and Methods

2.1. Surveys and leaf sample collection

In Kırşehir province, surveys were conducted in Kaman, Mucur and Central districts where tomato and pepper production are widespread. During the surveys, a total of 150 leaf samples were collected from tomato and pepper plants with symptoms similar to TMV, CMV, ToMV and TSWV. During the field studies, the sample number, collection location, plant species and observed symptoms on the plants were recorded. The number of samples collected from the districts was determined based on the cultivated area (decares) and production amounts (tons), and these data are shown in detail in *Table 1*.

Table 1. Tomato and pepper cultivated area, production amounts in 2023 (TurkStat, 2025) and number of samples collected by districts

District	Tomato			Pepper		
	Cultivated area (decares)	Production (tons)	Number of Samples Collected	Cultivated area (decares)	Production (tons)	Number of Samples Collected
Center	1.119	3.999	39	1.546	1.344	42
Mucur	760	2.555	21	248	176	18
Kaman	450	1.395	15	130	144	15
Total	**2.329**	**7.949**	**75**	**1.924**	**1.664**	**75**

The collected tomato and pepper samples were placed in polyethylene bags and brought to the laboratory with a cold chain (in ice box). After the samples brought to the laboratory were examined symptomatologically, they were photographed and the damaged leaf area (%) was calculated using WinDIAS Leaf Image Analysis System. Then, they stored in the fridge at +4 °C and -20 °C for use in laboratory studies.

2.2. Serological (DAS-ELISA) tests

Tomato and pepper samples collected from the land and brought to the laboratory in polyethylene bags with cold chain were stored at +4 °C until serological tests (DAS-ELISA) were performed. The enumerated tomato and pepper leaf samples were tested against TMV, CMV, ToMV and TSWV according to the company's protocol (Clark and Adams, 1977; Bioreba, 2017).

2.2.1. DAS-ELISA testing stage

According to the protocol, the following steps were taken when conducting DAS-ELISA tests;

- An amount of 1:1000 dilution of virus-specific IgG was added to the coating buffer in the commercial kits, and then 200 µl of the prepared coating buffer was dispensed into each well of the plates. The coated plates were covered with parafilm or a protective cover and incubated overnight at 4 °C. At the end of the incubation time, 200 µl of washing buffer was added to each well and washed 3 times.
- Tomato and pepper leaf samples from the surveys were weighed 100 mg each, placed in sample extraction bags and numbered. Approximately 2 ml of extraction buffer was then added to each sample bag and the samples were homogenized by grinding. The homogenized plant extracts were transferred into numbered 1.5 ml eppendorf tubes and stored in the refrigerator at +4°C until used in the tests.
- 200 µl of the plant samples prepared using extraction buffer was added to each well in the coated, washed and dried plates. In addition, 200 µl of extraction buffer (for blank), negative control and positive control of the tested virus were added to one for each. The plates were covered with a protective cover or parafilm and incubated overnight at 4°C. At the end of the incubation time, the plates were washed 3 times with washing buffer and dried.
- Conjugate was added to the conjugate buffer included in the DAS-ELISA kits to be diluted 1:1000 and conjugate buffer was prepared as many times as the number of samples. 200 µl of this buffer was added to each well, then the ELISA plates were covered with parafilm and incubated at 32 °C for 4 hours. After incubation, the plates were washed 3 times with washing buffer and dried.
- The substrate pNPP (para-nitrophenylphosphate) was dissolved in substrate buffer to a final concentration of 1 mg ml^{-1} and 200 µl of the prepared buffer was dispensed into each well. To prevent false yellowing of the substrate by exposure to light, the plates covered with substrate buffer were incubated in the dark at room temperature (20-25°C) for at least half an hour until the positive control showed yellow color.

2.2.2. Evaluation of test results

Yellow coloration of ELISA plates was assessed both visually and spectrophotometrically. For spectrophotometric evaluation, after substrate buffer was added and incubated for 30-120 min, OD values were measured at 405 nm wavelength on the Biobase ELISA Reader device (China). The cut-off value for each test was calculated according to the formula in the company's data analysis descriptions, and mean OD values above the cut-off value were considered positive (Bioreba, 2014).

3. Results and Discussion

3.1. Results obtained from surveys

During the 2023 cultivation season, plant samples were collected from tomato and pepper production areas in the Central, Kaman and Mucur districts of Kırşehir province. Viral disease-like symptoms observed in tomato and pepper plants were recorded during the surveys. The general symptoms observed in the plants within the scope of the research were yellowing of the leaves (chlorosis), mild or severe mosaic, leaf deformation, blister mosaic, vein banding and stunting of the plant (*Figure 1*). Symptomatological observations made in the laboratory and in the surveys are important as a preliminary step for the detection of viruses.

Figure 1. Some symptoms observed in the cultivated areas during the surveys. A: Vein banding on pepper plants, B: Severe mosaic and vein banding on pepper plants, C: blistering mosaic and vein banding on tomato plants

During the surveys carried out vegetable production areas in Mucur district, the most common symptoms observed in tomato plants were chlorosis, mosaic, curling, deformity and vein banding on leaves. In Kaman district, the common symptoms of tomato plants were chlorosis, mosaic, blister mosaic and distortion, while in the Central district, mottling symptoms were observed in addition to chlorosis, mosaic, blister mosaic and vein banding on leaves *(Figure 2)*. In a similar study conducted to determine virus diseases in tomato production areas of Bursa, Bilecik and Yalova provinces, it was reported that the most characteristic symptoms seen in the fields were chlorosis, mosaic, curling, necrotic spots and deformations on the leaves (Geyik, 2017; Randa-Zelyüt et al., 2024). In addition, another study investigating the prevalence and distribution of TSWV in vegetables cultivated in Antalya province reported that common symptoms in tomato and pepper plants included chlorosis, downward curling, and necrotic lessions on the leaves; chlorotic and necrotic ring spots on the fruits. As a result of the DAS-ELISA tests performed, TSWV infections were detected in 81% of tomato leaf and fruit samples and 92% of pepper samples with these symptoms (Bozdogan and Kamberoglu, 2015).

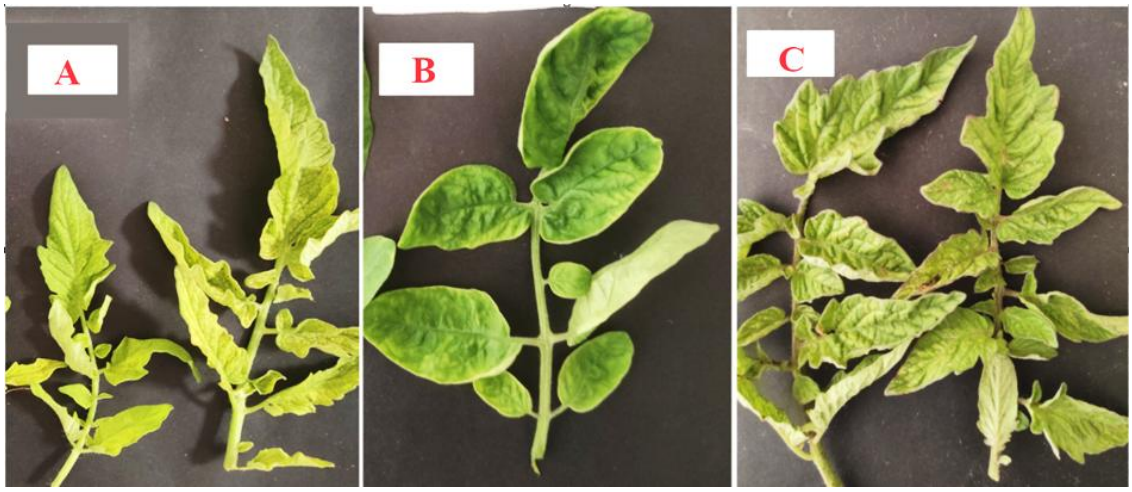

Figure 2. Some symptoms observed in tomato plants. A: chlorosis and mottling; B: blister mosaic, leaf distortion and vein banding; C: blister mosaic and vein banding.

In Mucur district of Kırşehir, the most common symptoms recorded in pepper production areas were chlorosis, mosaic and blister mosaic on leaves. In addition to these symptoms, curling, deformation, vein banding on leaves and stunting of plants were recorded in Kaman and Central districts *(Figure 3)*. In a study conducted with pepper plants in four different regions of Türkiye, which are Aegean, Mediterranean, Black Sea and Marmara, it was emphasized that the most common symptoms in production areas were mosaic, chlorotic or necrotic ring spots, mottling and deformation on leaves (Deligöz et al., 2023).

Figure 3. Some symptoms observed in pepper plants. A: mosaic, leaf distortion and vein banding; B: mild mosaic and leaf distortion; C: vein banding and leaf curling.

3.2. Results of DAS-ELISA tests

As a result of DAS-ELISA tests, it was determined that 50 (66.7%) of 75 tomato samples collected from Kırşehir districts were infected. Single infections of ToMV in 18 (24.0%), CMV in 9 (12.0%), TSWV in 7 (9.3%); mixed infections of TSWV+ToMV in 6 (8.0%), TMV+TSWV+ToMV in 4 (5.3%), TMV+ToMV in 3 (4.0%) and TMV+TSWV in 3 (4.0%) of the samples were detected *(Table 2)*. Similar to our study, ToMV (22.3%) and CMV (20.2%) were found to be the most common viral agents in 94 tomato samples tested with DAS-ELISA in tomato production areas of the Marmara region, while TSWV single infections were detected in 2.1% of the samples. The status of mixed infections in tomato samples was ranked as CMV+ToMV with 14.9% infection rate, CMV+TSWV with 4.3%, CMV+ToMV+TSWV with 4.3%, ToMV+TSWV with 1.1% (Geyik, 2017).

ToMV was identified as single or mixed infection in 31 of 75 tomato samples from Kırşehir province and was the most common virus with 41.3% infection rate (*Table 2*). ToMV, one of the most widespread and destructive viruses of tomato plants (Mrkvová et al., 2022), is reported to be rapidly spreading and causing serious damage to all especially susceptible tomato varieties (Pozharskiy et al., 2022), and is known to be responsible for yield losses of up to 50.0% (Linn and Wricht, 1951). In tomato plants, ToMV was followed by TSWV with 26.7% infection rate, TMV with 13.3% and CMV with 12.0%, respectively. TMV was not detected as a single infection in any of the tomato samples and other viruses were found both as single and mixed infections *(Table 2)*. In studies conducted worldwide, it was reported that TSWV caused 75-100% yield loss in tomato plants (Gitaitis et al., 1998), and in a study conducted in Samsun province in our country, it was reported that TSWV caused 46.0% yield loss and over 95.0% loss of marketable value (Şevik and Arlı-Sökmen, 2012). Likewise, losses due to CMV infections in tomato plants can reach up to 20.0%, and products become unmarketable due to low quality fruit formation (Palukaitis and García-Arenal, 2003).

In this study, 72 (96.0%) of 75 pepper leaf samples collected from pepper production areas in Kırşehir province were found to be infected with viruses. TSWV infections were detected in 21 (28.0%), TSWV+ToMV in 15 (20.0%), CMV in 9 (12.0%), ToMV in 9 (12.0%), TMV+ToMV in 9 (12.0%), CMV+TSWV in 4 (5.3%), TMV+CMV+ToMV in 3 (4.0%) and TMV+TSWV in 2 (2.7%) of the pepper samples *(Table 2)*. In a similar study conducted by Deligöz et al. (2023) to determine the viruses infecting pepper plants, TSWV was the most common virus detected in 55.0% of the pepper samples tested by DAS-ELISA, followed by CMV with 22.2%, CMV+TSWV with 4.5%, TSWV+PVY with 0.6%, TSWV+PMMoV with 0.5%, CMV+PMMoV and CMV+TSWV+PVY with 0.3%, and CMV+TSWV+PMMoV with 0.2% respectively. In another study conducted in Hatay pepper production areas, it was reported that PVY and CMV were the two most common viruses detected in 13.8% and 5.5% of the tested samples respectively, and many mixed infections of ToMV and TSWV were found in plants (Özdağ and Sertkaya, 2017).

In Kırşehir province, the presence of these four virus infections or their combinations was detected in 66.7% of the tomato and 96.0% of the pepper samples collected cultivation areas. The reason why peppers are more infected than tomatoes may be due to differences in the susceptibility of the varieties used in cultivation, higher density of vector populations such as thrips for peppers and more favorable conditions for the survival and multiplication of viruses and vectors. The combination of these factors may have led to a higher rate of virus exposure in pepper plants compared to

tomato plants. Therefore, it is very important to practice integrated pest management strategies and to prefer resistant varieties in pepper cultivation.

Table 2. Virus infections detected in tomato and pepper leaf samples and their prevalence rates (%)

Plant Species	District	Number of Samples			Single Infections				Mixed Infections					
		Tested	**Infected**	**Negative**	**TMV**	**CMV**	**TSWV**	**ToMV**	**TMV+ToMV**	**TSWV+ToMV**	**TMV+TSWV**	**CMV+TSWV**	**TMV+TSWV+ToMV**	**TMV+CMV+ToMV**
TOMATO	Mucur	15	8 53.3%	7 47.0%	-- --	-- --	7 46.7%	-- --	-- --	-- --	-- --	-- --	1 6.6%	-- --
	Kaman	21	12 57.0%	9 43.0%	-- --	6 29.0%	-- --	3 14.0%	-- --	-- --	3 14.0%	-- --	-- --	-- --
	Center	39	30 77.0%	9 23.0%	-- --	3 7.7%	-- --	15 39.0%	3 7.7%	6 15.0%	-- --	-- --	3 7.7%	-- --
	Total	**75**	**50** **66.7%**	**25** **33.0%**	**--** **--**	**9** **12.0%**	**7** **9.3%**	**18** **24.0%**	**3** **4.0%**	**6** **8.0%**	**3** **4.0%**	**--** **--**	**4** **5.3%**	**--** **--**
PEPPER	Mucur	15	12 80.0%	3 20.0%	-- --	3 20.0%	9 60.0%	-- --	-- --	-- --	-- --	-- --	-- --	-- --
	Kaman	18	18 100.0%	-- --	-- --	6 33.3%	6 33.3%	-- --	-- --	-- --	2 11.0%	4 22.2%	-- --	-- --
	Center	42	42 100.0%	-- --	-- --	-- --	6 14.3%	9 21.4%	9 21.4%	15 35.7%	-- --	-- --	-- --	3 7.2%
	Total	**75**	**72** **96.0%**	**3** **4.0%**	**--** **--**	**9** **12.0%**	**21** **28.0%**	**9** **12.0%**	**9** **12.0%**	**15** **20.0%**	**2** **2.7%**	**4** **5.3%**	**--** **--**	**3** **4.0%**
General Total		**150**	**122** **81.3%**	**28** **18.7%**	**--** **--**	**18** **10.0%**	**28** **18.7%**	**27** **18.0%**	**12** **8.0%**	**21** **14.0%**	**5** **3.3%**	**4** **2.7%**	**4** **2.7%**	**3** **2.0%**

* The prevalence rates of viruses were indicated in %. Undetected virus infections were indicated with '--' instead of '0'

TSWV, which was detected as single and mixed infection in 42 of 75 pepper samples collected from Kırşehir pepper production areas, was the most common virus with 56.0% infection rate, followed by ToMV with 48.0% and CMV with 21.3%. The infection rate of TMV, which was found in only mixed infection with various viruses in 14 pepper samples, was 18.7% *(Table 2)*. TSWV, which also includes pepper among its common hosts (Parrella et al., 2003) and is reported to cause over 1 billion dollars loss in agricultural production every year (Griep et al., 2000), is reported to cause 40.0% yield loss in pepper plants (Gracia et al., 1999). From this point of view, TSWV is one of the most important diseases to be considered in pepper production in Kırşehir province. As all tobamoviruses, ToMV is a seed-borne virus (Almeida et al., 2018). In recent years, there have been some studies that provide evidence that TSWV can also be transmitted in pepper seeds (Wang et al., 2022; Uslu and Yorgancı, 2024). Vegetable cultivation in Kırşehir province is mostly practiced with seedlings produced from the seeds taken by the farmers themselves. Considering this situation, the fact that TSWV and ToMV are highly widespread in pepper cultivation areas suggests that the diseases are spread by seeds. Therefore, farmers should be informed as soon as possible, especially about the use of healthy plant propagation materials (seeds or seedlings).

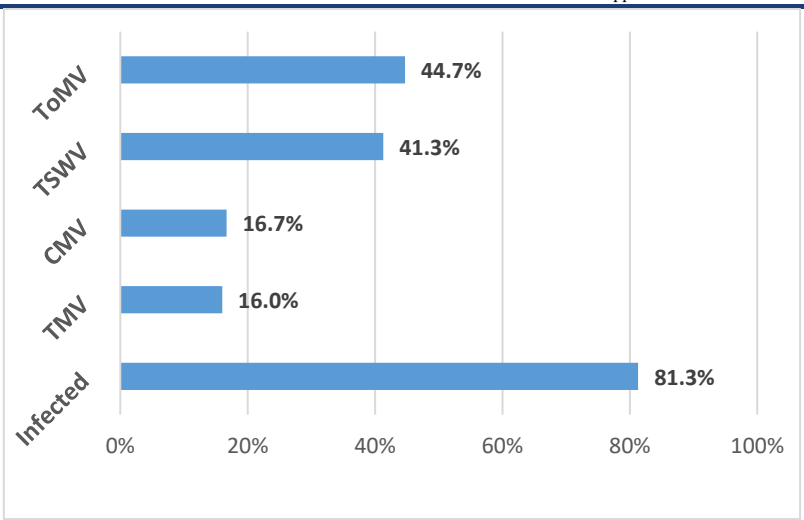

Figure 4. Prevalence rates of viruses detected in tomato and pepper plants.

As a result of the DAS-ELISA test performed on 150 plant leaf samples (75 tomato and 75 pepper samples) collected from Kırşehir districts, 122 of the samples (81.3%) were found to be infected with various viruses analyzed *(Table 2, Figure 4)*. 18.7% (28 samples) of the samples were infected with TSWV, 18.0% (27 samples) with ToMV and 10.0% (18 samples) with CMV singly and none of the samples were detected to have TMV single infections. When the status of mixed infections in tomato and pepper plants was evaluated, TSWV+ToMV infections were detected in 14.0% (21 samples), TMV+ToMV in 8.0% (12 samples), TMV+TSWV in 3.3% (5 samples), CMV+TMV and TMV+TSWV+ToMV in 2.7% (4 samples each), and TMV+CMV+ToMV in 2.0% (3 samples) (*Table 2*). The most common virus detected in tomato and pepper samples collected from Kırşehir production areas was ToMV with a disease rate of 44.7%, followed by TSWV with 41.3%, CMV with 16.7% and TMV with 16.0% *(Figure 4)*. In a study conducted in Eskişehir province similar to our study, it was reported that 72.3% of the 170 tomato and pepper samples were infected with various viruses as a result of DAS-ELISA tests and the most common virus was TSWV with an infection rate of 38.2%. TSWV was followed by CMV with 21.2%, PVY with 7.6%, TMV with 3.5%, and ToMV with 1.8% (Öncü, 2021).

3.3. Effect of virus infections on damaged leaf area (%)

The leaf damage caused by virus infections to tomato and pepper plants was calculated using WinDIAS Leaf Image Analysis System. Accordingly, the most important infections affecting the average damaged leaf area were TMV+CMV+ToMV (54.6%) in pepper plants and TMV+TSWV+ToMV (88.8%) in tomato plants. TSWV single

Table 3. Damaged leaf area (%) of tomato and pepper plants by virus infections

Determined Virus Infection	Pepper Leaf Samples		Tomato Leaf Samples	
	Number of Infected Plant Samples	Damaged Leaf Area (%)**	Number of Infected Plant Samples	Damaged Leaf Area (%)**
TSWV	21	17.94	7	53.72
ToMV	9	47.01	18	81.59
CMV	9	51.38	9	54.29
TMV+TSWV	2	30.16	3	84.79
CMV+TSWV	4	34.46	---	---
TSWV+ToMV	15	35.83	6	77.66
TMV+ToMV	9	53.72	3	79.84
TMV+CMV+ToMV	3	54.55	---	---
TMV+TSWV+ToMV	---	---	4	88.84

* Undetermined virus infections are indicated in "---". ** Damaged leaf area values (%) are mean values and were calculated by averaging the damaged leaf area values (%) of all infected plants

infections had the least impact on the average damaged leaf area in both plant species (17.9% for pepper samples and 53.7% for tomato samples). It is often seen that viruses can cause more damage to plants in cases of mixed infection *(Table 3)*. It is known that image processing techniques have started to be used especially in the creation of visual disease severity scales and diagnosis of plant diseases. Calculating the average damaged leaf area (%) using various programs is an important step that contributes to these techniques (Petrellis, 2018). Although the rate and severity of disease caused by viruses varies according to the host plant, presence of vectors, virus type and environmental conditions (Mazourek et al., 2009; Lueloff and Hudelson, 2024), these types of quantitative assessments provide more concrete outputs for preliminary evaluation (Nutter et al., 2006).

3.4. Prevalence of virus diseases by districts

When the status of virus diseases detected in 150 plant samples collected from tomato and pepper production areas of Kırşehir province was observed, it was identified that Mucur had an infection rate of 66.7%, Kaman had an infection rate of 76.9% and the Central district had an infection rate of 88.9%. The most common viruses were TSWV with 56.7% infection rate in Mucur, CMV with 41.0% in Kaman and ToMV with 77.8% in the Central district *(Figure 5)*. According to DAS-ELISA test results of tomato plants, 7 (46.7%) of 15 tomato samples from Mucur district with 53.3% infection rate were infected with TSWV and 1 (6.6%) with TMV+TSWV+ToMV, while 6 (29.0%) CMV, 3 (14.0%) ToMV and 3 (14.0%) TMV+TSWV were detected in 21 samples from Kaman district with 57.0% infection rate. Finally, ToMV was determined in 15 (39.0%), TSWV+ToMV in 6 (15.0%), CMV in 3 (7.7%), TMV+ToMV in 3 (7.7%) and TMV+TSWV+ToMV in 3 (7.7%) of the 39 samples collected from the Central district with 77.0% disease rate (*Table 2*). Symptomatologic evaluation of the results showed that there were also differences in the symptom distribution recorded in tomato plant samples. For example, mottling on leaves in the Central district and leaf curling in Kaman were also observed in addition to the common symptoms of chlorosis, mosaic, blister mosaic, vein banding and deformation on leaves. It was concluded that the samples showing symptoms of leaf yellowing and curling were infected with TSWV, while the samples showing symptoms of vein banding and leaf mottling were infected with TSWV+ToMV. Among the symptoms caused by ToMV in tomato plants are vein banding and mottling (Pozharskiy et al., 2022), while TSWV causes leaf chlorosis and leaf curling (EPPO, 2021).

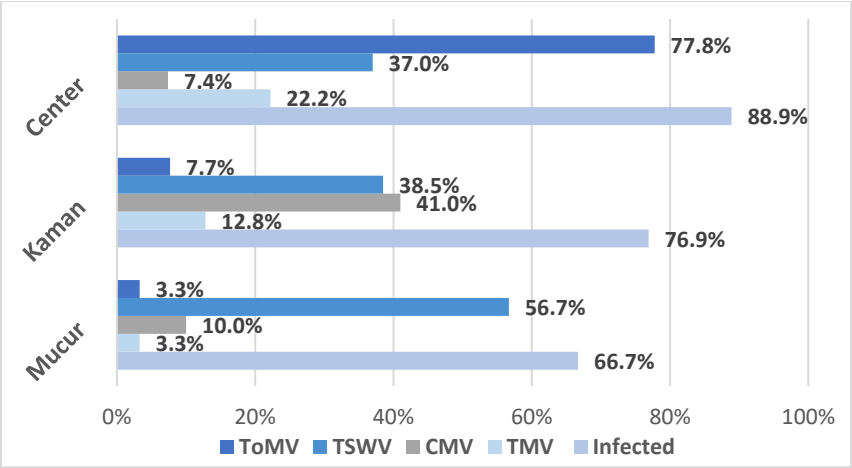

Figure 5. Viruses detected in tomato and pepper plants by districts

As a result of DAS-ELISA tests applied to pepper plants, TSWV and CMV infections were detected in 9 (60.0%) and 3 (20.0%) of 15 pepper samples obtained from Mucur, which has an 80.0% infection rate, and the samples were negative for other viruses. In Kaman and Central districts, the occurrence rate of all four viruses was found to be 100%. Among the 18 pepper samples collected from the Kaman district, 6 samples (33.3%) had single infections of CMV, and 6 samples (33.3%) had single infections of TSWV. Additionally, 4 samples (22.2%) were infected with the mixed combination of CMV+TSWV, and 2 samples (11.0%) showed mixed infections of TMV+TSWV. Finally, TSWV+ToMV infections were determined in 15 (35.7%), ToMV in 9 (21.4%), TMV+ToMV in 9 (21.4%), TSWV in 6 (14.3%) and TMV+CMV+ToMV in 3 (7.2%) of 42 pepper samples from the Central district (*Table 2*). When the results were evaluated symptomatologically, it was observed that the

common symptoms in pepper plants included chlorosis, mosaic, and blister mosaic. In the Kaman and Mucur districts, in addition to these symptoms, leaf curling, deformation, vein banding, and stunting were frequently recorded. Within the scope of the study, single infections of ToMV were detected in pepper samples (3 samples) showing chlorosis and curling symptoms on leaves; TSWV in 21 samples showing chlorosis, deformation and vein banding symptoms on leaves; CMV single infections were detected in 9 samples showing chlorosis, mosaic, rugose, vein banding on leaves and plant stunting. Lastly, TSWV+ToMV mixed infections were detected in 15 samples with chlorosis, curling, vein banding, internode shortening and stunting symptoms. Depending on the infection period, the symptoms of TSWV and CMV on pepper leaves vary, but severe chlorosis is observed in the early stages and stunting of plants occurs in the later stages caused by shortening of internodes (Abad et al., 2000; EPPO, 2021).

4. Conclusions

Viral pathogens have been identified as a significant threat to vegetable production in both global and national research efforts. Symptomatological investigations conducted in tomato and pepper production areas in Kırşehir province have identified the presence of current viral diseases. Determining the prevalence of viral agents through serological methods is critical for the development of effective control programs. In Kırşehir, the monoculture production method is commonly preferred. This approach is adopted to reduce the use of agricultural machinery, simplify production processes, lower costs, and achieve higher yields. However, monoculture practices lead to the depletion of soil nutrients, an increase in pest and disease intensity by providing a continuous host environment, and a significant reduction in ecological diversity. This study recommends more sustainable agricultural methods, such as crop rotation or polyculture, to improve agricultural productivity and protect the ecosystem. Additionally, the virus isolates obtained from this research provide valuable resources for future studies aimed at developing virus-resistant plant varieties. In this context, the study not only fills an important gap in literature but also serves as a foundational work for future research efforts.

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Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Literature Search: Çandar, A., Şavkan, A.; Sample Collection: Başak, H., Çandar, A., Aydın, A., Şavkan, A.; Sample Preparation for Tests and Symptomatological Observations: Çandar, A., Güngör, R., Şavkan, A., Aydın, A.; Laboratory Analysis: Çandar, A.; Writing, Review and Editing: Başak, H., Çandar, A., Aydın, A.

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