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Cover Crops and Flower Strip Plants as Potential Hosts for Sugar Beet-Infecting Virus Yellows Species and Their Attractiveness to the Vector *Myzus persicae*

Simon Borgolte | Mark Varrelmann

Department of Phytopathology, Institute of Sugar Beet Research (IfZ), Göttingen, Germany

Correspondence: Mark Varrelmann (varrelmann@ifz-goettingen.de)

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ABSTRACT

Virus yellows (VY), caused by beet chlorosis virus (BChV), beet mild yellowing virus (BMYV) and beet yellows virus (BYV), is a serious disease affecting sugar beet, leading to significant yield losses. The main vector is the green peach aphid *Myzus persicae*. Beet mosaic virus (BtMV) is often associated with VY due to the shared vector. Different host plants of VY-associated viruses can play an important role in the aphid's life cycle and the VY-epidemiology. This study evaluated the susceptibility of 25 cover crops and flower strip plants to VY-associated viruses as well as their attractiveness to *M. persicae*. None of the tested plants were susceptible to BYV or BtMV, while *Gypsophila elegans* tested positive for BChV and 13 species tested positive for BMYV. Seven of these, including important cover crops and flower strip plants such as *Linum usitatissimum*, *Trifolium resupinatum*, *T. incarnatum* and *Centaurea cyanus*, were identified as new BMYV hosts. Plant attractiveness to *M. persicae* varied widely. Under field conditions, only a few species, such as *Sinapis alba* or *Raphanus sativus* var. *oleiferus*, showed high levels of natural infestation by *M. persicae*. However, a field choice experiment revealed that BMYV infection can occur in different plants, even at low levels of *M. persicae* infestation. Field trials also confirmed that *M. persicae* can transmit BMYV from infected cover crops to sugar beet. The findings emphasise the potential importance of cover crops and flower strip plants as green bridges in VY-epidemiology and highlight the need for research in large-scale field studies.

1 | Introduction

Sugar beet (*Beta vulgaris* subsp. *vulgaris*) accounts for 20% of global sugar production and was cultivated on 4.5 million ha of land in 2023. With 3.0 million ha and 16.2 million tonnes of sugar, the European Union (EU) is the largest producer of sucrose from sugar beet (European Association of Sugar Manufacturers 2023; FAO [Food and Agriculture Organization of the United Nations] 2025).

Virus yellows (VY) is one of the most harmful virus diseases in sugar beet, causing yellowing, chlorosis and necrosis of the leaves and significant yield losses (Hossain et al. 2021). The VY complex consists of three viruses, beet chlorosis virus (BChV) and beet mild yellowing virus (BMYV), both family *Solemoviridae*, genus *Polerovirus* and beet yellows virus (BYV), family *Closteroviridae*, genus *Closterovirus* (de Koeijer and van der Werf 1999; Stevens et al. 2005). Beet mosaic virus (BtMV), family *Potyviridae*, genus *Potyvirus*, is not a typical VY member as it causes mosaic like patches on the canopy (Wintermantel 2005). However, it is often associated with VY due to their common vector. The main vector of all four viruses is the green peach aphid *Myzus persicae*. BChV and BMYV are persistently transmitted, BYV is semipersistently transmitted and BtMV is nonpersistently transmitted (Dusi and Peters 1999; Kozłowska-Makulska et al. 2009; Limburg et al. 1997; Schliephake et al. 1999). The earlier BChV, BMYV

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and BYV infections occur in sugar beet in spring, the greater the losses in sugar beet root yield and sugar content. BtMV causes only minor and no significant yield losses under field conditions (Borgolte et al. 2024; Hossain et al. 2021; Shepherd et al. 1964; Smith and Hallsworth 1990; Stevens et al. 2004). To date, no sugar beet varieties are available that exhibit high tolerance and resistance to all VY-associated viruses and have no yield penalty.

Myzus persicae is a host-alternating aphid and is very polyphagous, with secondary host plants in more than 40 plant families. Depending on the temperature in autumn/winter and the presence of the primary winter hosts (mainly *Prunus persica*), the life cycle can be divided into holocyclic, as eggs on the primary winter host after sexual reproduction, and anholocyclic, as parthenogenetic individuals on secondary hosts, for example, various crops and weeds. In the anholocycle, adult *M. persicae* can overwinter as viruliferous individuals on secondary hosts or can take up VY-associated viruses from VY host plants and return to sugar beet in spring. This can lead to an early primary infection of sugar beet, which can cause severe yield losses. In the holocycle, wingless individuals hatch from eggs and must first develop wings in the spring and then acquire VY-associated viruses from secondary hosts before they can primarily infect sugar beet. This reduces the risk of early primary infection compared to anholocyclic overwintering (Draycott 2006; Van Emden and Harrington 2007). In addition to secondary hosts, such as other crops or weeds, sugar beet seed crops, sugar beet clamps, harvest residues and sugar beet groundkeepers in the following crop can also act as VY reservoirs (Heathcote and Byford 1975; Heathcote and Cockbain 1966).

Many plant species have been described as hosts for one or more of the different VY-associated viruses (Bar-Joseph et al. 1979; Bennett 1949; Beuve et al. 2008; Duffus 1973; Duffus and Russell 1970; Graichen and Rabenstein 1996; Hartleb 1975; Hauser et al. 2000; Heathcote 1973; Heathcote and Byford 1975; Rogov et al. 1991; Russell 1965; Stevens et al. 1994; Yoshida and Tamada 2019). In the latest literature review for BChV and BMYV, Yoshida and Tamada (2019) described eight plant species from five families as hosts for BChV and 24 plant species from 10 families as hosts for BMYV. Duffus (1973) described 121 plant species belonging to 15 families as hosts for BYV based on a literature review. Of these, 79 species belong to the Amaranthaceae family and are closely related to sugar beet. Most of the host plant experiments described in the two reviews are from the 1950s to 1990s and not all of these studies used specific immunological or molecular techniques, such as ELISA or reverse transcription (RT)-PCR, for virus detection in plants. Molecular methods such as RT-PCR and RT-quantitative PCR (RT-qPCR) are essential for reliably distinguishing between closely related viruses. Furthermore, none of these studies described the attractiveness of the different VY hosts to the main vector *M. persicae* and most of them were conducted under greenhouse conditions and have not been verified under field conditions.

VY was successfully controlled by neonicotinoid insecticide seed treatment until its ban in the EU in 2018. Since 2019, EU sugar beet growers have had to find new strategies for VY control. In addition to broadcast sprays of contact or systemic insecticides with lower efficacy compared to the neonicotinoid seed treatment, integrated pest management (IPM) approaches combining several measures are becoming increasingly important (Favrot et al. 2024; Laurent et al. 2023). One possible IPM approach to reduce the risk of infection is to eliminate potential overwintering and secondary hosts in the life cycle of *M. persicae* that also represent hosts for VY-associated viruses. Furthermore, for *M. persicae* epidemiology modelling and VY risk prediction, it is essential to identify possible virus reservoirs.

In the last decade, the cultivation of cover crops as mixtures of more than two components before the spring crop (e.g., sugar beet or maize) has become increasingly popular in Europe due to agricultural policy requirements (Institut für Zuckerrübenforschung 2024). In addition, flower strips are also increasingly being planted next to sugar beet fields to promote beneficial insects and for biological pest control (Barascou et al. 2025). The focus of the above-mentioned host plant studies is on weed species rather than cover crop species and flower strip plants, which are currently widely cultivated. We therefore decided to re-evaluate the bibliography for a selection of plant species and to test new putative host species (mainly common cover crops and flower strip plants) under greenhouse and field conditions for susceptibility to the different VY-associated viruses (BChV, BMYV, BYV and BtMV) and their attractiveness for *M. persicae*. This work shows comprehensive host plant studies conducted under both greenhouse and field conditions. This includes the infection of sugar beet by *M. persicae* from BMYV-infected cover crops under field conditions, as well as the risk of infestation of different cover crops by *M. persicae* in autumn.

2 | Materials and Methods

2.1 | Aphid Rearing and Virus Isolates

For all inoculation experiments, adult wingless *M. persicae* individuals were obtained from the aphid rearing at the Institute of Sugar Beet Research (IfZ), Germany. Non-viruliferous aphids were reared under controlled conditions on healthy sugar beet plants in the greenhouse (23.0°C, 50%–75% RH, photoperiod of 16/8 h light/dark). The aphids from the rearing were tested regularly for virus contamination (BChV, BMYV, BYV and BtMV) by species-specific RT-qPCR and RT-PCR (see Section 2.4). For virus acquisition, adult wingless individuals were placed on virus-infected sugar beet plants to feed on them for at least 72 h. Isolates of BChV (GenBank accession no. MW367424), BMYV (MW367423), BYV (supplied by Mark Stevens, BBRO, UK) and BtMV (MT815987) were maintained in separate sugar beet plants, tested regularly and stored in tents to avoid contamination.

2.2 | Greenhouse Experiments

2.2.1 | Testing Plant Susceptibility for BChV, BMYV, BYV and BtMV

The seeds for the greenhouse experiments were obtained from Limagrain Netherlands, KWS Saat SE & Co. KGaA, Germany and Appels Wilde Samen GmbH, Germany. To test the susceptibility to the different VY-associated viruses and the transmission efficiency of *M. persicae*, 10 plants of each plant species (Table 1) at BBCH 12–16 (growth stage with 2–6 true leaves) were inoculated using 10 adult wingless viruliferous aphids per

TABLE 1 | Overview of tested plant species and greenhouse and field experiments conducted in this study.

				Greenhouse experiments[a]					Field experiments[a]		
				Susceptibility testing							
Plant family	Plant species	Common name	Agronomic use	BChV	BMYV	BYV	BtMV	BMYV choice test[b]	BMYV direct inoculation[b]	BMYV choice test[b]	Inoculation from cover crop[c]
Amaranthaceae	*Beta vulgaris* subsp. *vulgaris*	Sugar beet		×	×	×	×	×			×
Asteraceae	*Centaurea cyanus*	Cornflower	Flower strip	×	×	×	×	×			
Asteraceae	*Guizotia abyssinica*	Ramtilla	Cover crop	×	×	×					
Asteraceae	*Helianthus annuus*	Sunflower	Cover crop/ flower strip	×	×	×					
Asteraceae	*Matricaria chamomilla*	Chamomile	Weed	×	×	×	×				
Boraginaceae	*Echium vulgare*	Blueweed	Weed	×	×	×	×				
Boraginaceae	*Phacelia tanacetifolia*	Phacelia	Cover crop/ flower strip	×	×	×	×	×	×	×	×
Brassicaceae	*Camelina sativa*	False flax	Cover crop	×	×	×	×	×	×	×	×
Brassicaceae	*Raphanus sativus* var. *oleiferus*	Oilseed radish	Cover crop	×	×	×	×		×	×	
Brassicaceae	*Sinapis alba*	Mustard	Cover crop	×	×	×	×	×	×	×	×
Caryophyllaceae	*Gypsophila elegans*	Baby's breath	Flower strip	×	×	×	×	×			
Caryophyllaceae	*Silene noctiflora*	Night-flowering catchfly	Flower strip	×	×	×	×				
Fabaceae	*Melilotus albus*	Honey clover	Cover crop/ flower strip	×	×	×	×				
Fabaceae	*Pisum sativum*	Pea	Cover crop/ flower strip	×	×	×	×				
Fabaceae	*Trifolium alexandrinum*	Egyptian clover	Cover crop/ flower strip	×	×	×	×				
Fabaceae	*Trifolium incarnatum*	Italian clover	Cover crop/ flower strip	×	×	×					×
Fabaceae	*Trifolium pratense*	Red clover	Cover crop/ flower strip	×	×	×					

(Continues)

TABLE 1 | (Continued)

Plant family	Plant species	Common name	Agronomic use	Greenhouse experiments[a]					Field experiments[a]		
				Susceptibility testing				BMYV choice test[b]	BMYV direct inoculation[b]	BMYV choice test[b]	Inoculation from cover crop[c]
				BChV	BMYV	BYV	BtMV				
Fabaceae	*Trifolium resupinatum*	Persian clover	Cover crop/ flower strip	×	×	×		×			×
Fabaceae	*Vicia sativa*	Common vetch	Cover crop/ flower strip	×	×	×	×				
Linaceae	*Linum usitatissimum*	Linseed	Cover crop/ flower strip	×	×	×		×	×	×	×
Onagraceae	*Oenothera biennis*	Evening primrose	Flower strip	×	×	×	×				
Papaveraceae	*Papaver rhoeas*	Corn poppy	Weed/ flower strip	×	×	×	×				
Poaceae	*Avena strigosa*	Black oat	Cover crop	×	×	×					
Poaceae	*Lolium multiflorum*	Annual ryegrass	Cover crop	×	×	×					
Polygonaceae	*Fagopyrum esculentum*	Buckwheat	Cover crop	×	×	×	×				×
Violaceae	*Viola arvensis*	Field pansy	Weed	×	×	×	×				

Abbreviations: BChV, beet chlorosis virus; BMYV, beet mild yellowing virus; BtMV, beet mosaic virus; BYV, beet yellows virus.
[a]× indicates that this plant species was tested in the corresponding experiment.
[b]Choice tests and direct inoculation carried out with viruliferous aphids.
[c]Inoculation of sugar beet with aphids from BMYV-infected cover crop.

plant in tents under controlled conditions in the greenhouse. The aphids were placed on each individual plant with a brush. The inoculation access period (IAP) was 4 days. Five plants per species without aphids were used as a healthy control in separate tents (BugDorm-2S120 Insect Rearing Cage, MegaView Science Co. Ltd.). Sugar beet was used as positive control in each infection assay. Four days post-inoculation (dpi), all plants were spray treated with the systemic insecticide Teppeki (500 g kg^{-1} Flonicamid; Certis Belchim B.V.) to kill the aphids and the plants were kept in tents for a further 7 days. At 11 dpi, the plants were removed from the tents. To avoid contamination, the plants were inoculated with BChV, BMYV, BYV or BtMV in succession in separate experiments. Leaf samples for ELISA-based virus detection were taken at 30 dpi. Plant species that tested positive by ELISA were tested a second time in the same experimental set-up. The following greenhouse and field experiments focused on BMYV, as most of the species tested were found to be susceptible to BMYV (see Section 3.1).

2.2.2 | Choice Experiment With Viruliferous (BMYV) Aphids

Due to space limitations in the greenhouse and in the experimental design (4 × 6 multiplot trays, HerkuPlast Kubern GmbH; File S1) only eight plant species could be tested in the greenhouse choice experiment. Sugar beet served as a control, and the other seven species were selected based on the results of the susceptibility tests (see Section 3.1) and their relevance in Germany as a cover crop and flower strip plants.

The selected plant species (Table 1) were tested with viruliferous (BMYV) and non-viruliferous (healthy control) aphids for BMYV susceptibility and for their attractiveness to *M. persicae* under controlled conditions in the greenhouse. The different plant species were cultivated in 4 × 6 multipot trays. Two multipot trays were used for each treatment and each tray was divided into three subreplicates with full randomisation of the eight plant species. A total of six replicates of each plant species were tested. The *M. persicae* greenhouse choice experiment was set up by distributing six sugar beet leaf discs with aphids evenly on each multipot tray (one leaf disc in the centre of four plants). The leaf discs were selected to achieve uniform aphid density. The IAP was 4 days.

At 24, 48, 72 and 96 h post-inoculation (hpi), all plants were checked for aphid infestation and the number of adult wingless and winged *M. persicae* individuals per plant was counted. To kill the aphids, all plants were treated at 96 hpi with Teppeki. At 11 dpi, the plants were removed from the tents. Leaf samples for ELISA-based virus detection were taken at 30 dpi.

2.3 | Field Experiments

2.3.1 | Sugar Beet Inoculation With Aphids From BMYV-Infected Cover Crops

Due to space limitations in the greenhouse and field, only nine plant species could be tested in the field experiment. Sugar beet was selected as a control and the other eight species were selected based on the results of the susceptibility tests (see Section 3.1, Table 2) and their relevance in Germany as a cover crop and flower strip plants. The seeds were the same as in Section 2.2.

At two sites (Sieboldshausen and Harste) near Göttingen, an inoculation field trial was carried out in 2024 in sugar beet with different BMYV-infected cover crops colonised with aphids as inoculum source. The trial was set up in a complete randomised block design with two replicates. The VY-susceptible variety ZR 2411 (Bundessortenamt 2024) was sown with a row distance of 0.45 m and a sowing density of 120,000 plants/ha. Sugar beet seeds were only fungicide treated (7 g/unit penthiopyrad, 14 g/unit hymexazol). The plot size was 43.2 m^2 (12 rows × 8 m). Sowing date was 28 April 2024 in Sieboldshausen and 30 April 2024 in Harste. No foliar insecticides were applied, and all other crop management measures followed the official recommendations of the regional advisory service.

Eight different BMYV-infected cover crops colonised with aphids (Table 1), sugar beet as positive control and one control without aphids (non-inoculated control) were tested. To produce BMYV-infected cover crops, 20 plants per species were inoculated at BBCH 12–14 with 10 wingless viruliferous (BMYV) aphids from BMYV-infected sugar beet in mid-April in the greenhouse. The aphids remained on the plants to propagate. The inoculation density in the sugar beet in the field was 3% according to EPPO (European and Mediterranean Plant Protection Organization 2023) and the inoculated rows were rows 7–9. To inoculate sugar beet, leaf material from the different BMYV-infected cover crops (tested positive by ELISA) was placed in sugar beet row 8 of the plot. The plants to be inoculated were evenly distributed across row 8 of the plot. The time of inoculation was 30 days post-sowing (dps) in Sieboldshausen and 34 dps in Harste. Sugar beet development stage was BBCH 16. Field inoculation with cornflower (*Centaurea cyanus*) as aphid and virus source was not possible due to poor plant growth in the greenhouse and only nine treatments could be used for visual ratings.

Visual ratings of symptomatic plants (yellowing symptoms) started 3 weeks post-inoculation (wpi) and was continued weekly until harvest. The same personnel carried out the ratings on all dates. The percentage of symptomatic plants in the three inoculated rows was rated by estimation (% symptomatic plants per plot). In the non-inoculated control, rows 7–9 were also rated for symptomatic plants. Leaf samples were taken in mid-August from each plot for RT-PCR virus detection. The results of the weekly ratings were used to calculate the area under disease progress curve (AUDPC) in %-days according to Madden et al. (2017) using the following formula:

$$\mathrm{AUDPC} = \sum_{i=1}^{N_i - 1} \frac{(y_i + y_{i+1})}{2} (t_{i+1} - t_i)$$

where i is the date of rating, N_i the number of ratings, y the percentage of symptomatic plants per plot, and t the number of days after inoculation.

TABLE 2 | Susceptibility of different plant species tested in greenhouse experiments for beet chlorosis virus (BChV), beet mild yellowing virus (BMYV), beet yellows virus (BYV) and beet mosaic virus (BtMV).

Plant family	Plant species	Common name	Susceptibility based on literature review[a]	Susceptibility testing in greenhouse experiments[b]			
				BChV	BMYV	BYV	BtMV
Amaranthaceae	*Beta vulgaris* subsp. *vulgaris*	Sugar beet	BChV, BMYV, BYV, BtMV	10/10 10/10	10/10 10/10	5/10	5/5
Asteraceae	*Centaurea cyanus*	Cornflower	—	0/10	3/10 2/10	0/10	0/10
Asteraceae	*Guizotia abyssinica*	Ramtilla	—	0/10	0/10	0/10	n.a.
Asteraceae	*Helianthus annuus*	Sunflower	—	0/10	0/10	0/10	n.a.
Asteraceae	*Matricaria chamomilla*	Chamomile	—	0/10	2/10 5/10	0/10	0/10
Boraginaceae	*Echium vulgare*	Blueweed	—	0/10	0/10	0/10	0/10
Boraginaceae	*Phacelia tanacetifolia*	Phacelia	BMYV	0/10	9/10 10/10	0/10	0/10
Brassicaceae	*Camelina sativa*	False flax	BMYV	0/10	8/10 10/10	0/10	0/10
Brassicaceae	*Raphanus sativus* var. *oleiferus*	Oilseed radish	—	0/10	0/10 1/10	0/10	0/10
Brassicaceae	*Sinapis alba*	Mustard	BMYV	0/10	9/10 5/10	0/10	0/10
Caryophyllaceae	*Gypsophila elegans*	Baby's breath	BYV	6/10 0/10	1/10 0/10	0/10	0/10
Caryophyllaceae	*Silene noctiflora*	Night-flowering catchfly	—	0/10	1/10 0/10	0/10	0/10
Fabaceae	*Melilotus albus*	Honey clover	—	0/10	0/10	0/10	0/10
Fabaceae	*Pisum sativum*	Pea	BMYV, BtMV	0/10	0/10	0/10	0/10
Fabaceae	*Trifolium alexandrinum*	Egyptian clover	—	0/10	0/10	0/10	0/10
Fabaceae	*Trifolium incarnatum*	Italian clover	—	0/10	5/10 6/10	0/10	n.a.
Fabaceae	*Trifolium pratense*	Red clover	—	0/10	0/10	0/10	n.a.
Fabaceae	*Trifolium resupinatum*	Persian clover	—	0/10	10/10 7/10	0/10	n.a.
Fabaceae	*Vicia sativa*	Common vetch	—	0/10	0/10	0/10	0/10
Linaceae	*Linum usitatissimum*	Linseed	—	0/10	9/10 9/10	0/10	0/10
Onagraceae	*Oenothera biennis*	Common evening-primrose	—	0/10	0/10	0/10	0/10
Papaveraceae	*Papaver rhoeas*	Corn poppy	BMYV, BYV	0/10	5/10 0/10	0/10	0/10
Poaceae	*Avena strigosa*	Black oat	—	0/10	0/10	0/10	n.a.

(Continues)

TABLE 2 | (Continued)

Plant family	Plant species	Common name	Susceptibility based on literature review[a]	Susceptibility testing in greenhouse experiments[b]			
				BChV	BMYV	BYV	BtMV
Poaceae	*Lolium multiflorum*	Annual ryegrass	—	0/10	0/10	0/10	n.a.
Polygonaceae	*Fagopyrum esculentum*	Buckwheat	—	0/10	4/10 3/10	0/10	0/10
Violaceae	*Viola arvensis*	Field pansy	BMYV	0/10	0/10	0/10	0/10

Abbreviation: n.a., not assessed.
[a]Bennett (1949); Beuve et al. (2008); Duffus (1973); Graichen and Rabenstein (1996); Hartleb (1975); Stevens et al. (1994); Yoshida and Tamada (2019).
[b]Infections were verified by ELISA. Results from ELISA tests are presented as positive/total plants tested.

2.3.2 | Cover Crop Inoculation With Viruliferous (BMYV) Aphids

In 2023, two plant species were tested to evaluate the suitability of the experimental design for answering the research questions. In 2024, a commercial cover crop mixture (TerraLife BioMaxx Organic, DSV; File S2) was selected that included most of the species testing positive for BMYV from Section 3.1 (Table 2).

At one site (Harste) in 2023 and at two sites (Harste and Wolbrechtshausen) in 2024 a direct inoculation of cover crops and a field choice experiment with different cover crops was conducted under field conditions. A control area was established at all sites to assess natural migration of *M. persicae* to the different cover crops. In 2023, mustard (*Sinapis alba*) and phacelia (*Phacelia tanacetifolia*) were tested for aphid infestation and BMYV infection. In 2024, the following plant species were tested: mustard, phacelia, false flax (*Camelina sativa*), oilseed radish (*Raphanus sativus* var. *oleiferus*) and linseed (*Linum usitatissimum*) (Table 1). In 2023, mustard and phacelia were grown separately in the same field and in 2024 the species were grown as part of a cover crop mixture. Buckwheat, as a BMYV-susceptible species, was also included in the mixture and Persian clover (*Trifolium resupinatum*) was added manually before sowing, but the field emergence and the population densities were poor, so these two species were not considered for inoculation and ratings. The sowing date of the cover crops was 22 August in 2023 and 16 August in 2024.

For the direct inoculation, 10 viruliferous (BMYV) wingless *M. persicae* aphids were transferred using a brush to 10 plants of each species. For the field choice experiment, two BMYV-infected sugar beet plants infested with *M. persicae* (inoculum source with >1000 aphids) were planted in the centre of two cover crop strips (2.5 m wide) to assess the migration of *M. persicae* into the cover crop mixture (for detailed field plan see File S3). The field choice experiment was replicated four times per site in 2023 and three times in 2024. Direct inoculation and planting of the *M. persicae*-infested and BMYV-infected sugar beet plants was carried out when the cover crop mixture reached a height of 25–30 cm (10 October 2023 and 16 September 2024).

At 7 and 21 dpi in 2023 and 3, 7 and 21 dpi in 2024, 10 plants per species in the control area and all 10 plants that were inoculated directly were checked for *M. persicae* infestation (number of winged and wingless adults). In the field choice experiment, three plants of each species were evaluated for *M. persicae* infestation in the immediate vicinity of the sugar beet plants (rating location 0) and at a distance of 1 m (rating location 1) in each repetition. At 35 dpi, leaf samples were taken from 10 plants per species in the control area and from all directly inoculated plants per species. In the field choice experiment, a mixed sample of three plants per distance and species in each repetition was taken. Leaf samples were stored at −80°C until RNA extraction.

2.4 | Virus Detection (ELISA, RT-PCR, RT-qPCR)

In the greenhouse experiments, leaf samples of 200 mg fresh leaf mass were taken for ELISA detection. In the sugar beet inoculation field trial and in the field choice experiment, leaf samples of 80–100 mg fresh leaf mass were taken for total RNA extraction.

Virus detection in leaf samples from greenhouse experiments was performed by double antibody sandwich (DAS-)ELISA for BYV (specific antibodies) and BtMV (specific antibodies) and triple antibody sandwich (TAS-)ELISA for BChV and BMYV using polerovirus (beet western yellows virus, BWYV) specific antibodies and manufacturer's protocols (BYV DAS-ELISA, TAS-ELISA, Leibniz Institute DSMZ-German Collection of Microorganisms and Cell Cultures GmbH; BtMV DAS-ELISA, Loewe Biochemica GmbH). Plants were considered to be infected when A_{405nm} value was greater than the mean value of non-inoculated plants of the same plant species plus 3× the standard deviation (SD) of these values plus the value of the sample buffer (Clark and Adams 1977; D'Arcy and Hewings 1986).

Total RNA was extracted from field leaf samples using the Thermo Scientific KingFisher Duo Prime System and the corresponding MagMAX Plant RNA Isolation Kit (Thermo Fisher Scientific Inc.) according to the manufacturer's protocol. The concentration (ng/μL) of the extracted total RNA was determined using a DS-11 spectrophotometer (DeNovix Inc.). The integrity of the extracted RNA was checked by 1% agarose gel electrophoresis.

To synthesise cDNA for PCR, 200 ng of total RNA was used as template. In the first step, 1 μL random hexamers primer (Thermo Fisher Scientific Inc.) was added to the RNA and the volume was adjusted to 12.5 μL with nuclease-free water. The mixture was then incubated for 5 min at 65°C, followed by 5 min incubation on ice. In the second step, 4 μL 5× reaction buffer for RT (Thermo Fisher Scientific Inc.), 0.5 μL RiboLock RNase inhibitor (40 U/μL; Thermo Fisher Scientific Inc.), 0.5 μL dNTPs (10 mM), 0.5 μL RevertAid reverse transcriptase (200 U/μL; Thermo Fisher Scientific Inc.) and 0.5 μL nuclease-free water were added. The mixture was incubated at 42°C for 1 h, followed by 70°C for 10 min and cDNA was stored at −20°C until PCR analysis.

The PCR was performed in a Biometra TAdvanced PCR cycler (Analytik Jena GmbH & Co. KG). The PCR mixture consisted of 10 μL DreamTaq PCR Master Mix (2×; Thermo Fisher Scientific Inc.), 1 μL BMYV- or BChV-specific forward primer (400 nM; Stephan 2005), 1 μL BMYV- or BChV-specific reverse primer (400 nM; Stephan 2005), 7 μL nuclease-free water and 1 μL of cDNA template. PCR cycling conditions consisted of an initial denaturation step at 95°C for 2 min; followed by 30 cycles of denaturation step at 95°C for 30 s, annealing step at 62.3°C (BMYV) or 60.7°C (BChV) for 30 s and extension step at 72°C for 40 s. After 30 cycles, a final extension step at 72°C for 10 min was performed.

BMYV-specific one-step RT-qPCR was performed as described by Borgolte et al. (2025) using a CFX96 Touch Real-Time PCR Detection System (Bio-Rad). Extracted total plant RNA (2 μL) was used as template and the total volume per reaction was adjusted to 25 μL with nuclease-free water. Healthy and BMYV-positive controls from plants and untreated nuclease-free water control (NTC) were included in each plate run and two technical replicates were used for each sample.

2.5 | Statistical Analysis

Statistical data analysis was performed using R software (v. 4.4.2, R Foundation for Statistical Computing). All figures were generated using the R package *ggplot2*. The different data sets were checked graphically for normal distribution and homoscedasticity according to Kozak and Piepho (2018), and additionally for normal distribution using the Shapiro–Wilk test.

The rating data from the sugar beet inoculation field trial and the greenhouse choice experiment were log-transformed prior to analysis to obtain a normal distribution. A linear model was used to analyse differences between the plant species per treatment using the R function *lm()*. Analysis of variance (ANOVA) was performed using the R package *agricolae*. The Tukey test was used as a post hoc test using the *emmeans()* function from the *emmeans* R package. After analysis, the data was back-transformed. *M. persicae* rating data from the field choice experiments did not show a normal distribution and homoscedasticity, even after log-transformation, and were therefore analysed using the Kruskal–Wallis test and Dunn's test with *holm* adjustment as post hoc test.

3 | Results

3.1 | Susceptibility to VY-Associated Viruses as Determined in a Greenhouse Assay

The aim of the following experiment was to assess the susceptibility of different cover crops and flower strip plants (Table 1) to the different VY-associated viruses (BMYV, BChV, BYV and BtMV) using viruliferous *M. persicae* aphids under controlled conditions.

None of the 25 alternative plant species tested positive for BYV or BtMV by the respective ELISA. BChV was only detected in sugar beet and baby's breath (*Gypsophila elegans*). However, only 60% of the baby's breath plants tested positive for BChV in the first experiment run and none (0%) in the second. For BMYV, sugar beet and 13 other plant species from nine families tested positive by ELISA, with infection rates ranging from 10% to 100% (Table 2). On the other hand, 12 plant species tested negative. Sugar beet, phacelia, false flax, linseed, Italian clover (*Trifolium incarnatum*), cornflower and buckwheat (*Fagopyrum esculentum*) showed consistent infection rates in both experimental runs, whereas chamomile (*Matricaria chamomilla*), mustard and Persian clover showed high variation in infection rates between the two experimental runs. Oilseed radish, baby's breath, night-flowering catchfly (*Silene noctiflora*) and corn poppy (*Papaver rhoeas*) showed positive results in only one experimental run with infection rates between 10% and 50%. None of the cover crops or flower strip plants tested showed any clear virus symptoms compared to the non-inoculated control of each species.

3.2 | Inoculation of Sugar Beet With Aphids From BMYV-Infected Cover Crops

The objective of the sugar beet inoculation field trial was to assess the feasibility of infecting sugar beet plants via aphids that had been reared on cover crops infected with BMYV (Table 1) under field conditions.

The first yellowing symptoms of sugar beet plants appeared in early July in all inoculated plots at both sites. The sugar beet plants in plots inoculated with aphids from BMYV-infected mustard consistently showed the highest percentage of symptomatic plants. By mid-August, over 90% of the plants in all plots inoculated with aphids from BMYV-infected cover crops were symptomatic, except for plots that were inoculated with aphids from buckwheat, Italian clover and Persian clover (File S4). ANOVA showed no significant site × treatment interaction, so AUDPC was calculated as the mean of both sites. The non-inoculated control plots had the significantly lowest AUDPC, while those inoculated with aphids from BMYV-infected Italian clover and buckwheat had significantly lower AUDPC than all the other inoculated plots (Figure 1).

3.3 | Greenhouse Choice Experiment With Viruliferous (BMYV) Aphids

This greenhouse experiment combined a BMYV transmission experiment with a choice experiment in order to evaluate the

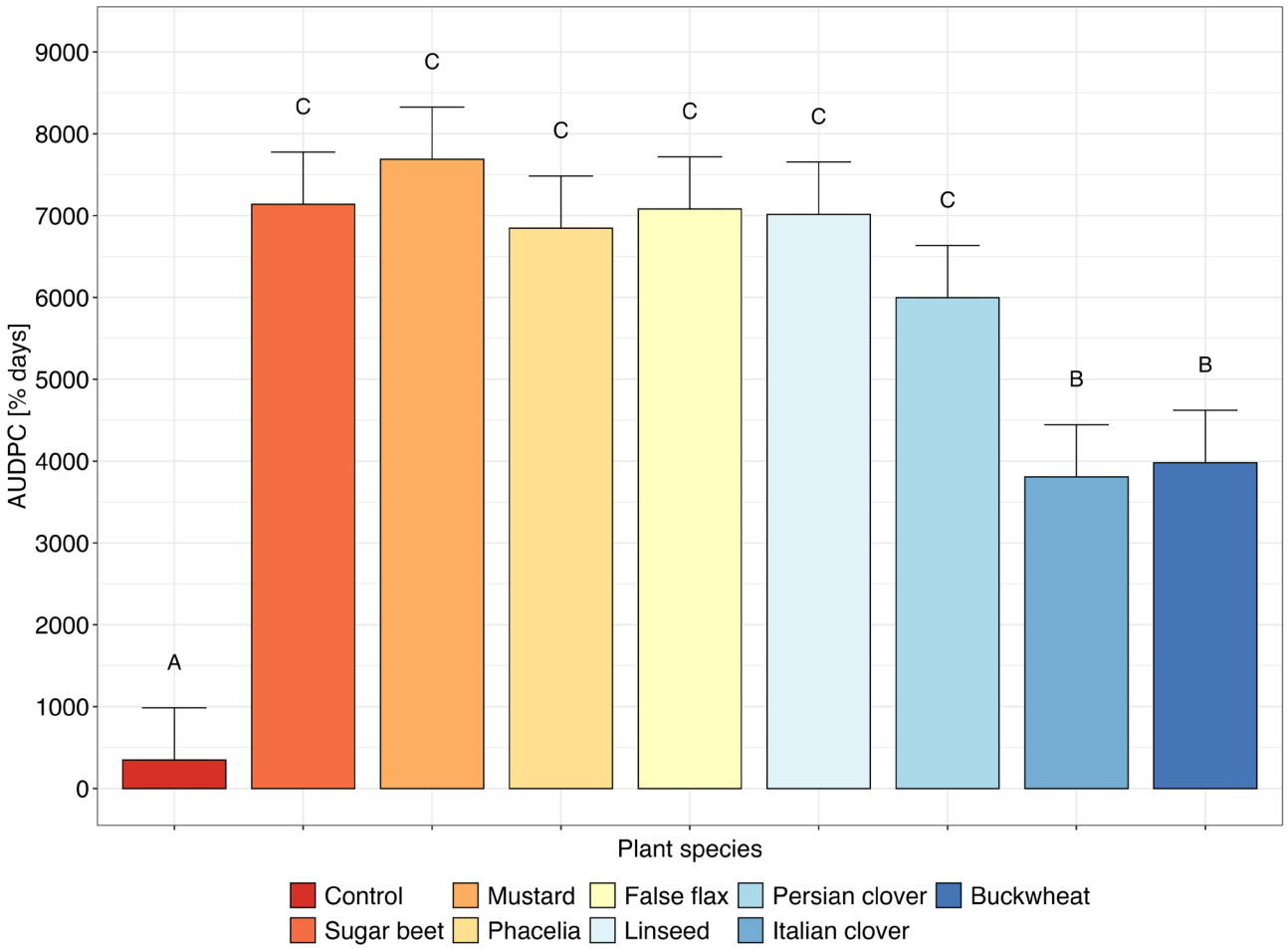


FIGURE 1 | Area under disease progress curve (AUDPC) in %-days for beet mild yellowing virus (BMYV) in sugar beet inoculated using *Myzus persicae* from different BMYV-infected and aphid-colonised cover crop species. Mean of two locations in Germany in 2024. Error bars indicate standard deviation. Means with the same letter are not significantly different (Tukey test, $\alpha = 0.05$).

attractiveness of seven different cover crops and flower strip plants (Table 1) to *M. persicae* and transmission efficiency in a controlled environment.

At 24 and 48 hpi, the tested plant species ranked differently in terms of mean number of *M. persicae* per plant between non-viruliferous and viruliferous (BMYV) aphids. In contrast, at 72 and 96 hpi, ranking of the different plant species was the same between non-viruliferous and viruliferous aphids (Figure 2). Few significant differences between plant species were observed at 24 hpi, while more significant differences were observed at 96 hpi for both aphid treatments.

Mustard consistently had the highest mean number of aphids across all time points for both aphid treatments. Linseed had the significantly lowest mean number of aphids per plant at 96 hpi for both aphid treatments. For non-viruliferous aphids, aphid numbers on cornflower, false flax, linseed and baby's breath increased from 24 to 48 hpi and then decreased. For the viruliferous aphids, a decrease was only observed for linseed and false flax between 72 and 96 hpi. Phacelia, sugar beet and mustard showed the largest increases in aphid number between 72 and 96 hpi for both treatments, with no significant differences between phacelia and sugar beet.

No BMYV infection was detected by ELISA in any control plant (non-viruliferous aphids). In the viruliferous aphid treatment, only baby's breath remained uninfected (0/6 plants positive). Cornflower showed an infection rate of 50.0% (3/6 plants positive) and Persian clover of 83.3% (5/6 plants positive). All other tested plant species showed an infection rate of 100% (6/6 plants positive).

3.4 | Field Cover Crop Experiments With Viruliferous (BMYV) Aphids

3.4.1 | Field Susceptibility Test and Natural Infestation

The field experiment described below aimed to evaluate the susceptibility of a selection of cover crops (Table 1) to BMYV under field conditions, as well as assessing the natural infestation of cover crops by *M. persicae*.

In 2023, *M. persicae* incidence in phacelia was consistently higher on inoculated plants than on control plants without inoculation. Aphid density was significantly greater on mustard plants compared to phacelia plants ($p \leq 0.001$; Figure 3).

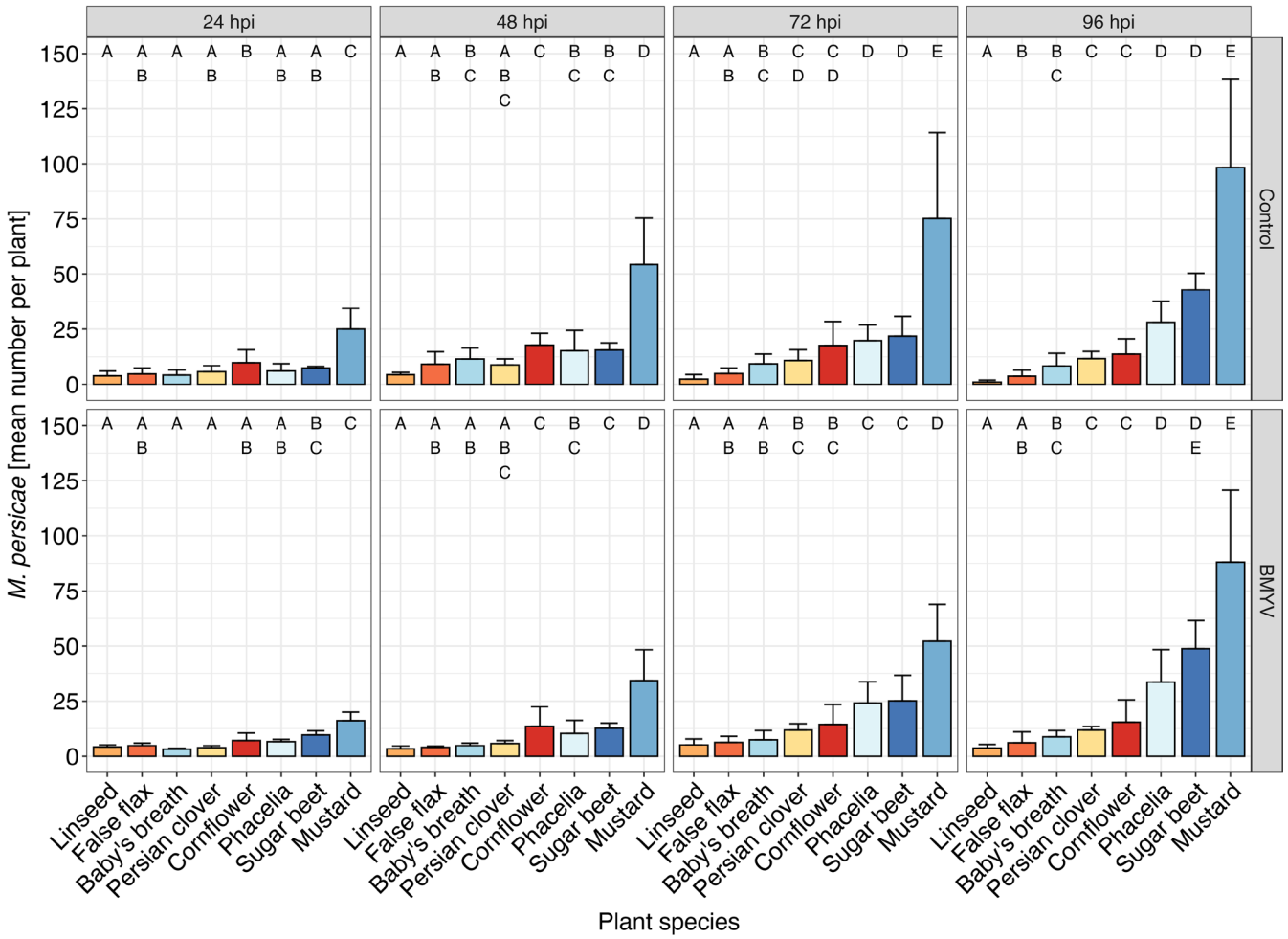


FIGURE 2 | Mean number of adult *Myzus persicae* per plant at different hours post-inoculation (hpi) for different plant species treated with non-viruliferous (Control) and viruliferous aphids (beet mild yellowing virus, BMYV) in a greenhouse choice experiment. Error bars indicate standard deviation. For each time point, means with the same letter within treatment are not significantly different (Tukey test, $\alpha = 0.05$, $n = 6$).

In 2024, the incidence of *M. persicae* was highest in mustard and oilseed radish at both sites, with aphid numbers increasing over time on these species on both inoculated and control plants (Figure 4; File S5). There were no significant differences in aphid numbers among mustard, oilseed radish and phacelia at any time point on inoculated or control plants at either site. In phacelia, the incidence only increased on control plants and remained high on inoculated plants. The incidence of aphids on inoculated linseed and false flax plants declined sharply (40%–80% to 0%) at both sites. Aphids were absent from control plants of these species, except for false flax at 3 dpi in Wolbrechtshausen and at 21 dpi in Harste. The number of aphids on mustard and oilseed radish was slightly higher on control plants than on inoculated plants. However, the opposite was observed for phacelia.

To confirm BMYV susceptibility of the varieties of the tested plant species in the commercial cover crop mixture, all plant species were first tested in the greenhouse using the method described in Section 2.2.2. All the varieties of the field-tested species except oilseed radish were susceptible to BMYV under greenhouse conditions (data not shown). In 2023, no BMYV infection was detected in the control plants without inoculation under field conditions. Among the plants which were inoculated with viruliferous aphids, 70% of the phacelia plants were infected, while all mustard plants remained uninfected (Table 3). In 2024 in Harste, no BMYV infection occurred in the control plants. BMYV was detected in false flax, linseed and phacelia plants (37.5%–57.1% infection rates) that were inoculated, but not in mustard and oilseed radish plants (Table 3). In Wolbrechtshausen, the infection rate was lower, with only 25.0%–28.6% of inoculated false flax and phacelia plants testing positive.

3.4.2 | Field Choice Experiment

The aim of the following field choice experiment was to evaluate the attractiveness of different cover crops to *M. persicae* and to assess the BMYV transmission efficiency under field conditions.

In 2023, all mustard plants in the field choice experiment were infested with *M. persicae* at all time points, while not all phacelia plants showed infestation (File S6). In phacelia the incidence decreased with distance from the inoculum source (aphid-infested BMYV-infected sugar beet). On mustard plants, significantly more aphids were recorded near the inoculum source (rating location 0) only at 7 dpi, whereas on phacelia plants, significantly more aphids were found at rating location 0 at both time points (Figure 5).

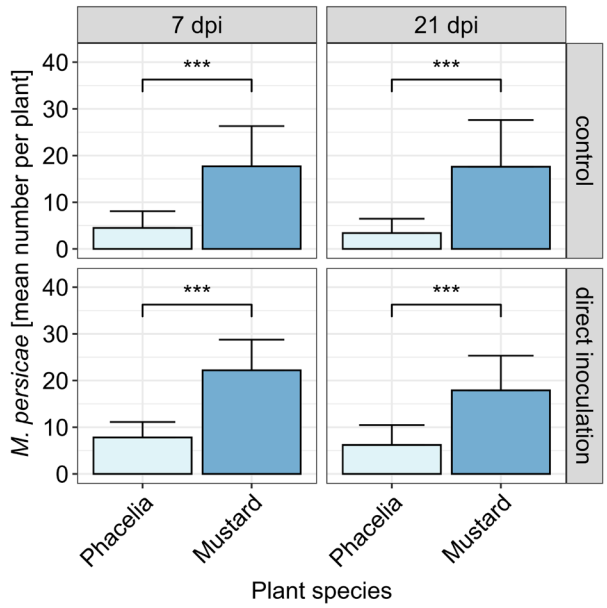


FIGURE 3 | Mean number of adult *Myzus persicae* per plant at different days post-inoculation (dpi) for phacelia and mustard not inoculated with aphids (control) and directly inoculated with viruliferous aphids (beet mild yellowing virus, BMYV) in a field choice experiment in 2023 in Harste, Germany. Error bars indicate standard deviation. $*p \leq 0.05$, $**p \leq 0.01$, $***p \leq 0.001$ indicate significant differences between plant species within time points (Dunn's test, $n = 8$).

In 2024, no aphids were found on linseed at either site at 7 and 21 dpi; only a single aphid was observed at 3 dpi in Wolbrechtshausen (Figure 6, File S6). On false flax in Wolbrechtshausen, significantly more aphids occurred at rating location 0 than at rating location 1 at 3 and 7 dpi. On mustard plants significant differences were found only at 21 dpi in Harste, with higher numbers on plants at rating location 0. In Harste, phacelia plants showed higher incidence and aphid numbers at rating location 0 across all time points, whereas in Wolbrechtshausen, differences between distances were not significant at 3 dpi. The highest aphid densities were observed on mustard and oilseed radish plants at both sites.

Due to wildlife damage in 2023, only three of four replicates per plant species were usable for RT-qPCR virus detection (Table 4). No BMYV was detected in mustard plants at any distance. In phacelia plants, BMYV was detected in all samples at rating location 0. In 2024, no BMYV was found in oilseed radish at either site (Table 4). BMYV was detected only once in mustard (Harste) and linseed (Wolbrechtshausen) at rating location 0. Sampling size in linseed was limited due to plant damage. In Wolbrechtshausen, BMYV was detected in false flax in two replicates at rating location 0. In phacelia plants, BMYV was consistently detected in all replicates and subreplicates at both sites, with higher infection rates at rating location 0.

4 | Discussion

This is the first study of VY-associated viruses and host plants focusing on agronomically relevant cover crops and flower strip plants. It showed that BMYV has a much wider host range than BChV, BYV and BtMV among the plant species tested. Furthermore, the study evaluated the susceptibility of preselected cover crops under field conditions on a limited scale.

No information on susceptibility could be found in the literature for 16 plant species from nine families that were tested in this study. Seven of these species were identified as new hosts for BMYV: cornflower, buckwheat, linseed, Persian clover, Italian clover, night-flowering catchfly and chamomile. Baby's breath was identified as a new host for both BMVY and BChV. The BMYV susceptibility from previous studies for false flax, phacelia, mustard and corn poppy (Beuve et al. 2008; Graichen and Rabenstein 1996; Hartleb 1975; Stevens et al. 1994; Yoshida and Tamada 2019) was confirmed in this study. For four species, the results obtained contrasted with those reported in the literature. Bennett (1960) described baby's breath and Duffus (1973) and Stevens et al. (1994) described corn poppy as hosts for BYV. However, neither species tested positive for BYV in this study. Stevens et al. (1994) described field pansy (*Viola arvensis*) as a host for BMYV, but it did not test positive in this study for BMYV. Based on a literature review, Yoshida and Tamada (2019) described pea (*Pisum sativum* subsp. *arvense*) as both a host and a non-host for BMYV, depending on the original study. Using the greenhouse assay described in this study, pea was not found to be infected with BMYV. Pea has also been reported as a host for BtMV (Bennett 1949), but it did not test positive in this study.

Reasons for the contrasting results may be that different isolates of the respective VY-associated viruses were used in this study compared to those in the literature. Different isolates of the same virus can have different levels of infectivity and pathogenicity within the same plant species. This can result in different infection rates and variations in host range within the same virus species (Congdon et al. 2023; Sáenz et al. 2001; Syller 1985; Tamada et al. 1984; Tanaka et al. 2019). Additionally, the transmission efficiency of plant viruses may be influenced by different clones of the same aphid species (Burrows et al. 2006; Kirk et al. 1991; Kozłowska-Makulska et al. 2009; Leybourne 2024; Limburg et al. 1997). Furthermore, it is also possible that different genotypes of the tested plant species have different levels of susceptibility to the VY-associated viruses. However, many of the studies mentioned used transmission experiments involving symptom assessment and back-transmission to sugar beet or other susceptible indicator plants (e.g., *Capsella bursa-pastoris* for BMYV) to evaluate host susceptibility and did not use immunological or molecular detection methods (Bennett 1949, 1960; Duffus 1973; Russell 1965). Assays without back-transmission and immunological or molecular detection methods can lead to uncertain results, as we observed no clear symptoms in any of the plants tested in the greenhouse compared to the non-inoculated control of each species.

Some plant species showed low infection rates of less than 20%, as well as highly variable infection rates ranging from 0% to 50% across the two experimental runs in the greenhouse. Uncharacterised populations were used for the flower strip plants in particular. Furthermore, as these species have not been domesticated, a high degree of heterozygosity can occur. This could mean that some genotypes are less susceptible than

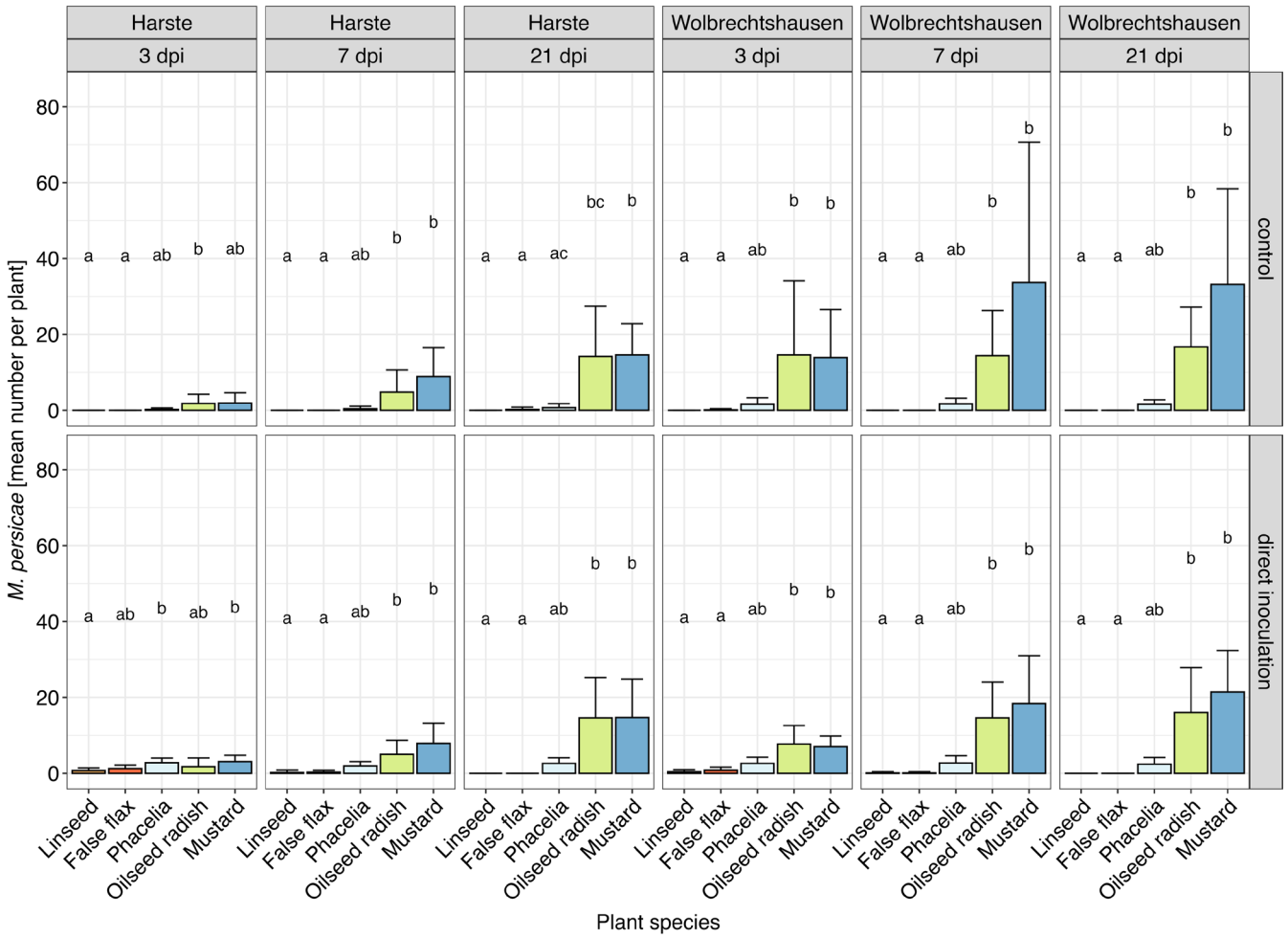


FIGURE 4 | Mean number of adult *Myzus persicae* per plant at different days post-inoculation (dpi) for different plant species not inoculated with aphids (control) and directly inoculated with viruliferous aphids (beet mild yellowing virus, BMYV) in a field choice experiment in 2024 in Harste and Wolbrechtshausen, Germany. Error bars indicate standard deviation. For each site and time point, means with the same letter within plant species are not significantly different (Dunn's test, $p \leq 0.05$, $n = 6$).

TABLE 3 | Beet mild yellowing virus (BMYV) infection rates of different plant species directly inoculated with viruliferous aphids determined by reverse transcription-quantitative PCR in field experiments in Germany in 2023 and 2024.

Year	Site	Method	Common name	BMYV (positive/total plants)
2023	Harste	Direct inoculation	Phacelia	7/10
			Mustard	0/10
2024	Harste	Direct inoculation	Phacelia	3/8
			False flax	4/7
			Oilseed radish	0/5
			Mustard	0/7
			Linseed	3/6
	Wolbrechtshausen	Direct inoculation	Phacelia	2/7
			False flax	1/4
			Oilseed radish	0/5
			Mustard	0/7
			Linseed	0/6

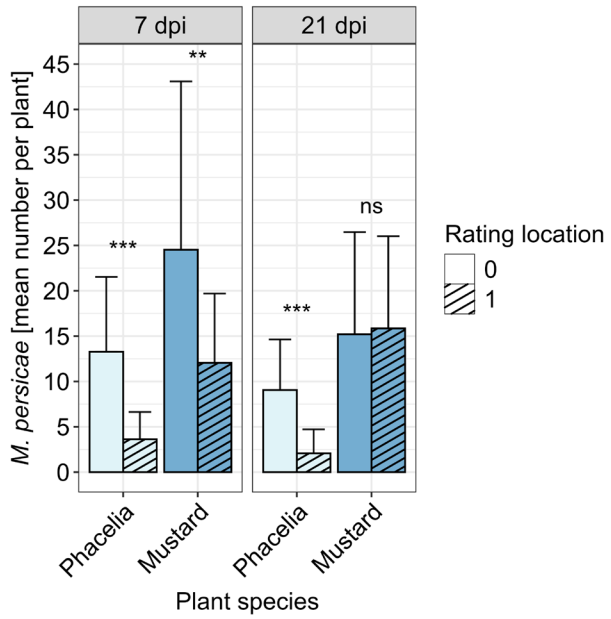


FIGURE 5 | Mean number of adult *Myzus persicae* per plant at different days post-inoculation (dpi) on phacelia and mustard. Field choice experiment with viruliferous aphids (beet mild yellowing virus, BMYV) in 2023 in Harste, Germany. Error bars indicate standard deviation. $^{*}p \leq 0.05$, $^{**}p \leq 0.01$, $^{***}p \leq 0.001$ indicate significant differences between the two rating locations 0 and 1 within plant species and time point; ns = not significant (Dunn's test, $n = 8$).

others. This could also explain the differences between the results of this study and those reported in the literature.

This study showed for the first time in an inoculation experiment in sugar beet, under field conditions, that sugar beet can become infected with BMYV via *M. persicae* that have fed on a broad range of different BMYV-infected cover crops. The significantly lower AUDPC for buckwheat and Italian clover can be explained by the fact that these two species were less colonised with *M. persicae*, leading to reduced disease progression at both sites. In the literature, an infection of sugar beet in the field from other hosts has only been described for *C. bursa-pastoris* (BMYV) and *Tetragonia expansa* (BYV) (Smith and Hallsworth 1990; Stevens et al. 2004).

In the greenhouse choice test, an experiment to assess the transmission of BMYV was combined with an evaluation of the attractiveness of seven different cover crops and flower strip plants to *M. persicae*. In this experiment, *M. persicae* strongly preferred mustard, sugar beet and phacelia plants. In contrast, there was no significant increase on linseed, false flax, baby's breath, Persian clover and cornflower plants. However, the lower number of aphids on these plant species resulted in high BMYV infection rates (> 50%). This suggests that linseed and false flax are less suitable hosts for *M. persicae*; however, they are particularly susceptible to BMYV. In the literature, significant variations in the attractiveness of different hosts to *M. persicae*, as well as differences in their survival rate and propagation on these plants, have been reported (Fernandez-Quintanilla et al. 2002; Hong et al. 2019; Jiang et al. 2022; Tamaki and Olsen 1979). Jiang et al. (2022) described *M. persicae* on oilseed radish that had increased phloem sap ingestion and reduced mechanical difficulties of the mouthparts in the probe pathway. Like mustard, oilseed radish belongs to the Brassicaceae family. This may explain why *M. persicae* were more attracted to mustard than to the other species in the greenhouse choice experiment. In general, the results from the literature also showed that *M. persicae* can survive on a wide range of plant species, but high propagation rates are only achieved on a smaller number of plant species (Jiang et al. 2022; Tamaki and Olsen 1979). Powell et al. (2006) defined six stages of host plant selection by aphids. The assessment of whether a plant species is suitable as a host plant is made upon first contact with the leaf surface (e.g., epicuticular wax) and upon first probing. This stage is particularly significant for the transmission of plant viruses by aphids, especially for nonpersistently transmitted viruses. Constant probing on different plants can lead to the rapid spread of viruses within and between plant species. This is underlined by the results of the greenhouse choice experiment, in which only a few aphids colonised linseed and false flax and remained on the plants only for 24 h. Nevertheless, a 100% BMYV infection rate was achieved in both species.

The field choice experiment clearly demonstrated that the attractiveness of different cover crop species to *M. persicae* varies more under field conditions. On the control plants with natural infestation, *M. persicae* was only found on up to 10% of the linseed and false flax plants. Phacelia was found to be intermediate in attractiveness between linseed and false flax, and mustard and oilseed radish. These results thus reflect the findings from the greenhouse choice experiment, demonstrating that linseed and false flax are not attractive to *M. persicae* under natural field conditions. The low attractiveness of these plant species was emphasised by the ratings of plants that were inoculated directly with aphids. These plants exhibited a low incidence with a low number of *M. persicae* per plant that decreased over time.

Due to the high level of natural infestation, fewer differences were found between the control plants and the plants that were inoculated directly, as well as between the two rating locations (distances) in the field choice experiment, for both mustard and oilseed radish. However, for phacelia a significant effect of distance was found in both years, with a higher number of *M. persicae* on plants directly at the inoculum source compared to plants at 1 m distance. This significant effect was also observed for false flax at one location. The distance effect was also found in BMYV infection rates for phacelia at all locations and for false flax at one location. More plants surrounding the inoculum source were infected with BMYV than those at a distance of 1 m. Therefore, even a small number of *M. persicae* per plant for a short period of time is sufficient for BMYV transmission under field conditions.

However, the results of BMYV infection in mustard from greenhouse experiments were not reproducible in the field. None of the plants that were inoculated directly with viruliferous aphids tested positive for BMYV in either year. Of those that were tested in the field choice experiment, none tested positive for BMYV in 2023, and only mustard plants in one repetition tested positive in 2024. One possible reason for this is that the level of natural *M. persicae* infestation was so high that intraspecific competition was intense, resulting in the viruliferous aphids that were inoculated to the plants being unable to infect the plants. However, a random selection of mustard leaf

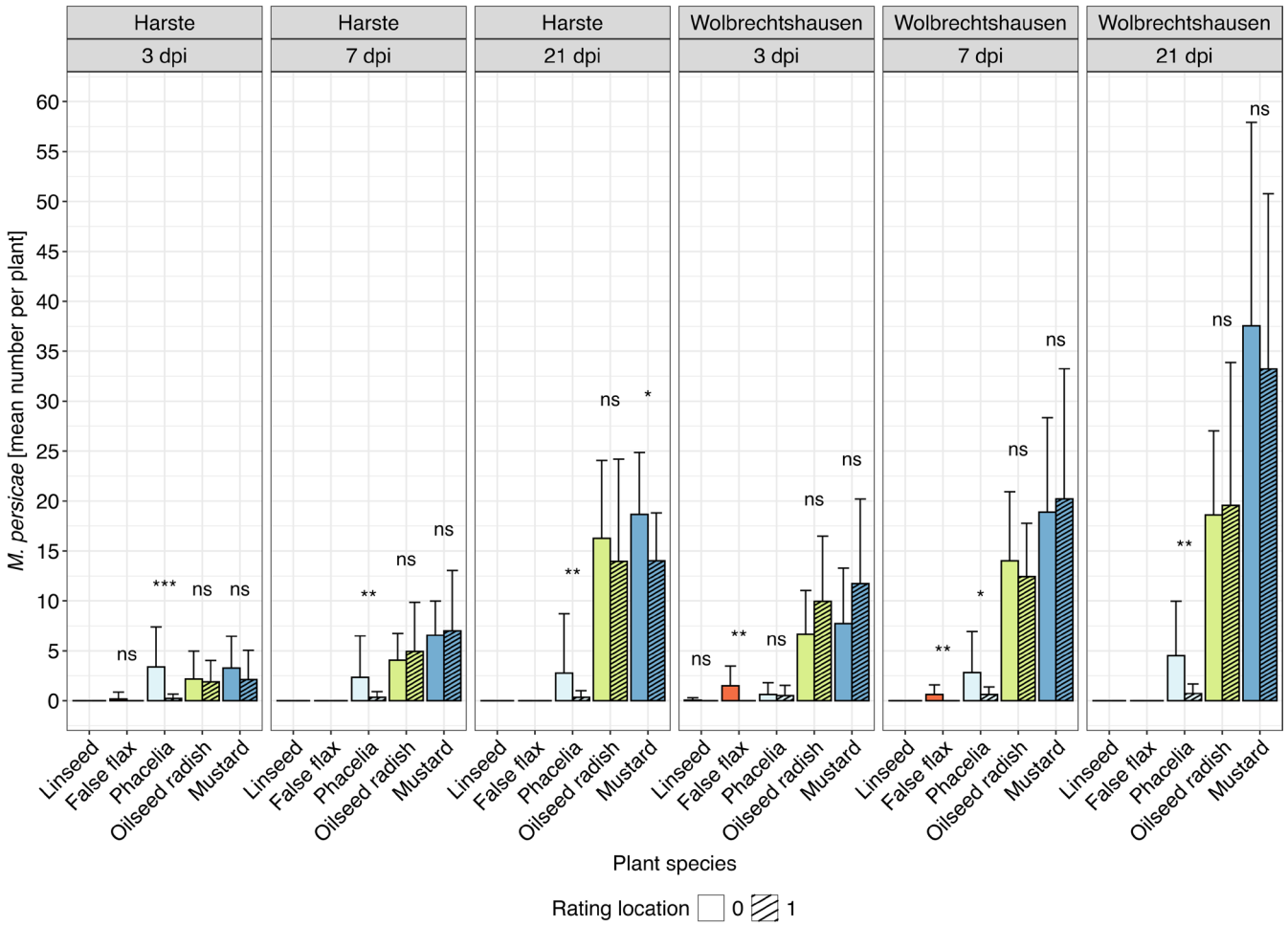


FIGURE 6 | Mean number of adult *Myzus persicae* per plant at different days post-inoculation (dpi) for different plant species. Field choice experiment with viruliferous aphids (beet mild yellowing virus, BMYV) in 2024 in Harste and Wolbrechtshausen, Germany. Error bars indicate standard deviation. *$p \leq 0.05$, **$p \leq 0.01$, ***$p \leq 0.001$ indicate significant differences between the two rating locations 0 and 1 within plant species site and time point; ns = not significant (Dunn's test, $n = 6$).

TABLE 4 | Beet mild yellowing virus (BMYV) detection by reverse transcription-quantitative PCR in different plant species tested in a field choice experiment with viruliferous (BMYV) aphids in Germany in 2023 and 2024.

			BMYV (positive/total samples)				
Year	**Location**	**Rating location[a]**	**Mustard**	**Phacelia**	**Oilseed radish**	**False flax**	**Linseed**
2023	Harste	0	0/6	6/6	n.a.	n.a.	n.a.
		1	0/6	0/6	n.a.	n.a.	n.a.
2024	Harste	0	1/6	5/6	0/6	0/6	0/5
		1	0/6	1/6	0/6	0/6	0/6
	Wolbrechtshausen	0	0/6	6/6	0/6	2/6	1/3
		1	0/6	2/6	0/6	0/6	0/4

Abbreviation: n.a., not assessed.
[a]0 = close to the inoculum source; 1 = 1 m from the inoculum source.

samples tested positive for turnip yellows virus (TuYV), which is also a polerovirus and closely related to BMYV, in both years (data not shown). If there had been a prior TuYV infection, cross-protection of mustard plants against BMYV is possible. Cross-protection occurs between closely related viruses and strains, and has been observed in oats (*Avena sativa*) and different isolates of the barley yellow dwarf virus, for example (Jedlinski and Brown 1965; Wen et al. 1991). However, Beuve et al. (2008) did not observe any cross-protection between BWYV and BMYV in sugar beet, and other co-infections with

closely related sugar beet-infecting poleroviruses are described in the literature (Puthanveed et al. 2023; Schlaefli et al. 2025). Further research is needed to confirm cross-protection between TuYV and BMYV in mustard.

In summary, several common cover crops and flower strip plants in this study are susceptible to BMYV, but not to BChV, BYV or BtMV. BMYV-susceptible plant species vary significantly in attractiveness to *M. persicae*. The results obtained in greenhouse experiments only partially translate to field level, where BMYV infection rates can be highly variable and are sometimes absent. Aphid infestation trends are similar to greenhouse findings but show greater species differences in the field. *M. persicae* can transmit BMYV from infected cover crops and flower strip plants to sugar beet, indicating that these plants may serve as overwintering reservoirs for BMYV. The risk that these plants pose to VY epidemics in sugar beet depends on many factors such as winter frost, proximity to sugar beet fields and wind direction. However, further field trials and monitoring are needed to evaluate this more thoroughly. The lack of clear symptoms in cover crops and flower strip plants in the event of BMYV infection makes field monitoring considerably more difficult. Nevertheless, this emphasises the importance of preventing green bridges and of carefully selecting plants for flower strips as part of the IPM.

Author Contributions

Simon Borgolte: conceptualisation, investigation, methodology, validation, visualisation, formal analysis, data curation, writing – original draft. **Mark Varrelmann:** conceptualisation, methodology, validation, supervision, funding acquisition, project administration, resources, writing – review and editing.

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Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **File S1:** Experimental set-up for the choice experiment in a greenhouse. **File S2:** Composition of the cover crop mixture (TerraLife BioMaxx Organic, DSV). **File S3:** Experimental set-up for the choice experiment in the field. **File S4:** Percentage of infected plants with beet mild yellowing virus (BMYV) in sugar beet inoculated using *Myzus persicae* from different BMYV-infected and aphid colonised cover crop species. **File S5:** Incidence (% infested plants) of *Myzus persicae* at different days post-inoculation (dpi) for different plant species treated with no aphids (control, natural infestation) and directly inoculated with viruliferous aphids (BMYV) in a field choice experiment in 2023 in Harste and 2024 in Harste and Wolbrechtshausen, Germany ($n = 8$ in 2023, $n = 6$ in 2024). **File S6:** Incidence (% infested plants) of *Myzus persicae* at different days post-inoculation (dpi) for different plant species.