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Profile

Biology and Management of the New Zealand Endemic Wheat Bug, *Nysius huttoni* (Hemiptera: Lygaeidae)

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Abstract

The wheat bug, *Nysius huttoni* White, mainly reported as a pest of wheat and forage brassicas, is native to New Zealand. This pest has been accidentally introduced into The Netherland and Belgium during apple exports from New Zealand. The bug population is abundant in open sparse vegetations and hot-dry habitats, and feeds on dropping seeds. It damages wheat grains during milk-ripe stage by piercing through the glumes into the developing grains that can reduce gluten protein and reduce baking quality. Bugs also suck phloem fluid from seedlings, which can reduce plant establishment in forage brassicas. Early scouting and field monitoring are suggested before making pest management decisions. Seed treatment with neonicotinoids, permethrin, and chlorpyrifos spray in the standing crops are chemical methods of management in New Zealand. These conventional synthetic pesticides have nontarget effects on human health, the environment, and biodiversity. However, preventive measures such as the use of less-susceptible cultivars, and using potential trap crops is other important pest management options. Alyssum (*Lobularia maritima* L. Desv. Brassicales: Brassicaceae) and wheat (*Triticum aestivum* L. Poales: Poaceae) are two potential trap crops of wheat bug. Kale (*Brassica oleracea* L.) cultivars, such as Corka and Regal, and wheat (*Triticum aestivum*) cultivars, such as Batten, Domino, and Oroua, are less-susceptible cultivars. Understanding the biology and ecology of the pest, and utilizing preventative pest management measures such as the use of trap crops and less-susceptible cultivars, and integrating these with 'soft' chemicals make a suitable integrated pest management strategy for this pest.

Key words: wheat bug, *Nysius huttoni*, host, integrated pest management, trap cropping

Species Description

The wheat bug, *Nysius huttoni* White (Fig. 1), a New Zealand endemic insect (Eyles 1960a, He et al. 2003, Aukema et al. 2005) is widely distributed in the North and South Islands (Myers 1926, Eyles 1960a, Eyles and Ashlock 1969) from sea level to 1,800 m (Eyles and Ashlock 1969). This species also reported in the Chatham Islands and the Three Kings Islands (Woodward 1954) of New Zealand. It was first named by Buchanan White in 1878 from the New Zealand collections of Hutton and Wakefield (Eyles 1960b); more recently, it has been recorded in the extreme southwest of the Netherlands (Aukema et al. 2005, Bonte et al. 2010) and north-western Belgium (Bonte et al. 2010). In New Zealand, over 142 genera and 319 species belonging to 28 families of Hemiptera (Larivière and Larochelle 2014); of them, two genera (*Nysius* and *Rhypodes*) with 32 species, belong to family Lygaeidae (Larivière and Larochelle 2014). Four *Nysius* spp., including three endemics and one adventive species, have been reported in New Zealand. *Nysius huttoni*, *N. liliputanus* (Eyles and Ashlock 1969), and *N. convexus* (Usinger 1942) are endemic; *N. caledoniae* Distant was accidentally introduced from Lord Howe Island and Tasmania (Eyles and Malipatil 2010) in 2006 and was first recorded in a lettuce crop in Auckland (Eyles and Malipatil 2010, Rowe and Hill 2015).

Adult wheat bugs are gray or black brown or sometimes creamy white. The apices of the femora and tibia are yellow. Adult wings are translucent or transparent. The body is elongate oval and dorsally flattened. The head is triangular, slightly narrower than pronotum, with prominent round eyes. There are one to four antennal segments; segments 1 and 4 are bigger than segments 2 and 3. The forelegs are thin with no spines (Eyles 1960a). The body is covered by a long, erect pubescence (Fig. 1). The morphological variations and other biological features of the four *Nysius* spp. are summarized in Table 1.

Biology

Various aspects of the biology and ecology of *N. huttoni* have been studied by many authors (Eyles 1963, Birtles et al. 1992, Farrell and Stufkens 1993, He and Wang 2000, He et al. 2002b, Wei 2008a,

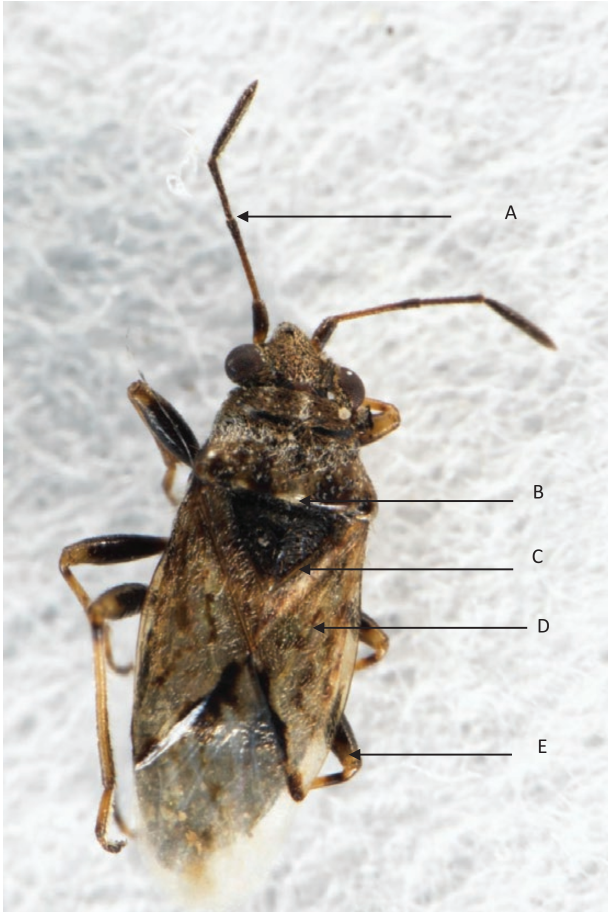

Fig. 1. Key morphological features of *Nysius huttoni*: (A) four-segmented antenna, the last segment is larger than the others; (B) long dense hairs on the pronotum; (C) long dense hairs on the scutellum and (D) on the hemelytron; (E) the distal end of the femur is yellow.

Bonte et al. 2010, Wei 2010). The bug has three life stages: egg, nymph, and adult (Fig. 2; Capinera 2001). *Nysius huttoni* likes hot, dry, and sparse vegetation where sunlight directly strikes the ground (Gurr 1952, 1957; Eyles 1960b), and feeds on the dropping seeds and stems (Wei, 2001; Fig. 3). Crop field margins are more prone to infestation by *Nysius* than the inner part of the field (Capinera 2001). Bugs are highly mobile during summer, are polyphagous, lay eggs in the soil, possess diapause behavior, and can migrate to overwintering sites during the cold season (Farrell and Stufkens 1993, Yang and Wang 2004). Males normally prefer females with a thicker abdomen, more mature eggs, and a longer ovipositor, whereas females favor males with longer antennae and a larger genital structure (Yang and Wang 2004). There are conflicting views on the number of generations per year: 1 per year (Myers 1926); 2 per year (Farrell and Stufkens 1993); and 3–4 per year (Wei 2008b).

Life Stages

Egg

Nysius huttoni females lay eggs in soil, particularly in groups in soil cracks (Fig. 4) and on the host plant parts such as seeds (Fig. 5), flowering heads, leaves, and stems (Farrell and Stufkens 1993, He and Wang 2000). The egg is slightly concave ventrally, convex dorsally and laterally. Eggs are laid in a group or singly (Figs. 4 and 5). Eggs when first laid are 'creamy white' but turn deep orange at hatching. Eggs are 0.77 mm long and 0.28 mm wide. One single female can lay 22 eggs per day at 35°C and produce about 484 eggs in a total oviposition period of 70–90 d (Eyles 1960a). Egg duration ranges from 6 to 12 d.

Nymph

Lygaeidae species usually have five instars (Eyles 1963, 1965; Krinsky 2002), but *N. huttoni* has either four to six instars (He et al. 2003, Wei 2010) or two to four instars (Wei 2001). The small nymphs are dark orange, but later instars are gray or brownish-gray (Fig. 6). The average body lengths of first, second, third, fourth, and fifth instars are 0.84, 1.23, 1.5, 2.05, and 2.52 mm, respectively (Eyles 1960a). Both temperature and photophase directly influence on the number of instars. High temperature and long day length cause frequent five or six instars, and low temperature and short day length result in four instars (Wei 2010). Higher mortality of wheat bugs has been observed in early instars than in late instars and at lower temperatures (<15°C), higher temperatures (>30°C) and in a short photophase (8-h photophase; Wei 2001). Nymph duration ranges from 20 to 21 d (Wei 2008a).

Adult

Adult wheat bugs are small to medium insects (2.4–4.5 mm long) and have various body forms on the basis of wing development (macropterous, sub-brachypterous, and brachypterous), called wing polymorphism (Eyles 1960a). Larger individuals have only macropterous forms (wings longer than the abdomen), whereas the medium and smaller individuals show the three different forms (Eyles 1960a). In field conditions, macropterous forms are predominate (94.1%). Macropterous (male) × macropterous (female) is the predominant mating combination (80.9%; Fig. 7), with macropterous (male) × sub-brachypterous (female) the second combination (13.7%; Wei 2010). Low (<15°C) and high (>30°C) temperature, and short photophase (8-h photophase) lead to sub-brachypterous and brachypterous wing development. Temperature ranging from 20 to 30°C, and a long photophase (12–16 h light) produces macropterous forms.

For larger individuals (macropterous), male and female lengths range from 3.55 to 3.86 mm and 3.74 to 4.34 mm, respectively; male and female widths range from 1.32 to 1.39 mm and 1.61 to 1.75 mm, respectively. The medium size male and female lengths range from 3.00 to 3.48 mm and 3.36 to 3.74 mm, respectively, and widths range from 1.15 to 1.32 mm and 1.44 to 1.53 mm, respectively. In the smallest size category, males and females range from 2.38 to 3.00 mm and 2.47 to 3.19 mm, respectively, and male and female widths range from 0.94 to 1.15 mm and 1.20 to 1.32 mm, respectively (Eyles 1960a). The adult duration ranges from 70 to 90 d. Their populations are abundant in hot and dry condition (Farrell and Stufkens 1993).

Ecology

Temperature and photophase are the critical factors for survival, development, reproduction including the geographical distribution and abundance of wheat bugs. Under Canterbury conditions, third-generation adults generally overwinter in mid-April or early May and emerge from overwintering sites in late August or early September (Wei 2008a). In laboratory studies, an equal sex ratio has been reported (Wei 2008b). However, low temperatures and short days produce a greater proportion of males, and high temperatures and long days produce a greater proportion of females (Wei 2008b).

Table 1. Morphological and other biological features of the four *Nysius* species recorded from New Zealand

Characteristics	*Nysius huttoni*	*Nysius convexus*	*Nysius liliputanus*	*Nysius caledoniae*
Morphological features	Have a complete double row of punctures following claval suture (Eyles and Ashlock 1969) with long and dense hairs on pronotum, scutellum, and hemelytra	A single row of punctures along the side of claval suture (Eyles and Ashlock 1969) and long erect hairs on pronotum, scutellum, and hemelytra	Punctures at claval suture absent and presence of short erect hairs on pronotum, scutellum, and hemelytra	Punctures are absent at claval suture, and scutellum are round
Origin	Endemic	Endemic	Endemic	Adventive
Wing forms, or type	Macropterous[a], sub-brachypterous[b], and brachypterous[c] (Eyles and Ashlock 1969)	Mainly sub-brachypterous (Eyles and Ashlock 1969)	Macropterous (Eyles and Ashlock 1969)	Macropterous (Rowe and Hill 2015), sub-brachypterous, and brachypterous (Eyles 1960a)
Host	Common hosts are Brassicaceae, Polygonaceae, Caryophyllaceae, Compositae, and Leguminosae	Moss associations on glacial moraines and in river-bank vegetations (Larivière and Larochelle 2004)	Moss associations on glacial moraines, on dry river beds, and also on ferns (at night; Larivière and Larochelle 2004)	Lettuce (Rowe and Hill 2015)
Damage potential	Pest of a wide range of cultivated crops (Myers 1926) including weed species	Damage not recorded in cultivated crops (Eyles and Ashlock 1969)	Damage not recorded in crops (Larivière and Larochelle 2004)	First recorded in lettuce but their damage on crops are not recorded (Rowe and Hill 2015)
Distribution	Widely distributed in the North, South, Chatham and Three Kings islands of New Zealand from sea level to 1,800 m, and partly distributed in the Netherland, Belgium, France, and the United Kingdom (Eyles and Ashlock 1969)	South Island (New Zealand; Eyles and Ashlock 1969)	South Island (New Zealand; Eyles and Ashlock 1969)	North Island (Auckland area, New Zealand; Rowe and Hill 2015)

[a]Macropterous (wings longer than abdomen).
[b]Sub-brachypterous (wings level with abdomen or slightly exceed).
[c]Brachypterous (wings are shorter than the abdomen).

Reproductive diapause of wheat bug has been reported (Farrell and Stufkens 1993). Diapause is generally induced in the second generation when the third and fourth instars are transferred to short day length (12:12 [L:D]), whereas a long day length (16:8 [L:D]) breaks diapause (Farrell and Stufkens 1993). Similarly, when fifth-instar nymphs are transferred from 16:8 (L:D) photophase to 10:14 (L:D) and 12:12 (L:D) photophase, all females enter into reproductive diapause (He et al. 2002a). In general, reproductive diapause occurs in *N. huttoni* for 30 d after oviposition (Farrell and Stufkens 1993). The proportion of gravid females is greatest (47–80%) during the first generation, 0.9–6.0% in the second generation, and a minimal proportion in the third generation (Farrell and Stufkens 1993). Nymph and adult wheat bugs cannibalize in the laboratory and could eat four to nine eggs per day (Wei 2001). Parthenogenesis does not occur in wheat bugs but demonstrate aggregation behavior (Wei 2001). The macropterous and sub-brachypterous forms of *N. huttoni* can fly when the air temperature exceeds 27°C and ground temperature exceeds >40°C; however, brachypterous individuals are flightless (Wei 2014).

Habitats and Hosts

Habitats

Wheat bugs are found almost all sparse vegetation where full sunlight directly falls on the ground (Fig. 8). In general, weedy fields, gardens, lawns, bare ground between rows of fruit trees, sandy riverbeds, ornamental gardens, pasture, wastelands, sandy ground supporting a few weeds, roadsides, and so on are the most common wheat bug habitat (Wei 2001). *Nysius huttoni* does not prefer dense vegetation and damp habitats. The populations in crop fields are significantly affected by the following potential weeds: *Capsella bursa-pastoris* (L.) medik (shepherd's purse: Brassicaceae) (Fig. 8), *Coronopus didymium* L. (twin cress: Brassicaceae) (Fig. 9), *Lolium multiflorum* Lam. (ryegrass: Poaceae), and *Bromus willdenowii* Kunth (prairie grass: Poaceae) (Gurr 1952, Every et al. 1990, Wei 2001).

Hosts

Nysius huttoni is a polyphagous species that feed on large numbers of cultivated plant species such as cereal crops, vegetables, horticultural crops, and many weeds (Eyles 1965, He et al. 2003, Yang and Wang 2004). Host plants not only support food materials for the wheat bug but also provide shelter during extreme weather conditions. The quantity and quality of the food greatly influence bug survival, adult longevity, population distribution, reproduction, and species development. The list of common host plants and their families is summarized in Table 2.

Injury and Damage

Evidence shows that *N. huttoni* is distributed on at least 75 plant species of >25 families (Table 2) including almost all cultivated brassicas as well as other cultivated crops and weeds (Myers 1926, Eyles and Ashlock 1969, Wei 2001). Hence, this bug is a very adaptable feeder that can live on almost all cultivated crops as well as a variety of weeds. Its infestations on wheat increase when surrounding weeds have matured and died (Wei 2001).

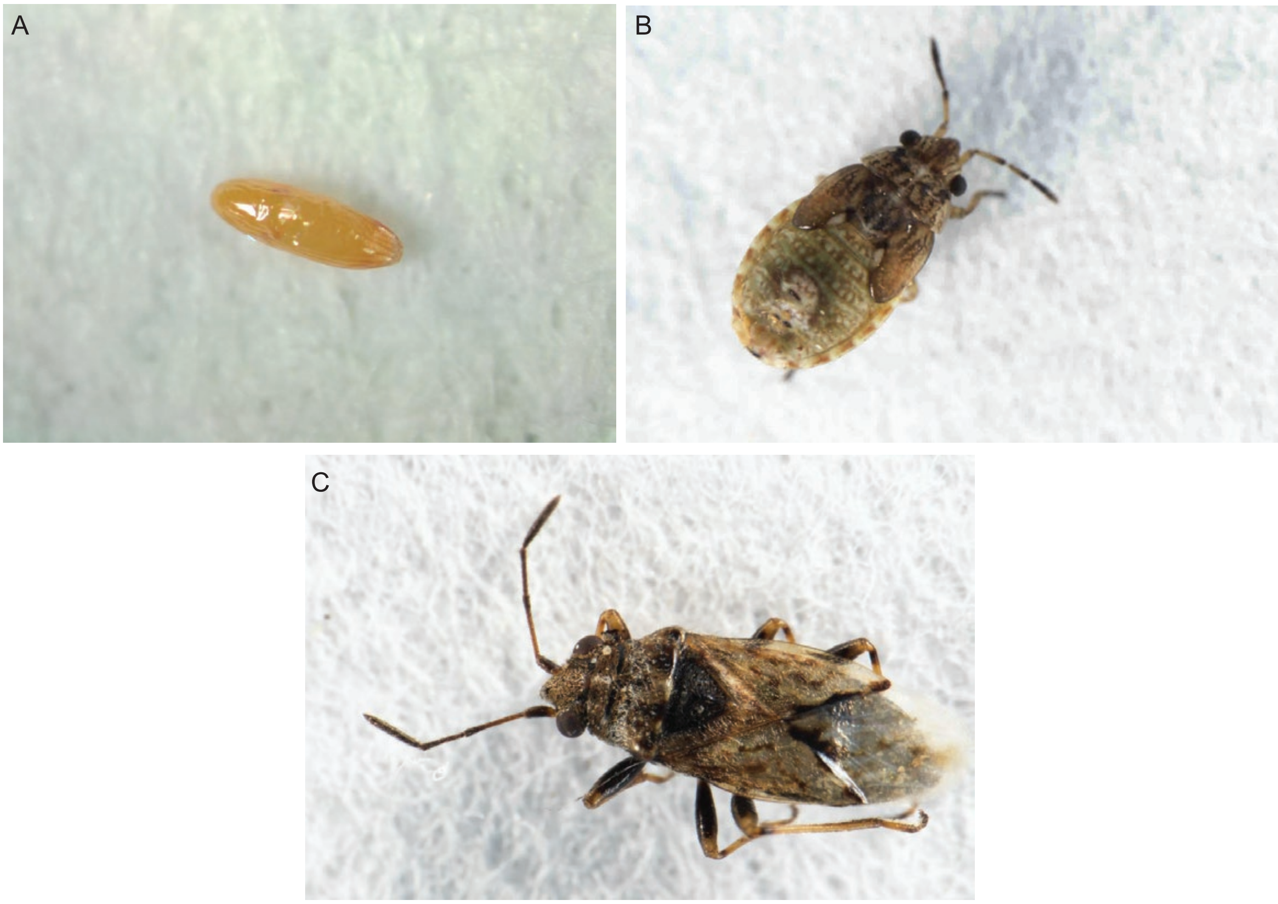

Fig. 2. Life stages of the wheat bug: (A) egg; (B) nymph; (C) adult.

Fig. 3. Suitable wheat bug habitat: (A) sparse vegetation and sunlight directly striking the ground; (B) Shepherd's purse (*Capsella bursa-pastoris*: Brassicaceae) seeds on the ground.

Fig. 4. Wheat bug eggs: (A) laid in a group in soil cracks in the open sparse ground.

The first New Zealand damage record of the wheat bug was on a wheat crop in 1936 (Morrison 1938). Two major wheat bug outbreaks were recorded between 1936 and 1950, and four outbreaks were recorded between 1961 and 1980 (Swallow and Cressey 1987). The worst outbreak was recorded in 1970; it led to the loss of up to 10,000 tons of wheat (Swallow and Cressey 1987). Both adults and nymphs can damage many cultivated crops. Bugs normally damage wheat grains that can reduce the gluten protein and reducing baking quality (Cressey et al. 1987, Every et al. 1992, Every et al. 1998). During feeding, bugs inject toxic saliva that contains a potent enzyme responsible for the quality deterioration of bread (Lorenz and Meredith 1988). Even a negligible infestation in wheat is enough to reduce the market and baking quality. Damaged wheat grains have

Fig. 5. Wheat bug eggs laid singly on sunflower (*Helianthus annuus* L.) seeds in a Petri dish in a laboratory experiment.

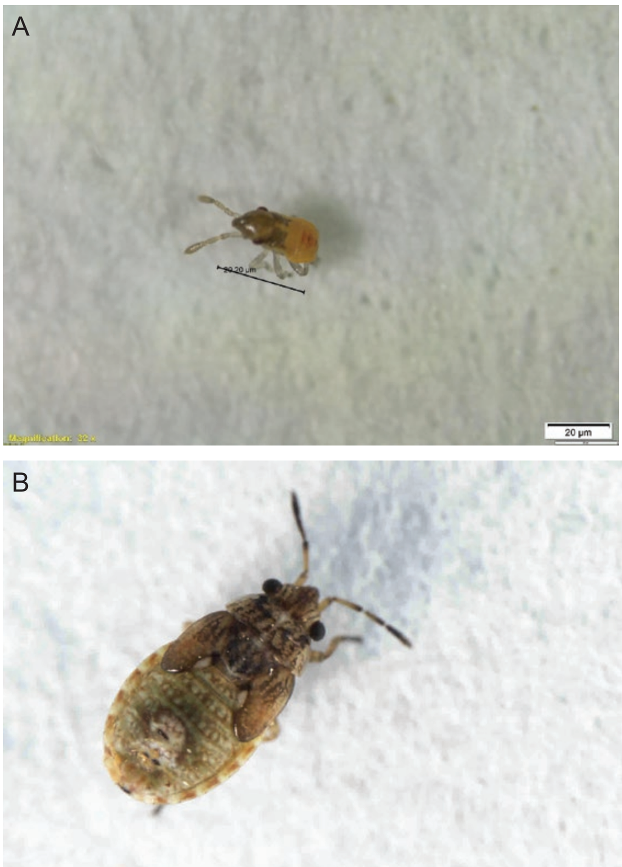

Fig. 6. Newly emerged wheat bug nymphs: (A) first instar; (B) fourth instars.

distinct feeding marks, a pale circular area with a dark puncture mark at the center (Gurr 1957, Miller and Pike 2002). Damage to wheat varieties ranges from 10 to 100% (Every et al. 1989). Damage in wheat and other crops increases with increased hot, dry conditions, which result in desiccation of the hosts.

Nysius huttoni is primarily a seed feeder but may also feed on the vegetative parts of plants such as stems and foliage. This bug is also an economic pest of forage brassicas. Both adults and nymphs damage brassica seedlings. Kale (*Brassica oleracea* L.), rape (*Brassica napus* L. var. *napus*), turnip (*Brassica campestris* L.), and swede

Fig. 7. Mating wheat bugs.

Fig. 8. A wheat bug host (shepherd's purse, *Capsella bursa-pastoris*) at Lincoln University, New Zealand.

Fig. 9. A wheat bug host (twin cress: *Coronopus didymium*) at Lincoln University, New Zealand.

(*Brassica napus* L. var. *napo-brassica*) are widely grown brassica crops for animal production systems in New Zealand (Speciality Seeds 2016). In brassica crops, the wheat bug primarily attacks seedlings by sucking fluids from the base of the plants, which leave a feeding puncture (Fig. 10), resulting in cankerous tissue growth or ring barking (Eyles 1965, Wei 2001). This interferes with sap flow and either causes total loss of the plant or makes them susceptible to breakage by wind or stock movement (He and Wang 1999; Fig. 11). Infestations in germinating seedlings can lead to plant death. Damage can reach up to 90% in direct drilled brassica crops (AgPest 2016, Speciality Seeds 2016). He and Wang (1999) reported that

Table 2. The host plant species of wheat bug, *Nysius huttoni* (Hemiptera: Lygaeidae)

Family	Host plants	Sources
Poaceae	Wheat (*Triticum aestivum* L.), ryegrass (*Lolium* spp.), barley (*Hordeum vulgare* L.; *Hordeum marinum* Huds.), brome grass (*Bromus* spp.), oats (*Avena sativa* L.), rye (*Secale cereal* L.), Yorkshire fog (*Holcus lanatus* L.), paspalum (*Paspalum dilatatum* Poir.), tussock (*Nassella trichotoma* Hackel ex Arech.), browntop (*Agrostis tenuis* Sibth.; *Agrostis capillaris* L.), annual bluegrass (*Poa annua* L.), vulpia hair grass (*Vulpia megalura* Rydb.), perennial ryegrass (*Lolium perenne* L.)	Myers (1926), Morrison (1938), Gurr (1952, 1957), Eyles (1965), Eyles and Ashlock (1969), Cressey et al. (1987), Swallow and Cressey (1987), Lorenz and Meredith (1988), Every et al. (1990), Every et al. (1992), Farrell and Stufkens (1993), Bejakovich et al. (1998), Every et al. (1998), Wise et al. (2000), EPPO (2006), CABI (2011)
Brassicaceae	Twin cress (*Lepidium didymium* L.), shepherd's purse (*Capsella bursa-pastoris* (L.) medic.), swede (*Brassica napo-brassica* Mill.), turnip (*Brassica rapa* L.), rape (*Brassica napus* L.), kale (*Brassica oleracea* var. *acephala* L.), narrow-leaved cress (*Lapidium pseudotasmanicum* Thell.), alyssum (*Lobularia maritima* (L.) Desv.), fodder beet (*Beta vulgaris* L.), cabbage (*Brassica oleracea* L.)	Gurr (1952, 1957), Eyles (1960b, 1963, 1965), Eyles and Ashlock (1969), Pearson and Goldson (1980), Farrell and Stufkens (1993), Ferguson (1994), He and Wang (1999), He and Wang (2000), Wei (2001), He et al. (2002a, 2002b, 2003, 2004), Yang and Wang (2004), EPPO (2006), Wang et al. (2008), Wei (2008a, 2010, 2012)
Fabaceae	Lucerne (*Medicago sativa* L.), suckling clover (*Trifolium dubium* Sibth.), red clover (*Trifolium pretense* L.), subterranean clover (*Trifolium subterraneum* L.), common broom (*Sarothamnus scoparius* L.), hare's foot clover (*Trifolium arvense* L.), strawberry clover (*Trifolium fragiferum* L.), clustered clover (*Trifolium glomeratum* L.), gorse (*Ulex europaeus* L.); white clover (*Trifolium repens* L.),	Myers (1921), 1926), Gurr (1952, 1957), Eyles (1960b), Schroeder and Chapman (1995), Wei (2001), EPPO (2006), CABI (2011)
Asteraceae	Sunflower (*Helianthus annuus* L.), onehunga weed (*Soliva sessilis* Rulz & Pav.), tauhinu (*Cassinia leptophyla* (G. Frost) R. Br.), cat's ear (*Hypochaeris radicata* L.), hawkweed (*Hieracium* spp.), narrow-leaved ragwort (*Senecio inaequidens* DC.), Scotch thistle (*Cirsium vulgare* (Savi) Ten.), hawksbeard (*Crepi* ssp.), Mexican daisy (*Erigeron karvinskianus* DC.), common fleabane (*Pulicaria dysenterica* (L.) Bernh.), dandelion (*Taraxacum officinale* G. Weber.), button weed (*Cotula* spp.)	Myers(1921, 1926), Eyles (1965), Eyles and Ashlock (1969), Syrett (1993), Wei (2001), He et al. (2002b), He et al. (2004), Yang and Wang (2004), EPPO (2006), Wang et al. (2008)
Polygonaceae	Red clover(*Rumex acetosella* L.), wireweed (*Polygonum aviculare* L.), lady's thumb (*Polygonum maculosa* S.F. Gray)	Eyles and Ashlock (1969), Farrell and Stufkens (1993), Wei (2001), He et al. (2002b, 2004), Yang and Wang (2004), EPPO (2006), Wang et al. (2008)
Caryophyllaceae	Catch fly (*Silene gallica* L.), chickweed (*Stellaria media* (L.) Vill.), red sand spurry (*Spergularia rubra* (L.) J. Presl & C. Presl.	Myers (1921, 1926), Eyles and Ashlock (1969), EPPO (2006)
Rosaceae	Strawberry (*Fragaria* spp.), raspberry (*Rubus* spp.), apple (*Malus* spp.)	Gurr (1952, 1957), Wei (2001), EPPO (2006)
Geraniaceae	Common storksbill (*Erodium cicutarium* (L.) L'Her.), cranesbill (*Geranium* sp.)	Gurr (1952); Wei (2001)
Various families	Flax (*Linum* spp: Linaceae), curnow's curse (*Calandrinia caulescens* Phil: Montiaceae), lamb's quarters (*Chenopodium album* L: Amaranthaceae), flowering kanuka (*Kunzea ericoides* (A. Rich) Joy Thomps: Myrtaceae), moss (*Triquetrella papillata* (Hook.f. & Wilson) Broth: Pottiaceae), red pimpernel (*Anagallis arvensis* L: Primulaceae), pine (*Pinus radiata* D. Don: Pinaceae), kapuka (*Griselinia littoralis* Raoul: Griseliniaceae), moss (*Gleichenia circinata* Swartz: Gleicheniaceae), pimelea (*Pimelea arenaria* A. Cunn: Thymelaeaceae), viper's bugloss (*Echium vulgare* L: Raginaceae), mallow (*Malva* spp.: Malvaceae), flannel leaf (*Verbascum thapsus* L: Scrophulariaceae), kiwifruit (*Actinidia*sps: Actinidiaceae), Monterey cypress (*Cupressus macrocarpa* Gordon: Cupressaceae), sleeping beauty (*Oxalis corniculate* L: Oxalidaceae), horokaka (*Disphyma* spp.: Aizoaceae)	Myers (1921, 1926), Gurr (1952, 1957), Eyles (1965), Eyles and Ashlock (1969), Farrell and Stufkens (1993), Wei (2001), EPPO (2006)

the highest percentage of damage to swede seedlings was recorded during a windy period.

Integrated Management Strategies

Field Monitoring

Regular monitoring and frequent field observations help assess pest populations and provide early detection of crop damage by the pest. A suction machine (Shred n Vac Plus, Stihl BG 75, 80 cm long × 12.0 cm inlet diameter) is a common monitoring tool used to study the population expansion of wheat bug in crop fields (Fig. 12). Wheat bugs management action should be followed when three or more bugs can be seen in a 10 × 10 cm area (AgPest 2016). Ring-barking symptoms, wilting of seedlings, leaf distortion, and breakage of seedlings in a windy period or after stock movement are the most visible signs of a wheat bug damage and likely in forage brassicas (Wei 2001, AgPest 2016). Damage to wheat grains is a distinct pale circular mark with a unique dark puncture at the center (Wei 2001). Therefore, monitoring adults and nymphs, and damage assessment early in the season have been recommended to evaluate the bug damage in crops.

Trap Cropping

Trap cropping is a common wheat bug management practice in forage brassicas in New Zealand (Tiwari et al. 2018a). This is based

Fig. 10. Wheat bug damage symptoms at the base of alyssum (*Lobularia maritima*) seedlings in a laboratory experiment at the Bio-Protection Research Center (BPRC), Lincoln University, New Zealand.

Fig. 11. Wheat bug damage symptoms in the kale (*Brassica oleracea*) seedlings in a laboratory experiment at the Bio-Protection Research Center, Lincoln University, New Zealand.

on growing one or more trap plant species adjacent to or within the main crop that can reduce pest density in the main crop (Shelton and Nault 2004). Alyssum (*Lobularia maritima* L. (Desv.)) and wheat (*Triticum aestivum* L.) are two potential trap crops of the wheat bug in forage brassicas (Tiwari et al. 2018a; Fig. 13). These trap crops can be deployed in brassica fields as a single trap crop (alyssum or wheat only) or as a multiple trap crop (alyssum and wheat together) around the perimeter of the brassica fields (Tiwari et al. 2018a). Depolyment of such trap crops in main field can protect the main crop either by preventing the wheat bug from reaching it or by leading them to a certain pat of the field where the insect can be economically managed either by removal of the trap refuges or using insecticides locally (Rea et al. 2002, Shelton and Nault 2004) The flowering stage of alyssum and the milk-ripe stage of wheat are the suitable growth stages for the wheat bug (Tiwari et al. 2019b). Flowering alyssum is a garden plant that can also deliver multiple ecosystem services in crop field by providing shelter, nectar, alternative food, and pollen to the pest natural enemies such as predators and parasitoids (González-Chang et al. 2019, Tiwari et al. 2019a).

Selection of Suitable Cultivars

The selection of suitable crop cultivars could be a viable option to reduce bug infestations. Some cultivars are less susceptible to wheat

Fig. 12. A suction machine used for monitoring the bug population in kale (*Brassica oleracea*) fields at the Biological Husbandry Unit (BHU), Lincoln University, New Zealand.

Fig. 13. Flowering alyssum (*Lobularia maritima*) used as a trap crop for the wheat bug in a kale field at BHU, Lincoln University, New Zealand.

bug and some are more susceptible. A study conducted in New Zealand over a wide range of kale (*B. oleracea*) cultivars suggested that cultivars Regal and Corka are less susceptible than Kestrel, Gruner, Sovereign, and Coleor. The two commercial popular kale cultivars in New Zealand, Kestrel, and Gruner are more prone to bug damage (Tiwari et al. 2018b). Similarly, Oroua, Batten, and Domino wheat cultivars are relatively less susceptible than Karamu, Otane, WW378 and ASPS 9927 (Every et al. 1998).

Chemical Control

In New Zealand, prophylactic use of pesticides is a common method of pest and disease management in forage brassicas (Trevor 2010). These synthetic chemicals have been used to attract, reduce, or kill selected crop pests. Seed treatment with neonicotinoids and spraying with chlorpyrifos and permethrin insecticides are common practices in *N. huttoni* management in forage brassicas (Trevor 2010, Goldson et al. 2015, Young 2018).

Biological Control

There are a very few records of biological control agents of *N. huttoni* in the literature. Some potential predators are *Neocicindela parryi* White (Coleoptera: Cicindelidae), *Metaglymma moniliferum* Bates (Coleoptera: Carabidae), *Coccinella trifasciata* L. (Coleoptera: Coccinellidae), *Nabis maoricus* Walker (Hemiptera: Nabidae), *Lycosa hilaris* Koch (Araneae: Lycosidae), and *Pardosa bellicose* Goyen (Araneae: Lycosidae) (Wei 2001). Chrysopidae species are other potential predators (Capinera 2001). Birds are suitable vertebrate predators of the wheat bug in irrigated pasture land in New Zealand (Lobb and Wood 1971).

Future Research Recommendations

Future research should be focused to develop a 'push–pull strategy' to manipulate the behavior of the pest and beneficial insects (Pyke et al. 1987), which is certainly useful in developing future integrated pest management (Aldrich et al. 2003, Cox 2004, Cook et al. 2006). The 'push' factor could be less-susceptible kale cultivars, deployment of such kale cultivars in kale fields, repel or deter the wheat bug or make the crop unsuitable for landing or feeding by the wheat bug (Khan and Pickett 2004). The efficiency of a less-susceptible kale cultivar 'push' factor can be enhanced by exogenous application of repellents (Griffiths et al. 1991, Gerard et al. 1993) or other biotechnological approaches (Eigenbrode et al. 1991). These could be research options in the future. The 'pull' factor could be a potential trap plant that can lure or attract wheat bugs and other insects away from the main crop (Khan and Pickett 2004, Cook et al. 2006). The wheat bug normally damages brassica seedlings (4- to 6-wk old; AgPest 2016). Hence, kale seedling protection using a trap crop could be a future important and challenging issue. Future research could also focus on the time of deployment of alyssum in kale fields, so that 4- to 6-wk-old kale seedlings can be protected from the bug damage. In summary, research should be focused on 'push–pull' strategies as a holistic agroecological wheat bug management strategy in forage brassicas and other crop fields.

Concluding Remarks

The wheat bug is a major pest of wheat and brassica seedlings in New Zealand and is a quarantine pest in Australia, Europe, and the United States. Accidentally, this pest has been introduced into some European countries such as the Netherlands, Belgium, France, and the United Kingdom. It is a polyphagous pest and has a wide host range from cultivated crops to several weed species. High temperatures and long photophase are the most suitable environment for their survival, reproduction, and abundance. Low temperatures (<15°C) and short day length (<12-h light duration) induce reproductive diapause. Diapause is an adaptive mechanism for insect survival under unfavorable condition. This is normally occurs at a specific stage and specific season. This bug has seven life stages: egg, five instars (1–5), and adult. Sparse vegetation, hot and dry conditions, and bright sunlight provide the most congenial environment for the wheat bug. Nymphs and adults primarily damage brassica seedlings and wheat grains and reduce grain quality and the number of brassica seedlings.

A range of control options is available to manage wheat bugs such as trap cropping, use of less-susceptible kale cultivars, and prophylactic use of pesticides. Integrated pest management has been considered an integral part of pest management to reduce pesticide risk to human health and the environment. Regular bug sampling with a suction machine (see above) and early damage assessment are suggested to assess the economic threshold level. Alyssum and wheat are two potential trap crops. Kale varieties Corka and Regal are less susceptible as are wheat cultivars Batten, Domino, and Oroua. Integration of potential cultivars with suitable trap crops, and using 'soft' chemicals on an as needed basis could be a useful integrated wheat bug management option in forage brassicas and other crops in some countries.

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