RUSSIAN WHEAT APHID:
TACTICS FOR FUTURE CONTROL

A RESOURCE FOR AUSTRALIAN GRAIN GROWERS AND ADVISERS

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- Intensive monitoring of early-sown crops, including cereals sown as pasture, should occur for the first 4-8 weeks after sowing.
- Populations frequently start to increase as temperatures warm in spring or typically from tillering onwards.
- Stressed areas of the paddock are often the first to be infested and hence monitoring may specifically target these areas first.

Symptoms

- Russian wheat aphid (RWA) can be detected in cereal crops by visual examinations. Plants will show characteristic symptoms such as chlorosis; necrosis; wilting, stunting; leaf streaking with whitish, yellow and purple longitudinal leaf markings; trapped awns (which give a hooked appearance); stunted growth; rolled leaves and heads that fail to flower.
- Growers should first inspect inside the leaf rolls and newest leaves for aphid infestations.

Environmental conditions

- RWA is primarily associated with cereal production regions characterised by warmer, drier climates.
- It is less prevalent in higher rainfall areas, with heavy rainfall reported to cause 50 per cent mortality.
- Despite having a significantly higher tolerance to cold temperatures than other cereal aphids, the population growth of RWA will be reduced with the onset of cold and wet conditions.
- Frequent spring rainfall and dry/hot summer conditions (no green bridge) will lower the risk of RWA infestations.

Management

- Wherever possible, save pesticide options until periods of peak aphid activity, during early crop establishment in autumn or during spring when populations are likely to increase and protection of the flag leaf is vital to maximise grain fill. Currently registered foliar applied insecticide sprays do not provide any meaningful preventative activity. Spraying low populations of RWA may also kill predators and other beneficials, potentially causing a spike in RWA numbers in spring when temperatures increase.
- Preserve populations of predators and other beneficials to help control aphid numbers.
- Managing the green bridge over summer and autumn will reduce the refuges which enable aphids to carry over from one season to the next. Grass weeds and cereal volunteers should be targeted.

Chemical management

- Adopt a threshold-based management strategy. Chemical control is warranted if infestations exceed thresholds of 20 per cent of seedlings infested up to the start of tillering and 10 per cent of tillers infested thereafter. Crop/yield loss may be minimised through protection of the top three (major yield contributing) leaves.
- If spraying is warranted, use softer chemistry (e.g. pirimicarb) where possible to encourage natural predators and beneficial insects, especially early in the season.
- Avoid prophylactic insecticide applications.
- Chlorpyrifos and pirimicarb are currently registered for control under two Australian Pesticides and Veterinary Medicines Authority (APVMA) Emergency Use Permits. Keep chlorpyrifos for heavy infestations. Good spray coverage and consideration of weather conditions (temperature, rainfall) in the 24 hours prior and shortly after application are important.

Seed treatments

- Neonicotinoid seed treatments are expected to provide effective early season control of RWA. Preliminary evidence indicates the length of protection is expected to be equivalent to that observed for other cereal aphid species.
- Prophylactic use of neonicotinoid seed treatments is discouraged and use should be targeted at those situations deemed to be of higher risk (early sowing, especially early sown barley crops; or areas where volunteer cereals and/or live aphids are identified prior to sowing).

Report sightings

- Grain growers and advisers across Australia should remain vigilant and keep a look out for unusual aphid activity in cereal crops. suspected infestations in areas where RWA has not been confirmed should be reported to your state or territory's department of agriculture or primary industries. In WA, NT and Qld, suspected new infestations need to be reported to the Exotic Plant Pest Hotline on **1800 084 881**.

Executive Summary

Russian wheat aphid, *Diuraphis noxia*, (RWA) is one the world's most economically important pests of barley (*Hordeum vulgare*), wheat (*Triticum aestivum*) and other cereal grains. Affecting more than 140 species of grasses within the Poaceae (or Gramineae) family, it has rapidly dispersed from its native origin of southern Russia, the Middle East and Central Asia into most major grain producing regions including Africa, Asia, Europe, the Middle East, North America and South America [1-5].

In 2016, RWA was found in Australia. The first case was identified in a wheat crop at Tarlee in South Australia's Mid North in mid-May 2016. Infestations now stretch into Victoria, New South Wales and Tasmania. Authorities have declared the pest unfeasible to eradicate and growers must implement a sound management plan to reduce both crop impact and its wider dispersal to further states and territories.

RWA's history of successfully invading new regions is partly due to its widely available host plants and capacity for rapid population growth. Australia's cereal cropping regions, which are characterised by warmer, drier climates, provide a suitable climate for the RWA to thrive and reproduce. Australia's cropping regions also feature a wide range of Graminaceous host plants, including cultivated and wild grasses, which are the aphid's preferred hosts. These hosts are also available as over-summering hosts, providing the green bridge to support its persistent population growth.

Aphids may infest host plants at any stage of plant development. RWA feeds on the leaves, flowers and seed-heads of grasses, with colonies preferring the youngest leaves [6]. At high densities it can be found on any foliar parts.

Like other aphids, RWA is a phloem feeder which damages the plants through nutrient drainage [6, 7]. However, unlike other common cereal aphid species, RWA also has the ability to inject, or transfer, a toxin into the phloem sap while feeding causing rapid, systemic phytotoxic effects on plants. This feeding damage is considered more economically important than its ability to act as a vector for plant viruses. In fact, unlike many other aphids, RWA does not seem to be a major vector of cereal viruses such as Barley yellow dwarf virus (BYDV) [8, 9].

Aphid feeding can result in significant yield loss in cereal crops, with barley being more susceptible than wheat. Early, heavy infestations on barley can cause total crop loss [6, 10] and/or significantly affect grain quality [11] [6]. Heavy infestations can result in tiller mortality and, in severe cases, plant death. Results published in international literature suggest that spring wheat suffers greatest yield loss when attacked during tillering to boot stage whilst winter wheat suffers greatest loss after vernalisation [6, 12]. The association between economic loss and the timing and level of RWA infestation is still to be determined under Australian conditions.

While the introduction of RWA presents yet another pest for growers to control in farming systems of south-eastern Australia, it is a manageable pest through implementation of a range of effective cultural, chemical and biological controls. Growers are advised to assess local risk and adopt a threshold-based management strategy, noting that genetic resistance; strategic use of insecticides; control of volunteer cereals and alternate grass hosts; and strategies that encourage the prevalence of natural enemies will be integral to the long-term management of RWA.


PHOTO: Michael Nash

1.0 Introduction

In May 2016, Russian wheat aphid (*Diuraphis noxia*) (RWA) was identified in a wheat crop at Tarlee in South Australia's Mid North. Since then, the aphid has become relatively widespread across the major cropping regions of South Australia and Victoria, parts of southern New South Wales and, more recently, Tasmania.

In June 2016, RWA was declared to be not technically feasible to eradicate from the major cropping areas of south-eastern Australia and the industry moved quickly to develop and implement an ongoing integrated pest management plan.

Since RWA has not been previously detected in Australia, limited research under local agro-climatic conditions and farming systems currently exists. Recognising the gaps in knowledge, availability of management tools and the need for information to better inform the development of integrated control strategies based on local risk, a team of experts has recently undertook a global review of literature relevant to Australian growing conditions. This document outlines the findings of this GRDC funded literature review and identifies tactics for future management for your consideration.

Aiming to address critical knowledge gaps relating to pest biology, population dynamics and development of sustainable methods of future control is a priority recognised by the GRDC. A great deal has been learnt and achieved in the 12 months since the first detection, driven by GRDC investments in insecticide efficacy trials; local testing of economic thresholds for control; determination of aphid biotype using differential sets; resistance screening of cereal germplasm and commercial varieties; aphid biology and ecology studies; and a range of communication and extension activities. The GRDC thanks its valued research partners who have helped to answer the many questions raised and, in particular, the dedicated team of entomologists who responded so quickly to the RWA incursion.

Whilst the threat posed by RWA is recognised, it is an inevitable fact that growers and advisers will need to continue to respond to in-season issues that may arise. RWA is one of many pests that can be managed using an integrated approach that employs cultural tactics, including control of the green bridge; encourages the prevalence of natural enemies; incorporates the strategic use of insecticides; and potential deployment of resistant germplasm. An integrated approach considers local risk and robust science.

I hope that the information contained here helps to expand your understanding of this new pest and better informs how it can be best managed in your farming business.

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2.0 Global distribution

Russian wheat aphid was first described in Russia by [13] (hence the name 'Russian' wheat aphid [4]), as a pest of barley and has since dispersed into Africa, Asia, Europe, the Middle East, North America and South America [1-5], and more recently Australasia (see Table 1 for dates). Endemic to central Asia, Russia, countries bordering the Mediterranean Sea, Iran and Afghanistan [14-16], the RWA only gained recognition as a global wheat pest when it expanded its range to the majority of the wheat producing continents over a 15 year period beginning in the 1970s [17-21].

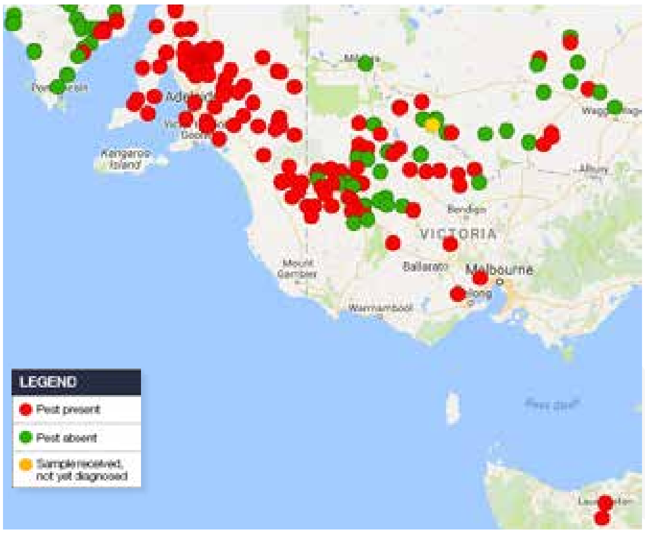
Table 1. Dates of the first recordings of RWA in different countries.

COUNTRY	FIRST RECORDED	REFERENCES
Russia	*1901*	[22]
Spain	1947	[23]
Ethiopia	1972	[24]
Yemen	Late 1970s	[25]
South Africa	1978	[4, 26]
Mexico	1980	[26, 27]
US	1986	[28, 29] [30] cited in [31]
Chile	1987	[32]
Canada	1988	[25, 33]
Hungary	1989	[34]
Argentina	1992	[35]
Czech Republic	1993	[3, 36]
Australia	2016	[37]

3.0 Incursion into Australia

On May 19, 2016, RWA was identified in a wheat crop at Tarlee in South Australia's (SA's) Mid North. Since then, it has been identified in many cropping regions across SA, Victoria, parts of southern New South Wales and Tasmania. The pest has mostly infested wheat and barley crops. The distribution of RWA in Australia has been mapped (Figure 1). Until confirmed as present, RWA is a notifiable pest in all other Australian states and territories.

Figure 1: Current known distribution of RWA in Australia at 23 January 2017.



(Source: AUSPestCheck, Plant Health Australia).

RWA infestations identified during the initial outbreak in SA appeared to have started on wheat volunteers. Large numbers of aphids were also supported on barley grass as an early germinating summer/autumn host. Rainfall in January 2016 may have created a green bridge that favoured RWA, as many of the heavier, paddock-wide infestations were in early-sown crops containing volunteer cereals. This is supported by the fact that most early infestations in other parts of SA and Victoria were first observed on volunteers. In other later sown and/or less infested paddocks, RWA was mostly limited to paddock edges, where local migration from grasses into the paddock is likely to have occurred [9].

Successful establishment of RWA is favoured by a continual green bridge of host plants over the summer/autumn period. In Australia, wheat and barley sowing can take place between February and July, with crops growing actively from March to December. Spring sowing can also occur. Volunteer wheat plants may also emerge over the summer period (December to March). This, along with summer growing grass species, may act as host plants allowing RWA populations to persist from one growing season to the next.

4.0 Identification

RWA is a small aphid (insect) which is light lime-green in colour and can appear to be coated in a fine white wax. The tips of the legs and antennae (which are distinctively short) are black [9]. Wingless adults grow up to about 2mm long. In comparison to other aphids, such as the oat aphid (*Rhopalosiphum padi*) and corn aphid (*Rhopalosiphum maidis*), which have a pear or globular body shape, the RWA has an elongated spindle-shaped body and lacks cornicles (commonly referred to as 'exhaust pipes') [9]. The adult RWA has two caudae, or a 'double tail', at its rear, which are clearly visible when looking at the aphid's profile using a hands lens or a microscope.

Figure 2: The RWA is elongated (left) compared with the globular body of the oat aphid (top right), and lacks the siphunculi or 'exhaust pipe' structures shown on the oat aphid and corn aphid (bottom right).

RWA is a small winged aphid which is light lime=green in colour and can appear to be coated in a fine white wax.

RWA has an elongated spindle shape.

The adult RWA has two caudae, or a double tail, that the rear.

RWA antennae

PHOTO: Michael Nash

The tips of the legs and antennae (which are distinctively short) are black.

Wingless adults grow up to two millimetres long.

5.0 Hosts

The host range of RWA includes more than 140 species of cultivated and wild plants within the Gramineae (grasses) family. These include wheat, durum, barley, triticale, rye, oats, pasture grasses and wild genera including *Poa, Bromus, Hordeum, Lolium, Phalaris* and others. A review of the international literature suggests that Jointed goatgrass (*Triticum cylindricum*), Blando bromegrass (*Bromus mollis*), Rattail fescue (*Vulpia myuros*), European dunegrass (*Elymus arenarius*), Canada wildrye (*Elymus canadensis*) and Field bromegrass (*Bromus arvensis*) are common hosts [38] [39].

Of the large number of host species most seem to be inferior compared with wheat and barley [40]. Within Triticeae, the *Hordeum* and *Thinopyrum* genera were ranked as susceptible; *Agropyron, Elymus, Pascopyrum,* and *Pseudoroegneria* genera as moderately susceptible; and *Leymus* and *Elytrigia* genera as moderately resistant to RWA attack [41].

Alternate plant hosts play a key role in the life cycle of RWA by providing a source of food during the interval between harvest and emergence of new crops. Suitable hosts in South Africa, for example, include volunteer wheat, rescue grass, oats, wild oats, barley and false barley [42]. These plants grow abundantly in and around wheat fields and also in road reserves.

There are a diverse range of host plants for RWA in Australia. Growers in the southern grain-growing regions pay particular attention to cereal volunteers which are important over-summering hosts. Pasture grasses and wild genera, as listed above, will also be predominant hosts. When there are suitable hosts in an area, RWA will survive successfully to the next season and be able to build up populations early in the season. These populations will spread to the emerging wheat crop and become a significant pest.

It is important to note that Australian researchers are still defining the local RWA host range through ongoing GRDC investments. This will enable growers and advisers to better understand the pest ecology and associated management options. Information will be issued via GRDC communication channels as more information comes to hand.

6.0 Feeding behaviour

RWA feeds on the leaves, flowers and seed-heads of grasses, with colonies preferring the youngest leaves or newly emerged growth [6]. However, at high densities it can be found on any foliar plant part. Plant selection by the aphid can be categorised in four phases [43].

- Phase 1 includes a pre-alighting behaviour, where the aphid selects a plant to land on and potentially feed from.
- Phase 2 involves the exploration of the plant surface and the immediate sub-epidermal tissues, when the aphid roams the leaves in search of a suitable feeding area.
- Phases 3 and 4 sees the aphid search the nutritional tissues for ingestion of nutrients [43, 44], then finding a suitable site on the leaf surface to penetrate and probe [43, 44].

Like other aphids, RWA is a phloem feeder which means the aphids feed by inserting their stylets between the mesophyll cells and into the phloem cells, where they drain the nutrients (sap) [6, 7, 45]. However, while feeding RWA also has the ability to inject, or transfer, a polypeptide toxin into the phloem sap which affects the phloem composition [46-48]. The toxin affects epidermal cells, and other tissues containing lignin, and also destroys chloroplast membranes which in turn affects the photosynthetic ability of the plant [49] cited in [45]. RWA feeding can damage the plant leaf tissue so badly that it cannot recover.


PHOTO: Alistair Lawson

Feeding of Russian wheat aphid colonies causes striped discolouration of leaves

PHOTO: Anna-Maria Botha et al., bio.biologists.org

Stunted growth and leaf discolouration caused by Russian wheat aphid

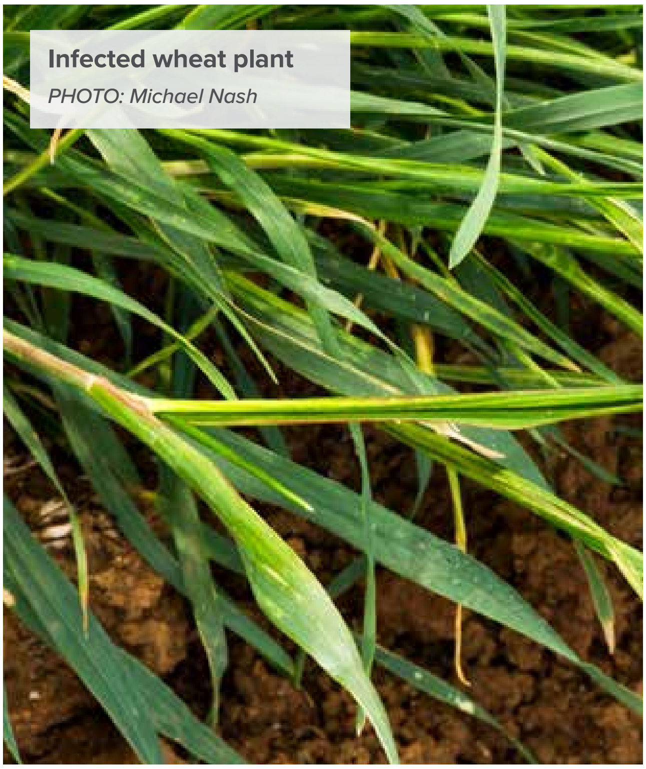
PHOTO: Phil Sloderbeck, Kansas State University, Bugwood.org

7.0 Symptoms

Russian wheat aphid feeding damage can be observed by a range of symptoms. Symptoms at the feeding site include chlorosis and necrosis [50] which can be characterised by white or yellow streaking [15] and systemic leaf symptoms include purple longitudinal streaks on leaves [9]. Affected plants can appear stunted and stressed and tillers may become prostrate [51]. Feeding during the vegetative stages can reduce plant vigour and growth and result in severe yield penalties. Heavy infestations during heading can also cause test weight reductions [51]. After the soft dough stage, further impact is thought to be minimal. Other characteristics of RWA feeding include discoloured leaves, bleached heads, rolled leaves and hooked-shaped head growth from awns trapped in curling flag leaves.

RWA feeding causes two types of leaf rolling; leaf folding in fully expanded leaves and the prevention of unfolding in newly formed and immature leaves [43]. In mature leaves, the leaf edges begin to roll inward. This can affect subsequent leaves as they may be trapped by the tightly rolled leaves [51], and it may also trap the developing grain head, which in turn affects self-pollination and grain-fill [52]. The prevention of proper unfolding of new leaves and reduction in leaf size is due to the aphid's feeding behaviour which can cause a reduction of leaf turgor below the threshold for elongation and cell wall extensibility [43]. It benefits the aphid by providing shelter from the elements and beneficial insects.

In wheat and barley, damaged leaf tissue does not recover. If aphids are controlled, new growth proceeds normally (new root and shoots are unaffected) and plants may recover unless excessively stressed. After soft dough stage, further impact is thought to be minimal [9].



Infected wheat plant
PHOTO: Michael Nash

Characteristic wheat leaf streaking
PHOTO: Michael Nash

Discolouration of wheat leaves caused by RWA

8.0 Vector for disease

Unlike other aphids, RWA does not seem to be a major vector of cereal viruses such as Barley yellow dwarf virus (BYDV) [8, 9]. South African research during the period 1979-1981 demonstrated laboratory transmission of several cereal viruses (including BYDV, brome mosaic and Barley stripe mosaic virus) by RWA [53]. Despite these findings, there are no published reports of RWA being associated as a key vector in field outbreaks of cereal viruses.

PHOTO: Alistair Lawson

9.0 Yield loss

Major yield losses of up to 80 per cent in wheat and 100 per cent in barley have been associated with RWA infestation in overseas studies.

Research has measured losses of between 35% and 60% in winter wheat [54]. Significant yield losses for wheat have been reported at tillering, jointing, heading, grain fill, dough stage [55]. One study found that yield loss reduced as the timing of infestation was delayed in relation to crop development stage, i.e. the greatest loss occurred from infestation at the tillering stage, and the least impact occurred from infestation at the dough stage. This study also recorded a reduction in grain protein from RWA infestations occurring during spring.

Research has also documented that early, heavy infestations on barley can cause total crop loss [10] and significantly affect grain quality [6, 11].

The relationship between wheat or barley yield and RWA infestation level is variable, influenced by variety, location and cereal growth stage. Most studies indicate a loss of approximately 0.5% in wheat yield for every 1% infested tillers, from tillering through flowering. Good data on losses after flowering is not readily available. Much more limited data indicates that losses in barley may be substantially higher, perhaps 0.8% per 1% infested stems [56]. More detailed damage loss assessments are yet to be established for the various regions of Australia.

10.0 Reproduction

The reproductive behaviour of the RWA varies in different parts of the world, as it is influenced by geography, winter temperature and day length. These factors determine if the aphid's lifecycle is holocyclic, anholocyclic, or a combination of both [57].

In Hungary, Spain and Russia, RWA is thought to be holocyclic [26]. Holocycly, also known as cyclical parthenogenesis, is the process where aphids produce eggs by sexual reproduction that overwinter in conditions too severe for adult survival.

RWA is anholocyclic in South Africa [58], Iran [16], France and Turkey. This lifecycle is based on asexual reproduction where adult aphids do not lay eggs but instead give birth to live, genetically identical nymphs which, after the fourth moult, develop into either wingless or winged adults. RWA appears less harmful to cereal crops in regions where it undergoes holocyclic reproduction [2].

In the US, RWA is primarily anholocyclic, but gynocyclic reproduction, in which egg bearing females (oviparae) occasionally produce sterile green eggs, and no males are present, has also been observed [59, 60].

RWA causes most crop damage in regions where it occurs with an anholocyclic lifecycle. Female aphids can produce up to 70 nymphs in their lifetime [63]. Further, RWA's multiplication success can be attributed to the 'telescoping' of parthenogenetic aphid generations. Telescoping aphids are adult female aphids which can be thought of as 'Babushka Dolls'. From birth (in fact, from the time each aphid was an embryo), each female aphid already has a number of developing embryos inside her. She is ready to give birth to the largest of these as soon as adulthood is reached. These newly born daughters already have within them the embryos of the first granddaughters too (Aphids on World Plants 2017). RWA development rates under temperature regimes across Australian cereal producing regions are likely to produce 15 or more generations per annum [58] [62].

Since RWA was only reported in Australia in 2016, little is known about its reproductive lifecycle here. However, evidence to date suggests that Australian RWA populations may be anholocyclic. Like most other introduced aphid pests in Australia, invasive populations of RWA have only been observed reproducing asexually, with females giving birth exclusively to live female offspring.

Streaking on wheat leaf

PHOTO: Alistair Lawson

11.0 Dispersal

RWA aphids can infest host plants at any stage of their development. Cereal cropping over winter provides ideal conditions for population growth, with the actively growing host plants supporting aphid reproduction, growth and development.

Early in the crop growth cycle, the vast majority of aphids are wingless. In cereal regions of the world where RWA causes problems, populations start to increase from tillering and stem elongation. Aphids can move by walking among leaves, tillers and plants, so that the percentage of infested plants increases during the crop cycle. Population growth often becomes most rapid from booting onwards. Aphids feed in dense colonies, typically at the base and sheath of younger leaves and within leaves curled by their feeding. Aphids prefer the newest leaves of plants, and are often found on the last two leaves unfurled.

Later in the crop cycle as aphid population density increases, the proportion of winged aphids increases and may reach high levels prior to ripening. At this stage, aphids migrate in search of alternate summer hosts before ripening makes the host plants poor for aphid infestation [15]. Populations then survive over summer on volunteers, where they will again migrate onto cereal hosts in autumn.

12.0 Environmental influences

The distribution of RWA is primarily associated with cereal production regions characterised by warmer and drier climates.

RWA is able to thrive at a range of temperatures, surviving down to as low as -37°C and as high as 45°C [63]. However, its development and reproductive rates are favoured between about 2°C and 25°C, with aphid numbers declining dramatically below and above these limits [63]. The optimum temperature range is considered to be around 18 to 21°C. At 19.5°C, female aphids have been shown to produce approx. 70 nymphs per reproduction event.

In southern grain-growing regions of Australia population growth is expected to be higher during the warmer months of autumn and spring, and relatively lower during either cold winter conditions or hot summer conditions. Some research has found that RWA populations increase during periods when there is moisture stress [64]. For example, field records in both South Africa and USA indicate that areas of high rainfall are unfavourable for infestation.

Despite having a higher tolerance to colder temperatures than other cereal aphids, the population growth of RWA will be checked by the onset of cold and wet conditions. Rainfall may wash aphids from upper leaves, and heavy rainfall may cause mortality of up to 50% of the population [65].

While research shows that cold weather can suppress RWA activity [66], Australian temperatures rarely reach the lower temperature thresholds for RWA. For example, [67] discovered that RWA can tolerate exposure to -1°C for up to 15 days and -5°C for up to 10 days, without increased mortality. Australian growers should also note that while international research shows that RWA appears to have far greater survivability in areas where annual rainfall is less than 500mm, this does not preclude the possibility of RWA causing issues to cereals in high rainfall zones (HRZ) of Australia. In fact, in 2016, RWA was deemed a big enough issue to spray in areas of Victoria with an annual rainfall well above 500mm. Further research and ongoing monitoring are essential.

13.0 Monitoring

RWA can infest crops during any stage of crop development. Therefore, crops should be monitored regularly, checking and recording population trends.

International research suggests crops are most likely to be infested in autumn, soon after emergence, from wingless aphids walking off nearby senescing hosts. Populations will then start to increase from tillering.

As a general rule, monitoring of early-sown crops, including cereals sown as pasture, should occur for the first eight weeks after sowing. Monitoring can be less frequent during winter but should be intensified in spring as temperatures start to rise and crops enter the period of high risk of loss due to RWA (GS31 (first node) to GS83 (early dough)).

The following approaches to monitoring should be taken:

- Target early sown cereal crops and volunteer cereals (and alternate grass weed hosts such as barley grass and brome grass if present), particularly along crop edges or on the windward side or adjacent to infested grasses. RWA also commonly occurs in areas of paddocks where plants are sparse, on sandy rises or adjacent to bare ground. After initial infestation, aphids can rapidly spread across a paddock.
- Sample following a repeatable sampling pattern which targets early sown and volunteer plants. A perimeter search and a 'W' shaped search pattern through each paddock will give a consistent sampling effort. Individual monitoring points could be logged using GPS to increase accuracy of repeated monitoring.
- RWA is often difficult to find when at low numbers so check for the characteristic and distinctive leaf streaking and rolling.
- Search for RWA in rolled leaves, particularly in the leaf base, leaf sheaths and, at high densities, on exposed parts at the base of the plant or, at low densities, shake the plant for detection.
- SARDI entomologists have observed weather conditions may affect distribution of aphids on plants. During inclement weather, RWA on volunteer cereals (GS5 to GS8) were only found on lower leaves and in their leaf sheaths, but were more broadly distributed over plants during fine weather.
- Note that symptoms of RWA infestation are often first identified in localised patches across a field. These patches should be monitored regularly during winter to determine the need to intervene using foliar insecticides based upon expansion in the number and area of patches observed within a field. Growers are reminded that the decision to spray should be based on an estimate of the percent of infested tillers for an unbiased plant sample.

14.0 Case study
RWA dynamics in 2016

After the detection of RWA in SA in 2016, researchers investigated why the sudden outbreak occurred. RWA infestations at the 'initial' outbreak in SA appeared to have commenced on wheat volunteers. The early onset of summer rainfall in January 2016 created a green bridge that favoured many of the heavier 'paddock-wide' infestations in early sown crops, with the presence of volunteer cereals being characteristic of the majority of first detected infestations in SA and Victoria. In other later-sown paddocks and/or those with lower infestations, RWA was mostly limited to the field borders, where local migration from volunteer cereals and weedy grasses into the paddock occurred.

In August 2016, SARDI conducted a GRDC-funded research program to monitor population dynamics in the field. Aphid numbers and development were intensively monitored across sixteen unsprayed paddocks infested with RWA across SA and Victoria (PIRSA 2016). This project demonstrated that aphid populations were very different between regions (from 0 up to 160 aphids/100 tillers), but universally declined during the month of September. Rains washed many aphids from plants and those surviving, or hidden in rolled leaves, were subsequently attacked by entomo-pathogenic fungi and died (Figures 3 and 4).

This sharp population decline was clearly unexpected, given RWA population numbers typically build up in spring, attacking the important yield-contributing flag leaves and causing head abortion. The high and often intense rainfall events that occurred during the winter and spring of 2016 are believed to have significantly reduced the potential impact of this aphid on grain yield and quality in most affected cereal crops.

Figure 3: The two aphids appearing 'yellow' have been affected by a fungus disease.

PHOTO: Michael Nash

Where insecticide control treatments were applied in these same population dynamic studies, symptoms continued to develop for one or two weeks after spray application, before plants grew 'through' and were observed to recover and develop normally. Some white heads were observed but generally in low numbers only. Harvest estimates showed no significant differences between unsprayed and sprayed areas in any of these paddocks, except for a very heavily infested durum wheat paddock (with greater than 50% of tillers showing symptoms in late September).

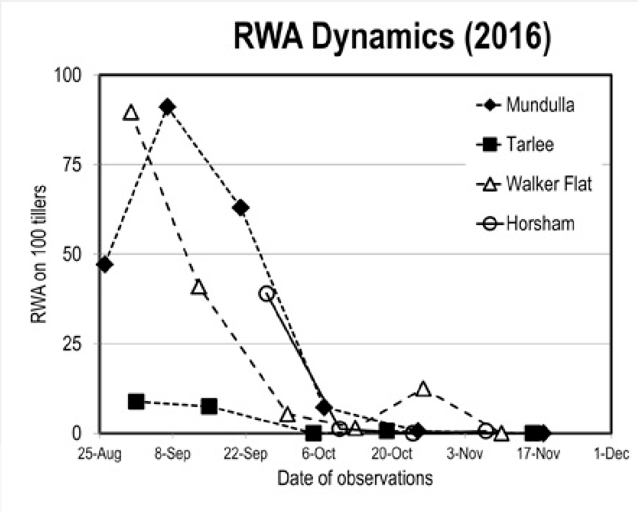
No pesticides were registered for control of RWA in Australia at the time of the initial outbreak. In June 2016, SARDI initiated insecticide trials in order to obtain emergency permits for use. These trials subsequently supported the use of both chlorpyrifos and pirimicarb for the control of RWA under APVMA Emergency Use Permit (APVMA PER 82792) until 30 June 2018.

Despite the proven effectiveness of a number of insecticides for the control of RWA, a threshold-based approach to insecticide use is recommended in order to:

- Avoid, where possible, harmful effects of some insecticides on predators and other beneficials, which may result in a spike in numbers of RWA (and other aphids) later in the season. Where insecticide application is warranted, consider use of 'softer' insecticides such as pirimicarb to minimise effects on natural enemies.
- Protect foraging honeybees from the off-target effects of insecticides. Speak to local beekeepers as appropriate.
- Minimise selection pressure from insecticide use through strategic and tactical application to reduce the potential for insecticide resistance development.

Due to the cryptic feeding habits of RWA – harbouring inside leaf rolls - good spray coverage is essential in order to ensure aphids come into contact with insecticide. Spray application practices that increase penetration into the crop canopy and leaf rolls, such as high water volume (100 L/ha) and nozzle pressure to produce medium-sized droplets (e.g. 2.5-3.0 bar pressure for flat fan nozzles), and use of an insecticide with fumigant or systemic activity are recommended.

Figure 4: RWA population dynamics in an unsprayed paddock in four regions of SA and Victoria (average of four paddock in each region).



15.0 Management for 2017 and beyond

The following management options have been guided by a review of the international literature in consultation with industry experts in Australia. Australian scientists are currently undertaking further research trials as part of a range of GRDC investments aimed to develop more tailored advice that will inform and validate future local control options.

15.1 Assessment of risks

Weather

Throughout the growing season, growers are encouraged to inspect crops prior to and then following any rainfall to determine if aphids have been washed off cereal plants, and the subsequent mortality this rain may have caused. While it is unlikely that Australian temperatures will get low enough in winter to cause populations crashes, monitoring populations before and after any frost events is encouraged. RWA populations are expected to reach their peak in spring as temperatures warm; this is a critical time to monitor susceptible crops.

Crop agronomy

The timing of the break of the season will have an impact on sowing dates and aphid activity. Early sown cereals may be more prone to RWA and initial monitoring should focus upon these crops, including cereals sown for pasture. Delaying planting when winged aphids are abundant may reduce populations. In addition, the longer and drier the interval between harvest and subsequent planting, the lower the chance of RWA survival. Growers should however, consider the broader agronomic and yield impacts of delayed sowing before adopting large shifts in sowing date. Some research suggests that late-planted wheat may suffer more from spring infestations [6].

Growers should aim to maximise early plant growth and vigour to increase the ability of plants to withstand RWA infestations. These practices include optimal fertilisation, proper variety selection, good seed quality, effective weed management and appropriate management of any other pest/disease problems. Healthy cereal plants are less affected by RWA presence. Sowing at seed rates to achieve an even and uniform plant density and rapid groundcover will reduce aphid landings.

15.2 Controlling volunteers and alternate plant hosts

Controlling the green bridge of cereals and grass weeds over summer will help reduce RWA populations. Growers should pay attention to cereal volunteers (wheat, barley and to a lesser extent oats and wild oats), pasture grasses and wild genera including *Poa, Bromus, Hordeum, Lolium* and *Phalaris*.

Where management of the green bridge is delayed until closer to sowing, growers need to consider the use of paraquat versus glyphosate with regards to the speed of kill (i.e. the slower activity of glyphosate means aphids may still survive on ‘dying’ plants). Growers should work to remove any green bridge early (during February), ensuring no living host is present for at least 2-3 weeks prior to planting.

Growers should note that a longer break will give improved control as well as provide other benefits (such as water and nutrient retention). If volunteers do emerge after February, they should be sprayed as soon as practical to keep RWA numbers low.

Note: More research is required to identify the common refuges of RWA in Australia. This should consider whether RWA is opportunistic or selects particular host species, and whether the host species changes depending on other variables.

Spraying the green bridge

PHOTO: Alistair Lawson

15.3 Natural enemies

A key RWA management strategy internationally is to preserve populations of natural enemies to help manage aphid numbers. Natural enemies include predators, parasitoids and pathogens (often referred to as 'beneficials'). Integrated pest management strategies should encourage the proliferation of natural enemies wherever possible and hence complement the implementation of a diverse range of other control tactics including strategic and targeted use of insecticides, cultural and genetic control options.

A diverse range of beneficial insects are known to predate on RWA, including those that commonly attack other cereal aphid species in the Australian environment. Beneficials include the minute parasitoid wasps (*Aphidius colemani*, *A. platensis, Diaeretiella rapae*, *Aphelinus asychis, A. varipes*) and generalist predators including ladybird beetles (*Coccinella* spp., *Hippodamia* spp.), lacewings (*Chrysopa* spp.), damsel bugs (*Nabis* spp.) and hoverflies (*Syrphus* spp.). Many of these species are likely to be most abundant in cereals in spring. The presence (and activity) of beneficials should be weighed up when determining the most appropriate management option, specifically in relation to insecticide timing and choice.

The control of other important insect pest species that may be present from pre-sowing through early crop establishment often requires additional consideration in south-eastern Australia. If other cereal pest species require control, including mites and lucerne flea, then insecticide choice should consider not only spectrum of control but also potential disruption to predators of RWA and other insect pests present. A poor choice is one that has minimum impact on RWA and maximum impact on predators.

Entomo-pathogenic (beneficial) fungi have been observed to attack RWA in Australia. These fungi were favoured by high rainfall during the 2016 growing season and seemed to play a substantial role in the unexpected and sharp decline of RWA populations in spring of that year. Mummification of RWA caused by the attacks of mainly *D. rapae* and *A. colemani* was observed.

Predator numbers often lag behind those of RWA during autumn and early winter as populations and activity build in response to the presence of aphids. The use of prophylactic sprays as a means for management of invading or dispersing RWA is not advocated due to the frequent detrimental effects on beneficial insect populations. These sprays can also create secondary pest outbreaks (such as other cereal aphids) by removing beneficial species. If spraying is warranted, aim to use the softer chemistry to maintain predators and beneficial populations.

Insecticide sprays can similarly be required in winter and spring to control a number of additional pests of cereals (e.g. armyworm) that may disrupt RWA predator activity. As per above, it is important when targeting other pests that insecticide choice considers impact on predators. Monitoring in the days and weeks after application for both RWA and aphid predator activity is important.

15.4 Chemical management

Adopting a threshold-based pest management strategy is recommended for control of RWA. International research indicates that whilst chemical control of RWA is highly effective, decisions on the need for foliar applied insecticide treatments should consider the economic return on investment based upon pest pressure (the proportion of seedlings or tillers infested and/or number of aphids per plant/tiller) and associated estimated yield loss (timing of infestation, crop type and varietal susceptibility, environment); estimated crop return (yield, quality and price); and cost of control.

Based on overseas research, control is warranted if infestations exceed thresholds of 20% of seedlings infested up to the start of tillering and 10% of plants infested through the high risk period of stem elongation to soft dough (GS31-85). During this period, protecting the top three leaves will be a priority for minimising yield loss.

Plants showing symptoms should be inspected for the presence of aphids. It is important that representative parts of the paddock are assessed before determining if the threshold has been reached. These economic thresholds (ET) have been established from international literature. They will be situation dependent and trial work is required to validate locally.

Insecticide efficacy trials undertaken as part of a GRDC investment in 2016 determined chlorpyrifos to be the most effective foliar applied product for control of RWA in wheat and barley. Dose rates of 150-600 grams of active ingredient per hectare (g ai/ha) were tested, with 300g ai/ha (600ml/ha of a 500g/L formulation) consistently providing high levels of control. Chlorpyrifos should be considered under higher pest pressure or later in the growing season due to potential adverse effects on beneficial insect species, especially at higher dose rates.

Pirimicarb was also found to provide an effective option when used at rates from 125-150 g ai/ha (250-300g/ha of a 500g/kg formulation), although efficacy was generally more variable in comparison to that achieved with chlorpyrifos. Pirimicarb should be considered for use early in the growing season as it is softer on beneficial insects. Growers are reminded however, that the fumigant activity of pirimicarb is less effective at lower temperatures (<15-20°C) and hence this should be considered in dose rate selection.

Limited trials evaluating the effect of adjuvant on insecticide performance in 2016 were largely inconclusive, with adjuvants providing improved control in some instances, although the degree of improvement depended upon both insecticide and adjuvant choice. There is some evidence to suggest chlorpyrifos may be responsive to the addition of either Uptake™ or BIOPEST® improving performance at some sites. More data is required to confirm initial results.

Spray application is important to maximise contact and ensure adequate penetration of the crop canopy and leaf rolls – consider spray volume, droplet size and adjuvant selection. Results from the 2016 trials suggest that a medium-coarse spray quality using a total spray volume of 100L/ha provides effective control.

Chlorpyrifos and pirimicarb are currently listed for control under two APVMA Emergency Use Permits:

- APVMA Permit 83140 from 22 October 2016 to 31 October 2018
  - Chlorpyrifos (500g ai/L) at 600ml/ha of a 500 gram per litre formulation (300 grams active ingredient per hectare)
  - Pirimicarb at 125-250g product/ha of a 500g/kg formulation (62.5-125g a.i./ha)

Growers and advisers are reminded to ALWAYS follow label directions and adhere to any relevant legislation regarding pesticide use. Growers should consider withholding periods for grazing and harvest and implement management practices that minimise any potential off-target effect of insecticides on foraging bees, human health and the environment.

While heavy rain played a major role in curbing RWA populations in 2016, some insects were still able to shelter and survive in leaf rolls. Therefore, assessment of populations before and after a spray application is essential.

15.5 Insecticide seed treatments

Seed treatments are an economical and practical way of combatting crop pests [68] and can provide more persistent protection than short-lived insecticide sprays [69]. Preliminary trials conducted by **cesar** suggest that seed treatments currently registered in Australia to control cereal aphids are likely to be equally effective in the control of RWA. This is supported by field reports from advisers and growers in 2016 across south-eastern Australia. For example, north of the initial detection site near Tarlee, SARDI researchers assessed aphid abundance and tillers for symptoms on 31 May 2016, in plots with and without neonicotinoid seed treatments. Wheat with seed treatment were free of aphids and symptoms, while the wheat with no seed treatment contained aphids and damage symptoms were evident.

Products containing imidacloprid, thiamethoxam and clothianidin are likely to prove effective against RWA, although more data is required to better understand the future role of seed treatments in management of this pest and to confirm the length of protection provided. Based on international literature and experience, it is unlikely that fipronil-based products will effectively control RWA [70].

Prophylactic use of neonicotinoid insecticides or use in situations deemed to be of low risk of RWA infestation requires careful consideration of the following:

(a) Neonicotinoid chemistry is critical for the long-term control of other key pests in canola and pulses and application in cereals may select for resistance in other non-target insect species (e.g. redlegged earth mite "RLEM".)

(b) Need and benefit of controlling RWA in higher rainfall areas or for later sown crops.

PHOTO: Michael Nash

Use of insecticide seed treatments should be targeted at those situations deemed to be of higher risk of RWA infestation. This includes early (Mar/Apr) sown cereals, especially barley crops or those sown for pasture/grazing^; paddocks containing volunteer cereals; and/or where live aphids have been identified prior to sowing.

^Note: Always refer to label withholding periods for grazing and export. Cereal crops treated with Gaucho® 600 (imidacloprid) cannot be cut for stock food or grazed within nine weeks of sowing, and this may differ for export.

15.6 Genetic resistance

Genetic plant-based (varietal) resistance has been deployed as a major management strategy in areas of the world where RWA is a serious risk. Breeding for wheat varieties resistant to RWA began in South Africa in the late 1980s, resulting in the identification of the first two resistance genes *Dn1* and *Dn2* [71]. To date, at least 14 resistance genes against RWA have been described, most of which have also been mapped to a particular chromosomal region (Table 2) [72-84].

Most of these genes have been identified in wheat accessions originating from different parts of the globe, but one (*Dn3*) was identified in *Ae. tauschii*, one of the progenitor species of bread wheat, and another (*Dn7*) was identified on a translocation from rye, *Ae. tauschii* (Table 1). All of the genes originating from wheat have been mapped to one of two chromosome arms, 1D or 7D. It is still unclear whether any of the co-located *Dn* genes are in fact allelic (alleles of the same gene), or whether they are linked as members of gene clusters – which is common for Nucleotide Binding Site-Leucine Rich Repeat (NBS-LRR) resistance genes.

A breeding program in the USA targeted the development of RWA-resistant barley varieties. From this program, two resistant lines (STARS 9301B, STARS 9577B) were identified that shared two resistance genes (*Rdn1*, *Rdn2*), with STARS 9301B also having a third gene (*Rdn3*) that provided an additional level of resistance [85]. These three resistance genes were located on three separate chromosomes, and none showed the dominance characteristics typical of NBS-LRR resistance genes that are often active gene-for-gene interactions in host resistance responses.

Table 2. Identified Russian wheat aphid resistance genes.

RESISTANCE GENE	SOURCE	CHROMOSOME	ACCESSION	REFERENCE
		WHEAT		
Dn1	Wheat (Iran)	7D	PI137739	Du Toit 1989
Dn2	Wheat (Russia)	7D	PI262660	Du Toit 1989
Dn3	*Ae. tauschii*		SQ24	Nkongolo et al. 1991a
Dn4	Wheat (Russia)	1D	PI372129	Nkongolo et al. 1991b
Dn5	Wheat (Bulgaria)	7D	PI294994	Marais and Du Toit 1993
Dn6	Wheat (Iran)	7D	PI243781	Saidi and Quick 1996
Dn7	Rye (*S. cereale*)	1RS.1BL	94M370	Marais et al. 1994
Dn8	Wheat	7D/1D	PI294994 derivative	Liu et al. 2001
Dn9	Wheat	7D/1D	PI294994 derivative	Liu et al. 2001
Dnx	Wheat (Afghanistan)	7D	PI220127	Harvey and Martin 1990
Dny	Wheat (Stanton cv)		PI220350	Smith et al. 2004
New	Wheat (USDA)	1RS.1BL	STARS 02RWA2414-11	Peng et al. 2007
New	Wheat (Iran)	7D	PI626580	Valdez et al. 2012
New	Wheat (Tajikistan)	7D	CI2401	Fazel-Najafabadi et al. 2015
		BARLEY		
Rdn1,2,3	Barley	1H,3H,2H	STARS-9577B	Mittal et al. 2008
Rdn1,2	Barley	1H,3H	STARS-9301B	Mittal et al. 2008

In South Africa, the first resistant variety containing Dn1 was released in 1992, and 27 additional resistant varieties were used in the subsequent 20 years. At least four independent resistance sources, including *Dn1*, *Dn2*, and *Dn5*, were used in these varieties in the hope that this would delay the evolution of resistance-breaking biotypes [22]. It was estimated that in the late 1990s, RWA-resistant varieties were planted on more than 70% of the wheat-growing area in South Africa [22]. In the USA, only one resistance gene (*Dn4*) was selected for use in the development of RWA-resistant wheat varieties, which was backcrossed into several different genetic backgrounds and deployed to cover about 25% of winter wheat acreage by 2003-2004 [86].

Research indicates that resistance in some wheat lines appears to be mostly from antibiosis with some tolerance [6, 71, 87]. 'Barley resistance is in part from antibiosis (RWA feeds and grows less on resistant lines' [6, 88, 89], [88, 90] and also from antixenosis [90]. Resistance was demonstrated by low rates of nymph production on whole plants and on excised leaves [88].

Genetic variation among RWAs collected from around the world has been detected using random amplified polymorphic DNA polymerase chain reaction (RAPD-PCR) and allozyme markers [91]. Genetic linkage mapping and marker-assisted selection (MAS) analyses have also been utilised to assist to discover agronomic and resistance genes [72, 92]. MAS has been readily utilised due to the opportunity of the pyramiding of genes. This enables multiple and durable resistance such as disease and insect resistance to be incorporated into plant breeding lines [75] [93] cited in [72].

Unfortunately, RWA biotypes now exist which have overcome host plant resistance [94]. As virulent RWA biotypes with greater fitness replace avirulent RWA populations, the result is a collapse of resistance and a loss of effective control of this aphid pest [95] (i.e. the resistance genes are ineffective in control [94]). Virulent RWA biotypes have been recorded in Europe [96], the US [86], South America [21], Asia [16] and South Africa [22]. This indicates that RWA has an inherent capacity to overcome genetic mechanism of resistance developed through plant breeding and while resistant varieties are important, they are just one tool that may be deployed to manage the pest.

A GRDC investment was initiated in response to the incursion in 2016 in order to determine what biotype/s of aphid has entered Australia, and once confirmed, breeders will have the required information relating to effective resistance genes. Initial screening of commercially available wheat and barley varieties in Australia has indicated some differences in susceptibility to the aphid, but such differences are unlikely to have a meaningful impact in relation to in-field management. Whilst early indications from Australian trials suggests germplasm carrying effective resistance genes is likely to be available, the deployment of resistant traits into commercial plant breeding programs is subject to private sector investment and will take some years before being commercially available.

16.0 Ongoing monitoring of spread

Following the declaration that the RWA was not technically feasible to eradicate from Australia, and as part of the National Management Plan, a RWA National Management Group was initiated by Plant Health Australia, to identify immediate control options, co-ordinate the management of Emergency Permits for insecticide use, co-ordinate the development and communication of key messages to the grains industry and identify suggested longer term research and development needs. The Technical Group comprised representatives from:

- Grains Research and Development Corporation
- South Australian Research and Development Institute
- **cesar**
- Queensland Department of Agriculture and Fisheries
- Department of Agriculture and Food WA
- Commonwealth Scientific and Industrial Research Organisation
- Agriculture Victoria
- NSW Department of Primary Industries
- Plant Health Australia.

RWA has been detected in South Australia, Victoria, New South Wales and Tasmania. Growers and advisers in all cereal growing areas nationally are encouraged to closely monitor their crops for signs of infestation. Suspected infestations in areas where the pest has not been confirmed as previously established should be reported to assist in improving our understanding of the range and rate of spread. Good biosecurity practice is encouraged to minimise the risk of spreading the pest further.

Report suspected new infestations to either the Exotic Plant Pest Hotline 1800 084 881 or using the contacts provided below. Take an image of the infestation. You might be asked to send a sample for identification.

- In Victoria, submit samples using the CropSafe Sample Recording Form. Or contact (03) 5362 2111.
- In South Australia, send samples to PestFacts, SARDI Entomology Unit, GPO Box 397, Adelaide SA 5001.
- In NSW, to assist with providing information on spread of RWA, any detections in central or Northern NSW should be reported by sending images to biosecurity@dpi.nsw.gov.au
- In Tasmania, RWA was detected for the first time in January 2017, and the reporting of RWA is still being encouraged. The Entomology Team in Plant Diagnostic Services of DPIPWE will identify aphids suspected of being RWA at no fee. For an initial opinion, photos (with location) can be sent to 0429 852 886 or emailed to Guy.Westmore@dpipwe.tas.gov.au
- In Queensland, RWA has NOT been detected so growers or advisers are asked to call Biosecurity Queensland on 13 25 23 or email photos of aphids or symptoms on plants to plantpestdiagnostics@daf.qld.gov.au
- In Western Australia, since RWA has NOT been detected, growers are asked to report the absence of aphids, rather than just the presence. For more information visit: https://www.agric.wa.gov.au/barley/biosecurity-alert-russian-wheat-aphid

For more information visit:

http://www.planthealthaustralia.com.au/russian-wheat-aphid-management/


PHOTO: Michael Nash

17.0 FAQs

1. What should I look for when inspecting my crop?

Detection of RWA is most likely to occur with the observation of symptomatic plants. Scout for symptomatic tillers in host crops and inspect for aphids. RWA is very small (less than 2mm) and a 10x magnification hand lens can be useful.

RWA may be present in mixed populations. If aphids are observed it should not be assumed these are the only ones present. Symptoms associated with the presence of RWA include:

- Leaves with white, yellowish and red streaks.
- Leaf rolling along margins.
- Awns trapped by rolled flag leaves.

2. What are the RWA thresholds at different crop growth stages?

Preliminary thresholds for RWA management in Australia have been based on international research and existing literature. At current thresholds, chemical control is warranted if infestations exceed 20% of seedlings infested up to the start of tillering and 10% of tillers infested thereafter. Heavy infestations from stem elongation to soft dough may be particularly damaging. During this period, protecting the top three leaves will be a priority for minimising yield loss. Local research will be required to test, and if needed, to modify these thresholds for Australian crop conditions

3. How effective are parasitoids against RWA?

Parasitoids are highly effective. International research suggests the main RWA parasitoid is *D. rapae* [97-99], which has the ability, along with *Aphidius* spp. to parasitise 40-100 aphids per day and 212-532 aphids over their 7-21 day lifetime at 20°C. In another study, *D. rapae* produced up to 60 mummified (parasitised) aphids per day at 21°C [100]. This parasitoid is present in Australia and was recorded commonly parasitising RWA crops in a survey in SA in 2016 (Thomas Heddle, pers. comm.).

4. At what crop stage does economic damage cease?

While there has been no opportunity to conduct research specific to Australian varieties and growing conditions, international literature suggests that the risk of economic yield loss caused by RWA feeding is greatly reduced once cereal crops reach the soft dough stage (GS85).

5. When are insecticide seed dressings justified?

While there is limited local data regarding the effectiveness of neonicotinoid seed treatments for control of RWA, it is expected that these products will be effective in control of this pest during the seedling stage. An APVMA permit currently exists for the use of imidacloprid in higher risk situations (APVMA PER82304) and may be appropriate, particularly for early sown crops where the green bridge has not been well controlled or where aphids are present at/or shortly prior to sowing. In many situations, RWA may be better managed by routine monitoring during cereal crop establishment and applying a strategic foliar insecticide application if aphid numbers warrant control.

6. Should growers use prophylactic sprays to manage RWA?

Prophylactic sprays for managing invading or dispersing RWA are not supported and are generally ineffective in providing protectant activity. These sprays may be detrimental to natural enemies and/or may create secondary pest outbreaks, such as other cereal aphids, by removing beneficial species. If spraying is warranted, aim to use pirimicarb as a softer chemistry to maintain beneficial insect populations.

7. What investments are GRDC making to assist Australian growers to manage RWA?

As part of an integrated approach to future management of RWA, investments are being made in many areas including determining the aphid biotype present in Australia; chemical control options (seed treatment and foliar); plant resistance activities (screening, germplasm access); importance of natural enemies; biology and population dynamics; yield loss and thresholds for control and various communication and extension activities, including the Find, Identify, Threshold Approach, Enact (FITE) strategy. GRDC will work to communicate the research outcomes as each project is completed.

8. Will RWA develop resistance to insecticides?

There is currently no evidence to suggest RWA has developed insecticide resistance globally. However, there has been relatively low historic selection pressure using foliar insecticides in cereals and limited research conducted in relation to potential for resistance development. Variation in RWA susceptibility to chlorpyrifos in the US led [101] to propose that RWA may develop insecticide resistance. Furthermore, RWA displays significant chromosomal heterogeneity and rapid biotype development under the selection pressure of plant resistance genes, which makes it likely that genetically-based insecticide resistance can occur under high selection pressure. Some experts have suggested the absence of reported insecticide resistance overseas is due to the relatively low selection pressure due to the past reliance on genetic resistance for control and associated low intensity on insecticides used for control of RWA.

Growers are advised to only use insecticides when warranted and always adhere to product labels. Protecting beneficial species of RWA will help reduce the potential for insecticide resistance by reducing the intensity of chemical applications.

9. How should growers manage RWA in cereal-based pastures?

Cereal-based pastures are generally sown early and are not only prone to RWA attack, but provide an effective green bridge for RWA multiplication and act as a source of RWA for other cereal crops. Management options are limited to the following:

- Use of insecticide seed treatments presently registered for the control of cereal aphids where grazing management and grazing withholding periods (WHP) are compatible. Growers are advised to consider the nine week WHP for imidacloprid and always adhere to label guidelines and relevant legislation regarding pesticide use.
- Monitor crops early and apply insecticides if necessary.
- Use livestock to graze paddocks which can keep aphid numbers and damage in check.

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