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The Occurrence of Cereal Aphids in Rainfed Wheat in Kenya: The Problem and Possible Integrated Pest Management Strategies

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Additional information is available at the end of the chapter

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Abstract

Cereal aphids cause direct damage to rainfed wheat through sucking of plants sap and cause losses of up to 90%, particularly in dry years in Kenya. The Russian wheat aphid (RWA) is the most destructive and may account for up to 50% yield loss or more depending on the severity and length of infestation. Current control strategies mainly rely on the use of insecticides to control cereal aphids' infestations. Chemicals improve yields in the short term, but adversely affect the environment, hence the need for development of effective IPM strategies. Early planted crops escape heavy aphid attacks and give good yields. A combination of seed rate of 100 kg and 100 kg N/ha provided the best cultural management of RWA. Ladybird beetles *Adonia variegata*, lacewings (*Chrysoppa* spp.) and parasitic wasp *Aphidius* sp. were the most important natural enemies. Control of cereal aphids can be achieved with systemic insecticides applied as seed dressings or foliar applied insecticides. Four lines of wheat were found to show RWA resistance and crosses with Kenyan wheat made and populations are being evaluated for resistance to cereal aphids.

Keywords: wheat, cereal aphids, natural enemies, cultural strategies, insecticides, host plant resistance

1. Introduction

Grain cereals contribute significantly to food security in Kenya. Bread wheat (*Triticum aestivum* L.) is the second most important cereal crop in Kenya, after maize. It was grown on 147,210 ha producing 328,637 tons of grain with a yield of 2232 kg/ha [13]. However, there

is still a gap between production and consumption of wheat in Kenya [44]. Increased population growth, urbanization and change in eating habits have led to increased wheat demand. The national demand is estimated at more than 990,000 tons per year while production is as low as 360,000 leading to importation to meet the difference [52]. It is mainly grown in Nakuru, Trans Mara, Uasin Gishu, Nyandarua, Narok, Meru Central, Trans Nzoia, Keiyo and Laikipia counties. The crop is grown in diverse agro-ecological zones at altitudes ranging from 1500 to 2900 m.a.s.l. in areas with 700–1000 mm rain per year.

The country in its strategic plan is struggling to become self-sufficient in wheat production either by increasing yields per unit area or by expanding the area under production in the marginal areas. This is possible when the gap between potential yield of wheat varieties (6–7 t/ha) and the actual yields (2.3 t/ha) realized by wheat growers in Kenya is filled. This gap is attributed to the lack of good quality seed, lack of appropriate technology and attack by diseases and pests, which have presented a continuous challenge to wheat productivity in Kenya. Cereal aphids are considered as one of most serious insect pests attacking rainfed wheat [8, 60]. Cereal aphid outbreaks are frequent in Kenya and are responsible for most of the control interventions on wheat. They are capable of completely devastating the crop by making it a total failure during years of severe infestation [59]. Aphids damage the cereals by direct feeding and transmitting barley yellow dwarf virus (BYDV) diseases, both causing losses in yield [22, 57]. Outbreaks of cereal aphids that are vectors of barley yellow dwarf are frequent in Kenya and often result in extensive use of insecticides [39, 58]. Their relative importance as pests/vectors varies considerably from one area with losses in the range of 1–100% [28]. Yield losses of 47% due to BYDV have been reported in wheat [57]. It is transmitted by cereal aphids in a persistent, circulative but nonpropagative manner. Five strains occur in Kenya and their principal vectors are RPV (*Rhopalosiphum padi*), RMV (*R. maidis*), MAV (*Sitobion avenae*), SGV (*Schizaphis graminum*) and PAV (*R. padi*, *S. avenae* and others) [25]. In the field, symptoms appear as yellow or red patches of stunted plants. In general, PAV causes severe symptoms, MAV moderately severe and RPV, RMV and SGV produce mild symptoms [16]. This chapter reports on cereal aphids affecting wheat in Kenya with emphasis on Russian wheat aphid *Diuraphis noxia*, their problem and possible integrated pest management strategies.

2. Cereal aphids occurring on rainfed wheat in Kenya

The six most important cereal aphid species reported as pests that attack wheat and barley include: Greenbug *Schizaphis graminum* R., English grain aphid *Sitobion avenae* F., Oat bird cherry aphid *Rhopalosiphum padi* L., Cereal leaf aphid *R. maidis* F., Rose grain aphid *Metopolophium dirhodum* W. and Russian wheat aphid *D. noxia* M. [31, 32, 42]. Of these species, the Russian wheat aphid which is a recent introduction in Kenya in 1995 is the most destructive followed by Greenbug *S. graminum* [25]. The other species are less serious and usually cause no significant yield reduction. In reality, there are usually two or more aphid species present at one time.

The Russian wheat aphid was first officially detected in June 1995 [25] and affected areas experienced damaging infestations resulting in 90–100% crop loss. Since then most reports

from major wheat and barley growing areas of Narok, Nakuru, Uasin Gishu, Trans Nzoia and Mt Kenya region indicate that *D. noxia* has become a serious pest causing estimated crop losses of 25–80% depending on the stage of infestation. The pest is now a major constraint to wheat production in eastern Africa region [54]. The appearance of these aphids resulted in a dramatic increase in use of insecticides in cultivated wheat crops. According to the economic losses attributable to Russian wheat aphid [25], it can be categorized as reduced grain yields, loss of kernel weight and quality and increased costs of production due to application of insecticides.

The Russian wheat aphid causes damage to host plants through direct feeding and by injecting toxins during feeding which cause leaf rolling and unfolding thus making it difficult to control by application of contact insecticides [21, 54, 56]. Visible damage to the susceptible host plants is manifested as chlorotic lesions, white streaking, purple discoloration and tightly curled leaves. The level of infestation, the growth stage of host plant and the duration of the infestation, all influence the severity of the damage caused by *D. noxia*.

3. Distribution of cereal aphids in Kenya

National aphid surveys were conducted in farmers' fields [32, 42] during wheat cropping seasons in Mt Kenya area, Mau Narok, Nakuru, Narok, Trans Nzoia and Uasin Gishu in order to determine the abundance and distribution of cereal aphids. In each area, 10 random assessments were taken. On every plant, the sampled aphid species were identified using taxonomic keys [37] and recorded. The different species of aphids found in the wheat fields were Russian wheat aphid *D. noxia*, which was the most predominant species with the highest overall density of 80.0%, followed by *M. dirhodum* (10.0%). The least species appeared were *R. padi* (5.3 %) and *R. maidis* (3.7%), while infestations of *S. graminum* was relatively low (1.0%) in all the areas (**Table 1**). It has also been reported elsewhere that wheat cultivars are usually attacked by a complex of cereal aphids' species [14]. The high incidence of Russian wheat aphids on the crops made the leaves to remain furled for a long time, thus creating conducive environment for other species such as *R. padi*, *R. maidis* and *S. graminum* to stay longer in the wheat crops after crop heading. The surveys complemented the Cereal aphid Forecast Bulletins in advising growers on control decisions [27].

Alternate host plants of RWA and other cereal aphids found in Kenya during the surveys included wild oats *Avena fatua*, brome grass *Bromus* spp., wild rye grass *Elymus* spp and foxtail grass *Setaria* spp. These grass weed are common in high altitude wheat growing areas in Mt Kenya and west Mau regions of Kenya and serve as reservoirs of cereal aphids during dry weather. Neglected volunteer wheat, barley and oats plants were also important for the survival of Russian wheat aphids and other cereal aphids. These host plants have also been reported [2, 6, 33] supporting RWA and thus provide a bridge for infestation of the next season wheat crop. These alternate host plants play an important role in supporting cereal aphids between crop harvest and emergence of the new crop in the next planting season.

Region	Incidence of cereal aphids species					
	Dn*	Md	Sa	Rp	Rm	Sg
Mt Kenya area	+++	++	++	++++	++	+
Mau Narok	++	+	+	++	++	+
Nakuru	++++	++	++	+++	++++	+
Narok	++++	++	++	+++	++++	+
Trans Nzoia	+++	++	++	+++	+	+
Uasin Gishu	+++	++	+++	+++	+++	+

Key: *Dn – *Diuraphis noxia*; Md – *Metopolophium dirhodum*; Sa – *Sitobion avenae*; Rp – *Rhopalosiphum padi*; Rm – *Rhopalosiphum maidis*; Sg – *Schizaphis graminum*.
Incidence: +++++, highly abundant; +++, moderately abundant; ++, abundant; +, low abundance.

Table 1. Incidence of Russian wheat aphid and other cereal aphids in wheat growing regions of Kenya.

Continuous cropping of wheat was practiced by wheat growers in Mt Kenya region, eastern Aberdares ranges and West Mau areas of Kenya [31, 33]. This enabled cereal aphids to migrate from one field to another and survive from one season to the next. Similar observations have been reported in wheat growing areas in the highlands of Ethiopia [40]. It was also observed that the different crop planting dates and eco-zones across the country as well as the presence of volunteer cereals and alternate host grasses provide a continuous source of alternative host plants and consequent spread source of cereal aphids to wheat crops planted the following season. The information being generated from field surveys has been used to advice farmers when to plant and which control options to adopt in order to escape the damaging species of cereal aphids.

Cereal aphids also have preferential performance on different hosts. Results observed in Kenya [49] revealed that aphid species differed in their time of colonization on wheat varieties. Aphid abundance differed among the species, wheat varieties and crop growth stages. *R. padi* appeared at two leaf stage, followed by *S. graminum* at the two tiller stage and *M. dirhodum* appeared at stem elongation stage. The aphids also differed in their points of colonization, thus the studies confirmed crop growth stage and feeding preferences among cereal aphids in wheat.

4. Cultural control of cereal aphids

Cultural practices can play a significant role in IPM strategies targeting cereal aphids. Cultural controls are generally the cheapest of all control measures because of their preventive measure and only require modifications to normal production practices. They do not possess some of the detrimental side effects of pesticides, such as killing of beneficial insects, no contamination of environment and development of resistance to pesticides [17]. Modified cultural practices can be important in minimizing cereal aphid infestations which include dates of planting, seed rates and fertilization to produce the healthiest crop possible.

In Kenya, studies on use of cultural control practices such as time of planting as alternative strategies for control of aphids to reduce cereal aphid populations have been assessed. Cultural control of aphids and its effect on the incidence of cereal aphids was addressed through research, especially the assessment of time of planting and subsequent cereal aphid population levels. Three planting dates were evaluated, namely, early planting (April), medium planting (May) and late planting (June). The data (**Table 2**) indicates that for late planted wheat crops, Russian wheat aphid density levels were very high and the resultant grain yields very low [30]. Seasonal mean aphid population was 7.4 and 2.1 times higher on late as compared to that on early and timely sown crop, respectively (**Table 2**). This indicates that changing sowing date of wheat will affect cereal aphids infestation, thus planting date may be adjusted to minimize cereal aphid infestations. The study also showed that early planted wheat crops escape heavy cereal aphid infestations and give good yields. It has been recommended that wheat growers should sow their crops early to avoid damaging levels of Russian wheat aphid and other cereal aphids. In addition, it is important to note that sowing should be done early in the season so that the crop benefits from the early rains and it should be timed such that harvesting coincides with the dry spell. The potential of cereal aphid infestations can be reduced by sowing wheat crops early in the season [1] and also cereal aphid infestation increases on late plantings and reduces yield as compared to normal planting [3].

Time of Planting	Mean no. of Russian wheat aphids/plant	Mean grain yield (kg/ha)
Early planting (April)	1.37a*	4822.0a
Medium planting (May)	5.13b	4226.0b
Late planting (June)	15.71c	3026.0c
Seasonal mean	7.4	

* Means in the same column followed by the same letter are not significantly different at the 5% level of the LSD test.

Table 2. Effects of time of planting on Russian wheat aphid densities and wheat yields at Njoro, Kenya (2160 m.a.s.l.).

The effects of sowing dates of planting dates and insecticide sprays on aphid populations and barley yellow dwarf incidence in Kenya were also assessed [57]. The most common important cereal aphids observed included *M. dirhodum*, *R. maidis*, *R. padi*, *Sitobion avenae* and *S. graminum*. BYD incidence was significantly decreased in plots sown with seed that had been treated with imidacloprid and later sprayed with cypermethrin foliar insecticide. Yield losses due to BYD were also significantly different between the treatments and between the early planted and late planted crop.

Field trials have also been conducted in Njoro, Kenya [47, 48] on development of environment-friendly and cost-effective cultural practices (utilizing seed rates and fertilization levels) for management of RWA in order to reduce/avoid use of chemicals in wheat production. It was observed that a combination of moderate seeding rate (100 kg/ha) and application of nitrogen (100 kg N/ha) was observed to be the best for the cultural management of Russian wheat aphids in wheat production. To minimize dependence on insecticides for cereal aphids' control, cultural practices like adjustment of planting dates and seed rates may be helpful.

5. Survey of natural enemies of cereal aphids

All commercial wheat varieties are susceptible to cereal aphid's damage and control is achieved by extensive use of insecticides. Chemicals improve yields in the short term, but adversely affect ecological and human health. There is a lot of concern about the expense and possible environmental pollution from insecticidal applications and farmers would prefer to minimize losses through the use of resistant cultivars and effective natural enemies (predators and parasites) because of sustainability and environmentally friendly action. Most farmers in Kenya are not aware of biological control and therefore do not perceive it to be effective. However, majority of farmers will be willing to stop spraying should the biological control strategy be effective.

In view of the large wide range of aphid species that attack wheat in Kenya, causing substantial yield losses, biological control strategies must be developed that will enhance the integration of these control agents in an IPM control strategy. Therefore, surveys were initiated to document the natural enemies that attack the Russian wheat aphid and other cereal aphids on infested wheat crops in farmers' fields.

A number of predators and parasitoids were observed to attack cereal aphids (**Tables 3 and 4**) but none of these biocontrol agents exerted adequate controls. The absence of successful aphid predators and parasitoids may be a prime reason for the rapid spread of Russian wheat aphid. Field observations also revealed that the natural enemies of Russian wheat aphid were only present late in the crop season when damage to wheat had already taken place. Ladybird beetles *Adonia variegata* and parasitic wasp *Aphidius* sp. were the most important natural enemies.

Scientific name	Cereal aphid species*					
Predators						
• Coleoptera (beetles)						
1. <i>Adonia variegata</i>	a	b	c	d	e	–
2. <i>Cheilomenes</i> spp.	a	b	c	d	e	–
• Diptera						
1. Syrphidae (hover flies)	a	–	c	d	e	f
• Arachnoidea (spiders)						
• Neuroptera (lacewings)	a	b	c	d	e	f
Parasitoids (Hymenoptera)						
1. <i>Aphidius</i> spp.	a	–	c	d	e	f
2. <i>Aphelinus</i> spp.	a	–	c	d	e	f

Key: a, Russian wheat aphid *D. noxia*; b, *R. maidis*; c, *S. graminum*; d, *Sitobion* spp.; e, *M. dirhodum*; f, *R. padi*.

Table 3. Predators and parasitoids recorded attacking cereal aphids in wheat in Kenya in 2004 cropping season.

The Russian wheat aphid was the most prevalent insect pest of rainfed wheat [31, 32]. The maximum number of RWA per tiller was 58.0 while rose grain (*M. dirhodum*), oat-bird-cherry

aphid (*R. padi*) and corn leaf aphid (*R. maidis*) were prevalent at low density ranging from 0.1 to 9.0 per tiller. The general aphid predators *Cheilomenes* spp., spiders, lacewings and the parasitoid *Aphidius* spp. were the natural enemies of cereal aphids found in Kenyan wheat.

Predators and parasitoids	Cereal aphid species			
	<i>Diuraphis noxia</i>	<i>Metopolophium dirhodum</i>	<i>Rhopalosiphum maidis</i>	<i>Rhopalosiphum padi</i>
Predators				
1. Coleopteran beetles <i>Cheilomenes</i> spp.	x	x	x	–
2. Neuroptera (lacewings)	x	x	x	x
3. Arachnoidea (spiders)	x	x	x	x
Parasitoids				
4. Hymenoptera <i>Aphidius</i> spp.	x	x	–	x

Table 4. Predators and parasitoids attacking cereal aphid species in Kenya 2015 cropping season.

Generalist predators, namely, Coccinellid beetle (*Cheilomenes* spp.), spiders (Arachnidea) and lacewings (*Chrysopa* spp.), were observed to occur at very low population densities from tillering stage to heading growth stages (**Table 4**). Similar observations have been reported in Ethiopia [2].

The natural enemies such as *Aphidius* spp., appeared late in the crop season when the cereal aphids population levels had passed damaging levels. Therefore, they may not contribute to season long control of RWA and other cereal aphids in the wheat crop.

The survey data revealed that the Russian wheat aphid is the most important and predominant cereal aphid. Its feeding habit led to leaf rolling, which enabled the other cereal aphids to stay longer on the crop thereby increasing their inoculation period of viral diseases such as barley yellow dwarf virus. Leaf rolling particularly the rolling of flag leaf interferes with the pollination of wheat flowers. The survey also revealed that grass weeds support cereal aphids; hence, good control of grass weeds is essential. Moreover, though the number of predator and parasitoid species recorded were sufficient, because of their low density, they are unable to keep cereal aphid populations below damaging levels. However, efforts should therefore be made to conserve these natural enemies as they are of great importance in controlling the cereal aphids. For development of an effective cereal aphids IPM package, there is need for comprehensive studies on population dynamics of cereal aphids' species and their natural enemies in wheat crops.

6. Chemical control of Russian wheat aphid and other cereal aphids

All commercially available wheat varieties in Kenya are susceptible to Russian wheat aphid and other cereal aphids and chemical control of cereal aphids has been the only option for many growers [25]. Research has focused on screening for more effective insecticides, application methods and development of recommendations for wheat growers on economical control

measures. Control of cereal aphids can be achieved with systemic insecticides applied as seed dressings or foliar spray and contact insecticides applied with aerial or ground equipment. The seed dressing insecticides controls the colonizing migrant aphids and prevents primary infestation. The foliar applied insecticides controls primary spread.

Control recommendations in Kenya include the use of systemic insecticides as shown in **Table 5** [33]. The rolling of leaves as a result of the feeding habit of RWA causes the leaves to roll around *D. noxia* aphid colonies thus protecting the aphids from being reached by the contact insecticides. A characteristic behavior of RWA is to feed and develop inside the rolled leaf whorl confining insecticide options to active ingredients with systemic action able to penetrate the rolled leaf [23]. Systemic insecticides presented in **Table 5** have proven to be effective against Russian wheat aphid and other cereal aphid species in rainfed wheat crops with resultant high grain yields [33].

Trade name of chemical	Active ingredient (a.i.)	Application rate
<i>Seed dressing insecticides</i>		
1. Gaucho 350FS	Imidacloprid 350 g/L	200 mL/100 kg seed
2. Cruiser 350FS	Thiamethoxam 350 g/L	150 mL/100 kg seed
3. Redigo Deter 300FS	Clothianidin 250g/L + prothioconazole 50g/L	200 mL/100 kg seed
4. Celest Top 312FS	Thiamethoxam 262.5 g/L + fludioxonil 25 g/L + difenoconazole 25 g/L	150 mL/90 kg seed
<i>Foliar applied insecticides</i>		
1. Pirimor 50WG	Pirimicarb 500 g/kg	0.75 kg/ha
2. Bulldock star 262.5EC	Betacyfluthrin 12.5 g/L + chlorpyrifos 250 g/L	0.5 L/ha
3. Thunder OD 145	Imidacloprid 100 g/L + betacyfluthrin 45 g/L	0.3 L/ha
4. Nurelle* D 50/500 EC	Cypermethrin 50 g/L + chlorpyrifos 500 g/L	0.5 L/ha
5. Engeo 247SC	Thiamethoxam 141 g/L + lambda-cyhalothrin 106 g/L	150 mL/ha

Table 5. Recommended insecticides for control of cereal aphids in rainfed wheat in Kenya.

Seed dressing is an insurance against infestation by early seedling pests such as the Russian wheat aphid. The use of seed dressers ensures a better crop establishment, more uniform and healthier crops with increased yields and quality. Cereal aphids occurring during other growth stages of wheat are controlled using foliar applied insecticides (**Table 5**). Applications of Gaucho 350FS followed by applications of systemic foliar insecticides achieved very good control of the Russian wheat aphid [26, 29, 33]. Contact insecticides are not effective against Russian wheat aphid but they are effective against *R. maidis*, *S. graminum*, *Sitobion* spp., *M. dirhodum* and *R. padi*. Satisfactory control of RWA using foliar applied aphicides depends on early detection of infestation through periodic scouting. This approach will therefore offer a cheaper strategy for cereal aphid and BYD control. Farmers are advised to scout their fields weekly in order to make an accurate decision on whether or not treatment is required. It is important for wheat growers to know that not all insects are pests. One should know the insects, which are beneficial to mankind. Ladybird beetles, hoverflies, lacewings, spiders, dragonflies and praying mantis feed on other insects. Using insecticides indiscriminately

can cause harm to the beneficial insects too. Farmers should monitor and consider beneficial insects when making control decisions and after treatment application, continue monitoring to assess pest populations and their control.

BYDV is a virus disease vectored by cereal aphids during feeding. The best control of this disease is by use of resistant varieties. However, majority of the current wheat varieties are susceptible to the disease and control is by use of insecticides to control the cereal aphid vector. Seed dressings control early cereal aphids' infestations and later infestations are controlled by use of foliar applied insecticides. Seed treatment is a good insurance against infection by seed borne, soil borne and early seedling pests. Seed dressings with insecticides also controlled early seedling pests such as barley bulb fly, cutworms, chaffer grubs and cereal aphids that also transmit BYDV [7]. The seed treatments provided early protection against cereal aphids, while the foliar applied aphicides provided good control for management of later infestations on wheat crops. Therefore, utilization of both seed dressing and foliar applied aphicides could be used in integrated pest management programs for controlling the cereal aphids.

However, controlling cereal aphids with insecticides has many risks, including destruction of natural enemies and accelerated development of insecticide resistance in cereal aphid species. In addition, chemical control of cereal aphids has proven expensive and there is need for development of resistant varieties.

7. Host plant resistance

Host plant resistance is an integral part of IPM of cereal aphids and is one of the most important alternative methods of management of cereal aphids. BYD resistance in wheat has been more difficult to assess and screening programs have yielded only a few possible sources of resistance, many of which showed susceptibility upon repeated testing due to the wide variation of BYDV strains. In addition, severe epidemics may render genotypes with useful resistance as being apparently highly susceptible [50]. All commercially available wheat varieties are susceptible to Russian wheat aphid and other cereal aphids and have to be chemically protected [20, 26, 35]. In Kenya, the development of RWA-resistant varieties has been constrained by variation in resident RWA populations and by concerns of possible existence of virulent biotypes [21, 36, 46, 45]. Collapse of resistant crop varieties due to biotype development is a major threat to food security and even a greater catastrophe would be caused by the unavailability of advanced breeding lines containing genetic variability potentially resistant to future biotypes [23]. Investigations to evaluate seven commercial bread wheat cultivars (Pasa, Mbuni, Kenya Heroe, Kenya Fahari, Chozi, Duma and Kwale) in five different environments in Kenya revealed that varieties K. Fahari and Duma suffered the lowest RWA damage [35]. K. Fahari which had been previously reported to be resistant to green bug *Schizaphis graminum* was observed to have some resistance to RWA.

While some protection against Russian wheat aphid can be realized by crop management practices, resistant varieties offer the greatest opportunity for reduction of crop losses. The sudden appearance of Russian wheat aphid has made resistance breeding program of high

priority now as farmers are currently relying on pesticides to control the aphids. The high cost of chemical control and concern for extensive and frequent use of insecticides has led to search for Russian wheat aphid resistance. Using host plant resistance instead could be economical, effective throughout the growing season, environmentally safe and it will require no elaborate technology transfer to farmers. Natural enemies and host plant resistance are considered as more desirable alternatives to insecticides because of their low cost and environmentally friendly mitigation strategy [12, 51] for effective management of cereal aphids in wheat.

Research has focused on screening wheat genotypes for possible source or sources of resistance against Russian wheat aphid for use in our national wheat breeding program as an alternative to chemical control. A search for sources of resistance from among introductions collected from other countries (CIMMYT, Mexico, South Africa and Turkey) identified four sources of resistance, viz., RWA 9, RWA 8, RWA 16 and RWA 230 [34]. These sources have been incorporated into the breeding program using back-crossing technique. In addition, doubled haploid technique is being used to shorten the breeding cycle by about 5 years. Host plant resistance should be used as on more control strategy with IPM, as the strategy is nonpollutant to the environment and does not demand specific knowledge by the wheat farmers. The use of host plant resistance that rarely requires treatment by application of aphicides has also been reported elsewhere as one of the most important methods for control of cereal aphids [10, 11, 19, 38, 61].

8. Future research needs

Action thresholds are lacking and there is urgent need to develop economic action levels (economic injury levels and economic threshold levels) for cereal aphid species infestation in wheat growing areas of Kenya during different seasons. They will be used as basis for making recommendation for cereal aphids control programs in wheat crops which will improve the development of integrated pest management strategies.

Breeding for resistance to cereal aphids is the most effective means of reducing yield losses associated with cereal aphids' infestation. Recently acquired wheat germplasm with resistance to cereal aphids especially Russian wheat aphid are now being screened and will be utilized in the breeding program. Resistance information of wheat genotypes to cereal aphids is important to be known by wheat breeders as a guide in selecting source of resistance genes to be used in the improvement of wheat varieties resistant to cereal aphids. However, since breeding is a slow procedure, it is necessary to consider other strategies to minimize yield losses. The use of one or more applications of aphicides, together with cultural practices such as early planting, application of right amounts of fertilizers and good seed rates could be very effective in providing considerable control of cereal aphids.

9. Conclusion

Cereal aphids are major insect pests of wheat in Kenya. Their outbreaks have significant economic impact through increased production costs due to the need to control barley yellow dwarf virus and aphid infestations with insecticides. In order to reduce the crop losses and minimize

production costs, the ultimate goal of KALRO—Food Crops Research Centre—Njoro national wheat program is to develop a sound integrated management strategy for cereal aphids. It was observed that at earlier seedling stages, the population of natural enemies was too low to exert effective cereal aphids' control. The populations of these natural enemies increased only with the rise of aphids. The increased numbers of natural enemies were observed not to have any effective impact on the population of RWA. However, efforts should therefore be made to conserve these natural enemies as they are of great importance in controlling cereal aphids in wheat.

Applications of either Gaucho 350FS or Cruiser350FS followed by applications of systemic foliar insecticides achieved very good control of the Russian wheat aphid. Contact insecticides are not effective against Russian wheat aphid but they are effective against *R. maidis*, *S. graminum*, *Sitobion* spp., *M. dirhodum* and *R. padi*. Seed dressing is an insurance against infestation by early seedling pests such as the Russian wheat aphid. The use of seed dressers ensures a better crop establishment, more uniform and healthier crops with increased yields and quality. Satisfactory control of RWA using foliar applied aphicides depends on early detection of infestation through periodic scouting. This approach will therefore offer a cheaper strategy for cereal aphid and BYD control.

While some protection against cereal aphids can be realized by crop management practices, resistant varieties offer the greatest opportunity for reduction of crop losses. The sudden appearance of Russian wheat aphid has made resistance breeding program of high priority now as farmers are currently relying on insecticides to control the aphids. The high cost of chemical control and concern for extensive and frequent use of insecticides has led to search for Russian wheat aphid resistance. Using host plant resistance instead could be economical, effective throughout the growing season, environmentally safe and it will require no elaborate technology transfer to farmers and is a good strategy for effective management of cereal aphids in wheat by wheat growers.

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