The ability of the green peach aphid (*Myzus persicae*) to penetrate mesh crop covers used to protect potato crops against tomato potato psyllid (*Bactericera cockerelli*)

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In Central and North America, Australia and New Zealand, potato (*Solanum tuberosum*) crops are attacked by *Bactericera cockerelli*, the tomato potato psyllid (TPP). 'Mesh crop covers' which are used in Europe and Israel to protect crops from insect pests, have been used experimentally in New Zealand for TPP control. While the covers have been effective for TPP management, the green peach aphid (GPA, *Myzus persicae*), has been found in large numbers under the mesh crop covers. This study investigated the ability of the GPA to penetrate different mesh hole sizes. Experiments using four sizes (0.15×0.15, 0.15×0.35, 0.3×0.3 and 0.6×0.6 mm) were carried out under laboratory conditions to investigate: (i) which mesh hole size provided the most effective barrier to GPA; (ii) which morph of adult aphids (apterous or alate) and/or its progeny could breach the mesh crop cover; (iii) would leaves touching the underside of the cover, as opposed to having a gap between leaf and the mesh, increase the number of aphids breaching the mesh; and (iv) could adults feed on leaves touching the cover by putting only their heads and/or stylets through it?

No adult aphids, either alate or apterous, penetrated the mesh crop cover; only nymphs did this, the majority being the progeny of alate adults. Nymphs of the smaller alatae aphids penetrated the three coarsest mesh sizes; nymphs of the larger apterae penetrated the two coarsest sizes, but no nymphs penetrated the smallest mesh size. There was no statistical difference in the number of aphids breaching the mesh crop cover when the leaflets touched its underside compared to when there was a gap between leaf and mesh crop cover. Adults did not feed through the mesh crop cover, though they may have been able to sense the potato leaflet using visual and/or olfactory cues and produce nymphs as a result. As these covers are highly effective for managing TPP on field potatoes, modifications of this protocol are required to make it effective against aphids as well as TPP.

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Abstract

In Central and North America, Australia and New Zealand, potato (*Solanum tuberosum*) crops are attacked by *Bactericera cockerelli*, the tomato potato psyllid (TPP). 'Mesh crop covers' which are used in Europe and Israel to protect crops from insect pests, have been used experimentally in New Zealand for TPP control. While the covers have been effective for TPP management, the green peach aphid (GPA, *Myzus persicae*), has been found in large numbers under the mesh crop

22   covers. This study investigated the ability of the GPA to penetrate different mesh hole sizes.

23   Experiments using four sizes (0.15×0.15, 0.15×0.35, 0.3×0.3 and 0.6×0.6 mm) were carried out

24   under laboratory conditions to investigate: (i) which mesh hole size provided the most effective

25   barrier to GPA; (ii) which morph of adult aphids (apterous or alate) and/or its progeny could

26   breach the mesh crop cover; (iii) would leaves touching the underside of the cover, as opposed to

27   having a gap between leaf and the mesh, increase the number of aphids breaching the mesh; and

28   (iv) could adults feed on leaves touching the cover by putting only their heads and/or stylets

29   through it?

30   No adult aphids, either alate or apterous, penetrated the mesh crop cover; only nymphs did this,

31   the majority being the progeny of alate adults. Nymphs of the smaller alatae aphids penetrated

32   the three coarsest mesh sizes; nymphs of the larger apterae penetrated the two coarsest sizes, but

33   no nymphs penetrated the smallest mesh size. There was no statistical difference in the number

34   of aphids breaching the mesh crop cover when the leaflets touched its underside compared to

35   when there was a gap between leaf and mesh crop cover. Adults did not feed through the mesh

36   crop cover, though they may have been able to sense the potato leaflet using visual and/or

37   olfactory cues and produce nymphs as a result. As these covers are highly effective for managing

38   TPP on field potatoes, modifications of this protocol are required to make it effective against

39   aphids as well as TPP.

40   Keywords: aphids, tomato potato psyllid, mesh crop covers, insect nets, insect exclusion screens.

41

Introduction

42

43 Potato (*Solanum tuberosum* L.) is a globally important food crop, having the fourth highest

44 production level of 388 million tonnes in 2017 after maize (*Zea mays* L.), wheat (*Triticum*

45 *aestivum* L.), and rice (*Oryza sativa* L.) (FAOSTAT 2020). In New Zealand, potatoes are the

46 highest grossing vegetable, with consumers purchasing approximately NZ $119 million in 2013

47 (Vegetables.co.nz 2020). However, potato production is threatened by the tomato potato psyllid

48 (TPP, *Bactericera cockerelli* (Ŝulc 1908) (Hemiptera, Triozidae)). This phloem-feeding insect

49 originated in North and central America and was first identified in New Zealand in 2006 (Teulon

50 et al. 2009) and in Western Australia in 2017 (International Plant Protection Convention 2017).

51 TPP feeds on plants in the Solanaceae and Convolvulaceae families (Wallis 1955), and can cause

52 complete crop loss (Munyaneza 2013; Munyaneza 2014).

53 Due to the negative impacts of TPP on potatoes in New Zealand, organic farmers asked

54 researchers to investigate non-chemical management approaches. Biological options such as the

55 predatory mite *Anystis baccarum* L. (Geary et al. 2016) were explored, but without commercial

56 success. In the laboratory, the coccinellid beetle *Cleobora mellyi* (Mulsant 1850) has very high

57 consumption rates of TPP, but this remains to be confirmed in glasshouse and field crops

58 (O'Connell et al. 2012; Pugh et al. 2015).

59 'Mesh crop covers' (also referred to as 'insect nets', 'Agronets', 'insect exclusion screens') have

60 been used in Europe for many years to protect a wide range of crops, but not potatoes, from both

61 invertebrate and vertebrate pests (Collier 2001; Collier 2002; Hill 1987; Saidi et al. 2013). In

62 New Zealand, however, such covers have only recently been investigated experimentally. Mesh

63 crop covers with a hole size up to 0.6 mm were completely impermeable to TPP in laboratory

64 tests, and were able to reduce TPP populations in field trials to very low levels, even

65 outperforming insecticides (Merfield 2017; Merfield et al. 2015a; Merfield et al. 2015b; Merfield

66 et al. 2019).

67 Despite the promising results obtained with mesh crop covers for control of TPP, an unexpected

68 result was that aphids, believed to be mostly the green peach aphid (GPA, *Myzus persicae*

69 (Sulzer, 1776) (Hemiptera: Aphididae)) appeared in large numbers under the mesh crop covers,

70 particularly in the 2016-17 field trials where their populations were significantly higher than

71 uncovered controls, even though the edges of the mesh crop covers were dug into the soil,

72 creating a complete seal (Merfield 2017; Merfield et al. 2019).

73 Aphids can significantly affect plant growth and development, reducing yields. In addition, GPA

74 in particular, is a vector of many plant viruses that also cause significant yield losses (Capinera

75 2001).

76 The GPA is the most common and widespread aphid on potatoes in New Zealand, as it feeds on

77 many host-plant species (Stufkens & Teulon 2001). It is also the most economically important

78 aphid on potatoes, both in New Zealand and worldwide, because it transmits both potato virus Y

79 and leaflet curl virus, which are among the most damaging of the potato viruses (Marczewski

80 2001; Saguez et al. 2013; Srinivasan et al. 2013; Woodford 1992). The main management tool

81 for aphids in potatoes is insecticides. However, the GPA has developed resistance to a number of

82 these (Bass et al. 2014; Foster et al. 2007), which means that both novel and improved non-

83 chemical control techniques are required.

84 With mesh crop covers being highly effective for TPP management on potatoes, the major

85 challenge is understanding how aphids are circumventing mesh crop covers. Also it is unclear if

86 adults can, from outside the mesh crop cover, feed on potato leaves touching the underside of it.

87 If so, this means aphids outside the mesh crop cover could transmit viruses to potatoes under it.

88   This could discourage seed-potato growers from using the mesh crop cover as a management

89   option for TPP because of virus transmission to tubers intended for propagation.

90   With these gaps in knowledge, the present research was therefore designed to investigate (i) if

91   aphid stylets can penetrate mesh crop cover of different hole sizes; (ii) if there is a difference in

92   this respect between alate and apterous adults and/or if their progeny have the ability to penetrate

93   mesh crop cover as individuals; (iii) if having potato leaves touching the mesh crop cover from

94   below increases the number of individual aphids penetrating it, compared to when the leaves do

95   not touch the mesh crop cover; and (iv) if adult aphids are capable of feeding on potato leaves

96   through the mesh crop cover.

97   **Materials and methods**

98   GPA was sourced from a colony cultured on *Brassica rapa* subsp. *chinensis* (L.) pak choi

99   (cultivar: Mei Qing Choi F1) kept at Lincoln University in a controlled-temperature room. The

100   room was kept at 16 h day length, temperature of 23°C with a 4 °C range and 60% relative

101   humidity. Potato plants (cv. Ilam Hardy) were grown in a glasshouse at the Lincoln University

102   plant nursery to provide leaflets for the laboratory experiment.

103   For the laboratory work, two, nine-cm diameter Petri dishes were used to create two

104   compartments separated by mesh crop cover; the top dish contained the aphids and the bottom

105   one a single potato leaflet. In the 'control' treatments, three aphids were placed in the bottom

106   dish (Fig. 1). A piece of moist tissue paper was placed in the bottom dish to maintain humidity.

107   Leaflets were then collected from potato plants and cotton wool was wrapped around the petiole

108   of the leaflet, which was inserted into an Eppendorf tube filled with water to maintain leaflet

109   turgidity. The tube with leaflet inserted was placed in the lower dish with the adaxial surface

110   facing up. The mesh crop cover was carefully glued around the full circumference of the opening

111   between the two dishes, because, in previous experiments by Hodge et al. (2019), aphids could

112   locate and penetrate minimal gaps between the mesh crop cover and hard surfaces. The two Petri

113   dishes were then held together with plastic food wrap. For the mesh crop cover treatments, three

114   adult aphids were inserted through a hole (15 mm diameter) in the top of the upper dish, after

115   which the hole was sealed with mesh crop cover (0.15×0.15 mm mesh) held in place by adhesive

116   tape.

117   There was a total of 24 treatments in a 4×2×3 factorial design: four mesh crop cover hole sizes ×

118   two aphid morphs (apterous or alate) × (three leaflet/aphid positions), in a randomised complete

119   block, with five replicates. Eight of these treatments were controls, one for each of the 4 mesh

120   crop cover hole sizes and 2 aphid morphs, in which three aphids were placed directly on the

121   leaflet under the mesh crop cover. The other 16 (=4×2×2) treatments had a mesh crop cover

122   barrier between aphids and leaflets. The mesh crop cover hole sizes stated by the manufacturer

123   were 0.15×0.15 mm, 0.15×0.35 mm, 0.3×0.3 mm and 0.6×0.6 mm. Aphid morphs were apterous

124   or alate, while leaflet positions were touching or not touching the mesh crop cover barrier. The

125   experiment ran for 72 h, at which point the number of aphids, both adults and nymphs, on the

126   leaflets were counted. The experiment was conducted in a controlled temperature room as above.

127   To investigate whether adult aphids could feed through the mesh crop cover, all adults in the

128   upper dish (n=240=16×5×3), were lightly touched with an artist's fine brush (size 00) at 12, 24,

129   36 and 48 hours through the opening of the top Petri dish. Therefore, 240 individuals were

130   touched four times each, giving a total of 960 tests of feeding. Those that moved following

131   probing were considered to not have been feeding, while those that remained in the same

132 position following probing were judged as having their stylets inserted into the leaflet and

133 therefore, to be feeding (Auclair 1963; Giordanengo et al. 2010).

134 Mesh crop covers with hole sizes 0.15×0.15 mm and 0.15×0.35 mm were supplied by AB

135 Ludvig Svensson (www.ludvigsvensson.com) as ECONET 1515 and ECONET 1535. Those

136 measuring 0.3×0.3 mm and 0.6×0.6 mm were supplied by Crop Solutions Ltd.

137 (www.cropsolutions.co.uk) and were custom-made for an earlier field trial (Merfield 2017). To

138 test the accuracy of the measurement for each mesh crop cover hole size used in this experiment,

139 ten random samples of each type were selected and 10 holes of each sample were measured

140 under a Nikon SMZ25 microscope (magnification range 0.63–15.75×). The mean, minimum and

141 maximum mesh hole size measurements are presented in Table 1.

142 All data were analysed in a randomised block analysis of variance (ANOVA) (with a factorial

143 treatment structure) using GenStat® 18th edition. The response variable (number of aphids on

144 potato leaflets) was subjected to a square-root transformation to normalise the data before

145 analysis. Also, the analysis was split into two ANOVAs to achieve homogeneity of variance. (1)

146 The eight controls (4 mesh hole-sizes × 2 aphid-morphs), which were relatively highly variable,

147 were analysed separately as a 4 × 2 factorial with 5 blocks. (2) For the 16 non-control treatments,

148 six were all zeroes and hence had zero variability, so were omitted from the analysis, leaving 10

149 treatments which were analysed as a (2 × 2 + 1) × 2 factorial with 5 blocks.

150 **Results**

151 For the eight control treatments, with aphids below the mesh, there were no significant

152 differences in nymph numbers produced by the two aphid morphs, no significant linear or

153   quadratic components of mesh crop cover hole size (assuming these were in the ratio 1 : 2 : 3 :

154   6), nor any significant interaction components (Table 2).

155   In the 16 treatments with adults placed above the mesh cover, only nymphal, not adult aphids

156   were able to pass through the mesh. Nymphs of the smaller alate adults penetrated the 0.15×0.35,

157   0.3×0.3 and 0.6×0.6 meshes but not the 0.15×0.15 mesh (Table 2). Nymphs of the larger

158   apterous adults penetrated the 0.3×0.3 and 0.6×0.6 meshes but did not breach the 0.15×0.15 and

159   0.15×0.35 ones.

160   Comparing when leaflets touched or did not touch the mesh crop cover, there was no significant

161   difference in the number of nymphs penetrating the mesh (P=0.612). The interaction between

162   aphid morph (alate and apterous) and the leaflet touching mesh crop cover or not was also not

163   significant (P=0.066).

164   No aphids, at any time fed through the mesh crop cover, as all moved when probed with the

165   artist's brush.

Discussion

166

167   **Mesh crop cover hole size and aphid penetration**

168   The fact that no adult aphids penetrated the covers, differs from the result of Hodge et al. (2019)

169   studying GPA and the melon aphid (*Aphis gossypii* (Glover 1877)). They found that adult GPA

170   did penetrate LS ECONET 1515, but no GPA adults penetrated the larger hole LS ECONET

171   1535, a result which appears inconsistent. Hodge et al. (2019) did, however, find that nymphs

172   penetrated the mesh, in agreement with these results.

173   That adults did not penetrate mesh, but newly hatched nymphs did, suggesting a means by which

174   aphids entered all mesh covered plots in the field trial of Merfield (2017): adult aphids that

175 alighted on the upper surface of the mesh, produced nymphs, which are small enough to

176 penetrate the mesh, and once through that they can reproduce on the potato crop. This result

177 needs to be verified under field conditions.

178 The extent to which of aphids penetrate mesh and for mesh to control aphids is clearly variable.

179 For example, Bethke et al. (1994) who worked with adult aphids, found GPA could not pass

180 through a square, brass mesh with hole sizes ranging from 0.19 mm^2 to 0.94 mm^2, but melon

181 aphid could penetrate meshes larger than 0.46 mm^2. Using mosquito nets of knitted polyester,

182 30 gm^{-2} and a mesh size of 25 holes per cm^2, untreated or treated with deltamethrin, supported

183 50 cm above seedling cabbages (*Brassica oleracea* L.), Martin et al. (2006) found the treated

184 nets had significantly lower numbers of plants infested with the mustard aphid (*Lipaphis erysimi*

185 (Kaltenbach 1843)). In subsequent work, Martin et al. (2013) used mesh with 0.9 mm diameter,

186 treated with alphacypermethrin and two untreated nets, one with the same hole size and the other

187 with a smaller one of 0.4 mm, and control without mesh, to cover pot-grown cabbages in the

188 field with the mesh supported 30 cm above the plants. They found no cabbage aphid

189 (*Brevicoryne brassicae* L.) under the 0.9 mm alphacypermethrin treated and untreated 0.4 mm

190 mesh, but a small, yet statistically significant greater number, under the untreated 0.9 mm mesh.

191 In comparison, both GPA and mustard aphids (counted together as 'green aphids'), were not

192 present under the treated 0.9 mm mesh but were present in much larger numbers than cabbage

193 aphid in the two other meshes. The untreated 0.9 mm mesh had a statistically significant

194 population 5.8 times larger than the non-covered control while the 0.4 mm mesh had more than

195 twice the number of aphids than the control, although the difference was not statistically

196 significant. Licciardi et al. (2007), using deltamethrin-treated polyester mesh with 40 holes/cm^2,

197 kept 50 cm above cabbages, with the mesh either removed during the day ('temporary') or kept

198   permanently on the crop, found that aphids infested the untreated control immediately on

199   planting out the crop. The temporary mesh was infested at 20 days after planting (DAP), and the

200   permanent mesh at 30 DAP, but then, the aphid numbers under the permanent screen rapidly

201   increased to finish at approximately four times that under the temporary mesh. In orchard trials

202   in France and Italy using mesh covers with hole sizes of either 2.2 × 5.4 mm or 3 × 7.4 mm to

203   control codling moth (*Cydia pomonella* L.), Alaphilippe et al. (2016) found that rosy apple aphid

204   (RAA, *Dysaphis plantaginea* (Passerini 1860)) and woolly apple aphid (*Eriosoma lanigerum*

205   (Hausmann, 1802)) populations increased. In contrast, Dib et al. (2010) found mesh covers

206   reduced RAA populations and also those of their ant mutualists as well as their predators under

207   covers also used for codling moth control. In a comparison of nets treated and untreated with

208   insecticides against black bean aphids (*Aphis fabae* (Scopoli 1763)) on French bean (*Phaseolus*

209   *vulgaris* L.), Gogo et al. (2014) found both mesh types significantly reduced aphid populations

210   compared with the control, but did not eliminate them.

211   In a few cases, mesh crop covers appeared to be impenetrable to aphids, or at least can prevent

212   aphids reaching crops, though this varies with aphid species e.g., cabbage aphid cv. GPA (Martin

213   et al. 2013), and could be related to size, though other factors, e.g., behavioural, may also have a

214   role. However, in most cases discussed above, mesh covers appeared only to delay aphids

215   reaching the crops, and, in some cases, aphid populations then rapidly built to levels much higher

216   than those in untreated controls or insecticide treatments. It is hypothesised that the mesh is

217   preventing, or at least reducing the range and number of aphid natural enemies that can reach the

218   crop.

219   Aphids are also not the only insect species that can circumvent mesh. Talekar et al. (2003) and

220   Piccard et al. (2007) reported that adult female moths of the armyworm (*Spodoptera littoralis*

221   (Boisduval 1833)) laid eggs on the top of a hooped screen, and the newly hatched larvae were

222   sufficiently small to penetrate the mesh and drop onto the crop below. Merfield (2017) found a

223   large number of lacewings (*Micromus tasmaniae* (Walker 1860)) in plots of potatoes under

224   mesh, following aphid outbreaks under the mesh. Lacewing adults are much too large to

225   penetrate mesh, and the mesh was dug into the soil preventing entry from the edges, so it was

226   hypothesised that the lacewings laid eggs on the mesh, and then the neonate larvae penetrated the

227   mesh. As aphids, lacewings and armyworms would not be expected to lay eggs or produce

228   nymphs in the absence of suitable hosts, this indicates that the insects can detect their hosts

229   through the mesh, even when the mesh is at some distance from the crop (Licciardi et al. 2007;

230   Talekar et al. 2003).

231   **Difference between the progeny of alate and apterous adults to penetrate mesh crop cover**

232   In the present study, nymphs produced by alate adults penetrated the 0.15×0.35 mesh crop cover,

233   while those produced by apterous adults did not. This supports the findings of (Dixon & Wratten

234   1971) who found that alate aphids were smaller, and produced fewer and smaller nymphs than

235   did apterous aphids, which indicates that only the smallest size mesh crop cover hole size

236   (0.15×0.15 mm) would be an effective barrier. For mesh crop cover with larger hole sizes,

237   neonate nymphs of both adult morphs can enter the mesh crop cover, so both alate and apterous

238   adults are potential threats to the crop. However, apterous aphids, lacking wings, could arrive

239   only on the outside of mesh crop cover from other plants bordering the mesh crop cover. In the

240   field trial of Merfield (2017) and Merfield et al. (2019), the periphery of mesh crop cover was

241   kept free of vegetation with residual herbicides and tillage such that apterous aphids walking

242   onto the mesh crop cover should have been eliminated, yet all mesh crop cover plots were

243   infested by aphids. It is therefore believed, that nymphs, which infested the mesh crop cover

244   treatments in those trials, were produced by alate adults.

245   **Adult aphid feeding through mesh and implications for virus transmission**

246   That adults were not found to feed through the mesh indicates potato viruses will not be

247   transmitted through mesh. However, this result is not direct evidence for lack of transmission, as

248   it only demonstrated a lack of feeding but not a lack of probing. GPA can also transmit viruses

249   by probing (Radcliffe & Ragsdale 2002). Direct testing of virus transmission is required, using

250   virus-infected aphids to test the rates of transmission when mesh is present or not.

251   **Solutions for aphids penetrating mesh crop covers.**

252   That some aphid species, and also armyworm (Licciardi et al. 2007; Talekar et al. 2003) can

253   circumvent mesh indicates that for some insect pests, additional control measures will be

254   required when using covers. Three general approaches are suggested: (i) modify the physical

255   properties of the mesh to prevent pests alighting or reproducing on it; (ii) use insecticide or

256   repellent-treated mesh covers to kill or repel alighting pests; (iii) use supplemental biological

257   control. For aphids on potatoes, the approach used should ideally also ensure that virus

258   transmission is minimised.

259   A range of research has altered the physical properties of mesh crop covers to both repel and

260   attract insects. Some of this research can be considered for field potatoes. These alterations

261   include: different colours (Ben-Yakir et al. 2012a), and ultra-violet light properties (Ben-Yakir et

262   al. 2012b), such that the mesh prevents aphids alighting.

263   Insecticide treated mesh crop covers have been discussed above, and, are clearly highly effective

264   in some situations. A further refinement of this approach has been to create attractive areas on

265   the mesh, e.g., yellow spots, with only the attractive areas treated with insecticides (Ben-Yakir et

266   al. 2014). Chemical repellants can also be used in place of biocides (Martin et al. 2013).

267   However, the insecticides and repellents are lost from the mesh covers over time, so the efficacy

268   of treated mesh covers reduces, meaning their effective lifespan can be less than that of untreated

269   mesh covers (Dáder et al. 2015). Treating mesh also increases cost, and may require personnel to

270   use protective equipment when handling and storing the mesh covers. If a single chemical is used

271   to treat the mesh, this is likely to create increased pressure for evolved resistance, both against

272   biocides, and, also repellents (Foster et al. 2007). This could be partially mitigated through

273   impregnating the mesh covers with multiple insecticides with different modes of action, but, at

274   further increased cost.

275   A range of biological control approaches could be used. In the case of armyworm (discussed

276   above), infestations were effectively controlled using the biological control agent (BCA) *Bacillus*

277   *thuringiensis* (Talekar et al. 2003). In field crops, microbial BCAs could be applied through the

278   mesh (Ester et al. 1994; Merfield 2018). Augmentative biological control using predators and

279   parasitoids is widely used in protected cropping, such as glasshouses. Mesh crop covers are

280   considered to be a form of protected cropping, in that they should prevent introduced BCAs

281   escaping from the crop, so existing glasshouse biocontrol solutions could be leveraged. For

282   example, Gagnon Lupien et al.(2014) suggested the release of the commercially available

283   coccinellid *Adalia bipunctata* (L.) to compensate for the lack of aphid natural enemies under

284   mesh crop covers. Other biological control agents (BCAs) that have been used to successfully

285   manage GPA in protected envrionments include, *Aphidius matricariae*, *Aphidius colemani*

286   (Zamani et al. 2007) and *Micromus tasmaniae* (Harcourt 1996; Jonsson et al. 2009).

287   Augmentative biological control with insects could be further enhanced by the use of banker

288   plants (which provide supplemental food for beneficial insects, which helps them maintain a

289   stable population) (Frank 2010) grown under the mesh / among the potato crop; this approach is

290   already used for control of GPA (Andorno & López 2014).

Conclusions

292   Because of commercial availability and cost, it is recommended that the 0.6×0.6 mm mesh crop

293   cover be used to manage TPP on potatoes, even though this mesh can be penetrated by GPA

294   nymphs. Further research is required to confirm GPA nymphs' ability to penetrate mesh covers in

295   the field and whether or not mesh is an effective barrier to virus spread, both by adults and

296   nymphs. A considerable amount of research is required into methods to control GPA and other

297   aphid species in mesh-covered potato crops. If mesh crop cover is combined with additional

298   approaches that achieve a high level of GPA control and therefore that of potato viruses, the

299   benefits to the potato seed industry are likely to be considerable. Mesh crop covers have been in

300   use across Israel and Europe since the early 1990s and the area used in Europe is estimated at

301   50,000 ha, with hundreds of ha on individual farms (Ian Campbell, Crop Solutions Ltd., personal

302   communication). Mesh crop covers are therefore a completely farm-proven, large-scale,

303   technology. If an effective means of managing aphids on potatoes under mesh crop covers can be

304   developed, it has the potential to be a viable option for management of TPP on potato in New

305   Zealand and globally.

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466   **Figure and Table Legends**

467

468   **Fig. 1.** Experimental set up: (1) top Petri dish, (2) bottom Petri dish, (3) hole for aphid
469   introduction, (4) mesh between dishes, (5) Eppendorf tube and leaflet. For the 8 'control'
470   treatments, aphids were placed below the mesh, while for the other 16 treatments, aphids were
471   placed above the mesh.

472

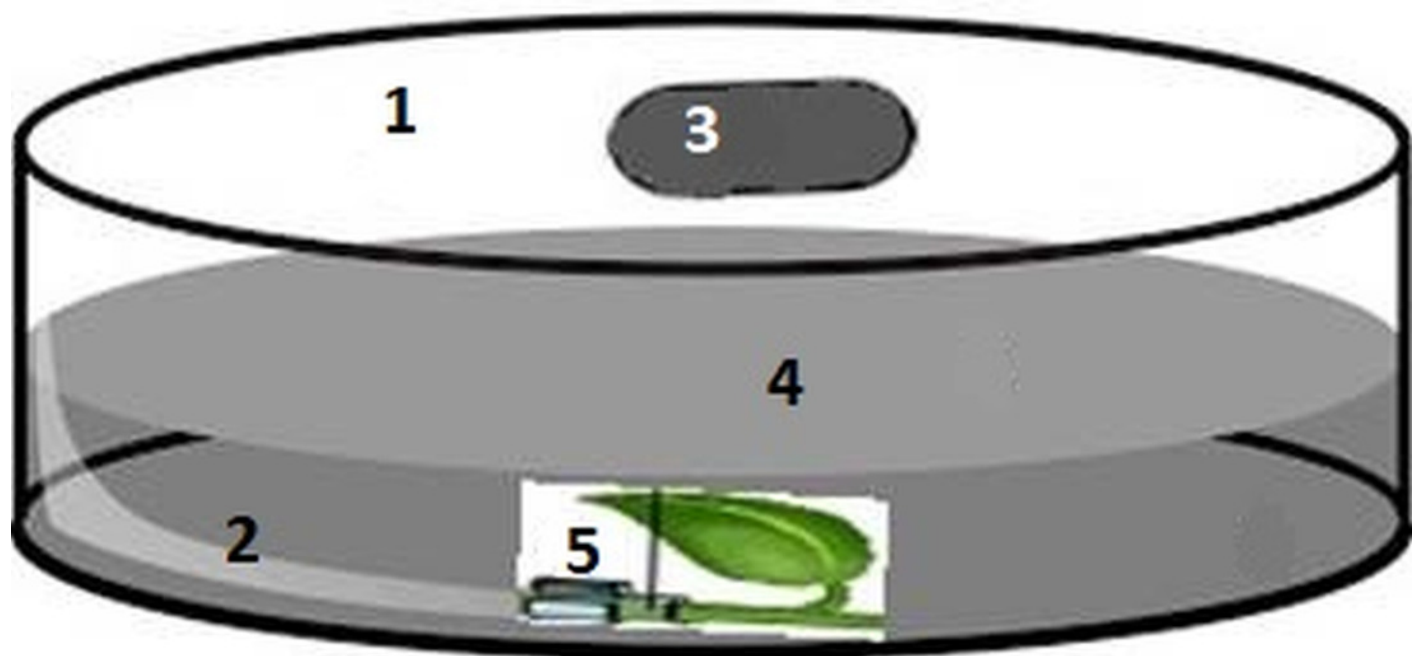
473   **Table 1.** Measurements of each mesh type.
474

475   **Table 2.** Mean (√) number of aphid nymphs of apterous and alate parents breaching different
476   mesh sizes when leaflets were touching the mesh or not. A: Controls were statistically analysed.
477   B: Treatments with means in brackets indicate those that were omitted because they had zero
478   mean and zero variance. m.e. = main effect.

479

480

Figure 1

Fig. 1. Experimental set up: (1) top Petri dish, (2) bottom Petri dish, (3) hole for aphid introduction, (4) mesh between dishes, (5) Eppendorf tube and leaflet. For the 8 'control' treatments, aphids were placed below the mesh, while for the other 16 tre

Measurements of each mesh type.

2   **Table 1.** Measurements of each mesh type.

	Mesh size (mm)							
	0.15×0.15		0.15×0.35		0.3×0.3		0.6×0.6	
Mean	0.14	0.13	0.15	0.32	0.37	0.23	0.52	0.52
Max.	0.16	0.15	0.18	0.37	0.53	0.31	0.57	0.55
Min.	0.12	0.10	0.12	0.30	0.27	0.17	0.45	0.47

Mean (√) number of aphid nymphs of apterous and alate parents breaching different mesh sizes when leaflets were touching the mesh or not. A: Controls were statistically analysed. B: Treatments with means in brackets indicate those that were omitted becaus

1 **Table 2.** Mean (√) number of aphid nymphs of apterous and alate parents breaching different
2 mesh sizes when leaflets were touching the mesh or not. A: Controls were statistically analysed.
3 B: Treatments with means in brackets indicate those that were omitted because they had zero
4 mean and zero variance. m.e. = main effect.

	Aphid morph	Mesh size (mm)	Mean of square root of # of nymphs below mesh	Back transformed means
A.				
Control	Apterous	0.15×0.15	2.460	6.05
		0.15×0.35	2.202	4.85
		0.3×0.3	1.940	3.76
		0.6×0.6	2.448	5.99
	Alate	0.15×0.15	1.823	3.32
		0.15×0.35	1.673	2.80
		0.3×0.3	2.455	6.03
		0.6×0.6	1.756	3.08
LSD 5%			**1.235**	
Significance of m.e., apterous vs alate			not sig.	
B.				
Leaflet not touching mesh	Apterous	0.15×0.15	(0.000)	0.00
		0.15×0.35	(0.000)	0.00
		0.3×0.3	0.483	0.23
		0.6×0.6	0.883	0.78
	Alate	0.15×0.15	(0.000)	0.00
		0.15×0.35	0.200	0.04
		0.3×0.3	0.283	0.08
		0.6×0.6	0.829	0.69
Leaflet touching mesh	Apterous	0.15×0.15	(0.000)	0.00
		0.15×0.35	(0.000)	0.00
		0.3×0.3	0.200	0.04
		0.6×0.6	0.400	0.16
	Alate	0.15×0.15	(0.000)	0.00
		0.15×0.35	0.546	0.30
		0.3×0.3	1.012	1.02
		0.6×0.6	1.029	1.06
LSD 5%			**0.905**	