Can grain growers and agronomists identify common leaf diseases and biosecurity threats in grain crops? An Australian example

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A B S T R A C T

The Australian grains industry relies upon growers and agronomists to be aware of pests and diseases in their crops and to notify their local State Department of Agriculture when they suspect an incursion of a high priority pest (HPP). This raises the question “Are growers and agronomists, within the Australian grains industry, able to meet this expectation?” A training needs analysis was undertaken to determine the capacity of growers and agronomists to identify three endemic diseases (powdery mildew in barley, stripe rust in wheat and blackleg in canola) in their crops. Their knowledge of the top four-biosecurity threats to the Australian grains industry (Karnal bunt, Khapra beetle, barley stripe rust and Russian wheat aphid) was also determined. Benchmarks for successfully identifying these diseases were set beforehand at 70% of growers and 80% of agronomists; participants’ ability to identify these endemic diseases in crops met these benchmarks. However, their ability to recognise blackleg in canola was significantly lower than for the two cereal foliar diseases. There was a significant correlation of region with these capabilities, with a greater proportion of participants in Western Australia (WA) recognising powdery mildew in barley than in Eastern Australia (EA). In contrast, a greater proportion of participants in EA were able to identify stripe rust of wheat than in WA. The education levels of participants corresponded with their ability to identify blackleg in canola. Participants’ knowledge and awareness of symptoms and signs associated with the top four biosecurity threats were well below expectations; fewer than half of the participants answered questions on these four HPPs. Gender, age and educational level did not correlate with the participants’ knowledge and awareness of the four HPPs with the exception of Karnal bunt. Participants with a higher level of education had significantly more knowledge of symptoms associated with Karnal bunt than did participants with lower levels of education. The use of diagnostic services by the grains industry participants is a vital component of general surveillance. This survey showed that use of these services by growers was significantly lower than by agronomists. Awareness of the National Exotic Plant Pest Hotline and GrainGuard was significantly lower than other diagnostic services for both growers and agronomists. Diagnostic services need to be promoted further to increase awareness and use by growers and agronomists. Correct diagnosis of disease and pest symptoms is vital for the biosecurity of the grains industry.

1. Introduction

Accurate and rapid diagnosis is required for the effective management of endemic diseases and pests and to prevent the incursion and establishment of biosecurity threats to the Australian grains industry. Early detection requires growers and agronomists to be aware of and to be able to identify symptoms and signs associated with these pathogens and pests.

In Australia, the Emergency Plant Pest Response deed (EPPRD) covers the management and funding of responses to emergency plant pest (EEP) incidents. Plant Health Australia (PHA) is the custodian of this document (Plant Health Australia, 2015). PHA is a not-for-profit company that is the national co-ordinator of the government-industry partnership for plant biosecurity in Australia.
(Plant Health Australia, 2015). The EPPRD has increased the capacity of Australia to respond to incursions by allowing rapid, efficient and effective responses (Plant Health Australia, 2015). An EPP is either: a) a known exotic plant pest; b) a variant form of an endemic plant pest; c) a previously unknown pest or d) an officially controlled pest. These are pests that have a significant impact (environmental or economic) nationally (Plant Health Australia, 2015). Eradication is facilitated by early detection (Plant Health Australia, 2015). The deed lists the following three EPPs for the grains industry: a) Tilletia indica Mitra 1931 (Karnal bunt); b) Trogoderma granarium Everts 1899 (Khapra beetle); and c) Diuraphis noxia Kurdjumov 1913 (Russian wheat aphid) (Plant Health Australia, 2015). The pathogen that causes barley stripe rust (Puccinia striiformis f. sp. hordei Eriksson 1894) is not on the list of EPPs, but is listed as a high priority pest (HPP) for the grains industry within Australia. These four pests and pathogens are referred to as high priority pests (HPPs) in this investigation.

Australia has a very diverse agricultural sector that includes crop production (broadacre and horticultural) and animal production (sheep, cattle – beef and dairy, pigs and poultry). The Australian Bureau of Statistics (ABS) reported that in 2011/2012, 405 million hectares of land were used for agriculture in Australia, with 32 million hectares being planted for crops. The value of Australia’s exported grain exceeded $10 billion (AUD) in 2013/2014 and included these three major crops; wheat ($6 billion), canola ($2 billion) and barley ($2 billion) (Australian Export Grains Innovation Centre, 2015). Nationally 29.9 million tonnes of wheat were produced, with a total area planted to wheat of 13.9 million hectares (Australian Bureau of Statistics (2012)).

Pests and diseases cause considerable loss of value to Australian crops. The estimated annual loss is $76.64 (AUD) per hectare in the Australian wheat industry (Murray and Brennan, 2009b). These losses represent 19.5% of the average annual value of wheat crop production over the past decade. Similar losses are reported in barley and canola crops (Murray and Brennan, 2009a, 2012). Improving the knowledge and skills of growers and agronomists to facilitate effective management of pests and diseases, should reduce these losses.

The Grains Research Development Corporation (GRDC) surveyed growers and agronomists about information products and services needs that they will require over a two-year period (Watson and Watson, 2014). Only 17% of growers thought that they would require information on pests and diseases in crops while approximately 30% of agronomists thought that this information would be required (Watson and Watson, 2014). This indicates that growers and agronomists within the grains industry believe that their existing skills are adequate for pest and disease management.

Community-based surveys and reporting by growers and agronomists can be used to address International Standards for Phytosanitary Measures (ISPM) 04 requirements for Area Freedom (2001; FAO, 2011; Hammond et al., 2016a; Mangano et al., 2011). The ability of community groups to detect exotic or HPPs (both disease and insects) was tested by Mangano et al. (2011) in a simulated exercise where three fictitious pests (two insects and one disease) were used. Success in detection of these pests was correlated with both participants’ age and professional experience. The term ‘general surveillance’ is used to encompass information that is collected through diagnostic services, reports from experts, growers and agronomists and reports to government departments. These activities are an important contributor to the early detection of a possible HPP (FAO, 2011; Hammond et al., 2016b).

The probability of a grower detecting a disease in their crop directly influences the sensitivity of general surveillance for that disease (Hammond, 2010), i.e. the higher the probability of detection by the grower, the greater the sensitivity of the surveillance. When knowledge and awareness are lower than a benchmark level this is likely to impact on the ability of growers and agronomist to report suspected HPPs. The animal and plant industries have considered this using scenario tree analysis, based on probabilistic modelling (Hadorn and Stark, 2008; Hammond, 2010; Martin et al., 2007). The sensitivity of general surveillance for the detection of foot and mouth disease in animal production areas of Australia varied according to a number of factors including the attitudes, behaviours, the knowledge and understanding of this disease by farmers and livestock inspectors. This was demonstrated using a stochastic scenario tree model (Martin et al., 2015). In this model, disease awareness was broken down into three main components: a) the probability of clinical signs being observed in the animals, b) the probability that the farmer recognises these clinical signs as being a problem and c) the probability that a veterinary officer is notified of the problem (Martin et al., 2015). Therefore, the earlier that growers and agronomists recognise symptoms associated with HPPs in grain crops, the greater the probability that a HPP will be reported early, allowing for a more effective response to occur.

In a previous survey by Hammond et al. (2016a), knowledge of the symptoms and signs associated with the top four HPPs of the grain industry was determined among growers and agronomists within Western Australia (WA). Participants had greater knowledge of the symptoms and signs associated with the pathogens causing Karnal bunt and barley stripe rust than of the two insect pests Khapra beetle and Russian wheat aphid.

There is little published literature concerning increasing the capacity of growers and agronomists to identify plant pests and diseases, although Levy (2005), Bagamba et al. (2006) and Yang et al. (2008) indicate that the awareness of growers and industry was increased when information was provided during a biosecurity campaign. However, there is more literature published within the animal industry examining the skills of farmers, veterinarians and other professionals in their identification and awareness of exotic diseases to determine what capacity building is required (Kunda et al., 2008; Martin et al., 2015; Musa et al., 2010).

No benchmark has been set previously in the grains industry for assessing the ability of growers and agronomists to identify endemic diseases in crops, nor is there an equivalent in the animal industry. The aim of this study was to use a training needs analysis (TNA) of Australian grain growers and agronomists to determine their ability to identify endemic leaf diseases in crops and the top four HPPs in grain crops. A TNA is often used before designing a course to determine what training the learners require. The TNA determines the level of discrepancy between the perceived knowledge or skill level of a learner and the actual knowledge or skill level of the learner (Print, 1993). The TNA can be done using a questionnaire, as in our study reported here. The relationship of age, gender, level of education and location with the ability of growers and agronomists to identify the pests and diseases was also examined. This is an initial step in determining if there is a gap in the skills of growers and agronomists within the grains industry and if so, what capacity building is required. For our study, the following disease identification benchmarks of 70% of growers and 80% of agronomists were established. The results from the questionnaire given to growers and agronomists will determine if 70% of growers are able to identify diseases in their crops and if 80% of agronomists can identify diseases in crops.

2. Methods

2.1. Surveys

Two questionnaires were developed to examine the training needs of participants in the grains industry of Australia. One
questionnaire was targeted towards growers and the other questionnaire was targeted to agronomists, as their training needs could be quite different. The questionnaires consisted of six sections that examined: a) how they like to obtain information, b) the types of training that they had attended in the previous 12 months, c) pest and diseases in their crops, d) knowledge levels of diseases in crops, e) knowledge level of biosecurity threats and f) demographic information.

The survey was administered using Qualtrics (Qualtrics, Provo, UT) and developed following the principles of Fowler (2009) and Dillman et al. (2009); using questions which are simple and easy to understand and provide reliable and valid measures.

For this study, a grower was defined as a person who lives and farms land to produce grain crops. An agronomist was defined as a person employed by grain growers to provide technical information in relation to grain crop production. The information provided by agronomists to growers includes recommendations for fertiliser application, implementation of fungicide and herbicide spray programmes and general crop husbandry advice.

Sections d (knowledge of diseases in crops) and e (knowledge of biosecurity threats) within the two questionnaires were identical so that comparisons could be made between growers and agronomists. The questions were designed to determine the baseline knowledge level of participants in the identification of plant diseases commonly found in grain crops and the participants’ knowledge of the biosecurity threats to the Australian grains industry. For this research paper, the results from the following four sections were analysed and reported:

1. Participants were asked to identify from photographs three common leaf diseases found in grain crops (Questions, 32, 33, and 34 in Appendix A). These were blackleg of canola, stripe rust of wheat and powdery mildew of barley. The photograph of each disease was accompanied by a choice of four possible identifications.
2. Participants were asked to identify the symptoms associated with the top four HPPs within the grains industry (Questions 35, 36, 37, and 38 in Appendix A). The HPPs were Karnal bunt, Khapra beetle, barley stripe rust and Russian wheat aphid. A list of seven associated and non-associated symptoms was provided for each HPP and participants were asked to choose which symptoms were associated with the HPP, or indicate that they did not know any symptoms for that HPP.
3. Participants were asked whether they were aware of any particular diagnostic services relevant to the grains industry in Australia, whether they had submitted any samples and if so, how many (Question 31 in Appendix A). The diagnostic services listed included the following: a) GrainGuard — a diagnostic service for quarantine threats to Western Australia with a focus on regional threats, to minimise risks to production and access to grain markets (Department of Agriculture and Food, 2015). Growers and agronomists can submit samples free of charge if they believe the problem is new to their region; b) National exotic plant pest hotline — a national service where growers, agronomists and the general public can ring and report a new pathogen or pest that they may have seen. This is serviced by the relevant State Agricultural Department; c) PestFax/PestFacts — a state based newsletter service which operates only during the growing season to which growers and agronomists report what they have seen in crops. These reports are collated on a weekly basis and distributed by an email service. Each report is verified by an entomologist or pathologist before publication; e) Indicta® soil testing service — a national service to which growers and agronomists send in soil samples to determine the risk of soil-borne pathogens infecting future crops; f) private diagnostic services — a fee for service enterprise used which test soil and plant material for a range of pathogens and other factors such as nutrition; g) state diagnostic services — these operate as a fee for service and are delivered through most state Agricultural departments.

4. The final section collected demographic information from the participants (Questions 39—44 in Appendix A). Other information collected included: a) how often crops were inspected (Q25); b) if growers employed an agronomist (Q28); c) how many years they had worked (Q40) and d) what crops were grown (Q45) (Appendix A).

Ten agronomists and researchers within the Department of Agriculture and Food, Western Australia (DAFWA) pretested the agronomists survey to ensure that questions were clear. Unclear questions were modified and then a pilot survey was undertaken at the GRDC Agribusiness Crop Updates held in Ballarat, Victoria in February 2014. A similar process was used for the grain growers survey, a test for clarity was conducted with three farmers in Goomalling, WA and then the pilot survey was held at the GRDC Grains Research Update for Growers at Lake Bolac, Victoria in February 2014. Approval for this work was gained from the Human Research Ethics Committee of The University of Western Australia (RA/4/1/6607).

The questionnaires for growers and agronomists were distributed in March 2014 as an online questionnaire (Qualtrics, Provo, UT) and as a paper-based questionnaire. The online questionnaire was advertised through local grower group newsletters in WA, Queensland and Victoria. The paper-based questionnaires (400) were distributed with a reply-paid envelope at six regional crop updates held by the following Western Australian grower groups; Liebe, Mingenew — Irwin (MIG), West Midlands Group, Southern DiRT, Fitzgerald Biosphere Group, Stirlings to Coast and Ravensthorpe Districts, (Fig. 1). The questionnaires were also posted to growers and agronomists (200 growers and 100 agronomists) who were members of the Birkich Cropping Group in Victoria (Fig. 1). The survey was closed on 30th June 2014.

Crop updates and research updates are forums that are held at the beginning of each year around Australia, to inform growers and agronomists and others of the latest research in the Australian grains industry.

2.2. Data analysis

The data from the survey were compiled using Qualtrics software, 2013. Statistical Package for the Social Sciences (SPSS) (IBM ver. 22) was used to analyse the data using cross tabulation and Pearson’s Chi-Square test ($x^2$) to determine the influence of occupation (grower or agronomist), age, gender, education level and location on the ability to identify the three leaf diseases in grain crops and assess participants’ awareness of the symptoms associated with the four HPPs. If Pearson’s Chi-Square test failed the assumption that more than 20% of the cells had a frequency count of less than 5, then the Likelihood ratio was used in its place.

The demographic data contained the following variables used in the data analysis: Age ($\leq 30$ years, $31–50$ years, $> 51$ years); Education level (school, vocational education training (VET) University); Occupation (grower, agronomist); Location (Western or Eastern Australia) and Gender (male, female) (Table 1).

Questionnaires with incomplete demographic data (n = 47) such as no postcode were not included in the analysis. Due to low number of questionnaires returned from Queensland, NSW, Victoria and South Australia separately, the data collected from these states were combined together to form “Eastern Australia” (EA) which was used in the corresponding cross tabulation and
Pearson’s Chi-Square analysis.

Questions 31–34 on endemic leaf diseases were analysed using cross-tabulations and Pearson’s Chi-Square test. Frequency data was determined for the number of correct and incorrect responses for each endemic leaf disease. McNemar’s test was then used to determine if there were significant differences between participants’ ability to identify the three different leaf diseases.

Responses to the questions related to high priority pests (35–38) were analysed using the method of Hammond et al. (2016a). Each HPP had eight symptoms from which the

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**Table 1**

Pearson’s Chi-Square analysis of demographic data collected from growers and agronomists who completed the training needs analysis survey on the identification of endemic diseases and high priority pests (HPPs) in grain crops.

<table>
<thead>
<tr>
<th>Group</th>
<th>Subgroup</th>
<th>Number of growers (n)</th>
<th>Growers (%)</th>
<th>Number of agronomists (n)</th>
<th>Agronomists (%)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>State</td>
<td>Western Australia</td>
<td>89</td>
<td>67</td>
<td>47</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Eastern Australia</td>
<td>44</td>
<td>33</td>
<td>61</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(133)</td>
<td>(100)</td>
<td>(108)</td>
<td>(100)</td>
<td></td>
<td>≤0.001</td>
</tr>
<tr>
<td>Pearson’s Chi-Square</td>
<td>Education</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>School</td>
<td>57</td>
<td>13.27</td>
<td>5</td>
<td>13.27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vocational Education</td>
<td>46</td>
<td>34.1</td>
<td>17</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>University</td>
<td>32</td>
<td>23.7</td>
<td>91</td>
<td>80.5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(135)</td>
<td>(100)</td>
<td>(113)</td>
<td>(100)</td>
<td></td>
<td>≤0.001</td>
</tr>
<tr>
<td>Pearson’s Chi-Square</td>
<td>Age</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>≤30 years</td>
<td>15</td>
<td>11.1</td>
<td>28</td>
<td>24.8</td>
<td></td>
</tr>
<tr>
<td></td>
<td>31-50 years</td>
<td>63</td>
<td>46.7</td>
<td>59</td>
<td>52.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≥51 years</td>
<td>57</td>
<td>42.2</td>
<td>26</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>(135)</td>
<td>(100)</td>
<td>(113)</td>
<td>(100)</td>
<td></td>
<td>≤0.001</td>
</tr>
<tr>
<td>Pearson’s Chi-Square</td>
<td>Gender</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>116</td>
<td>87.2</td>
<td>88</td>
<td>78.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>17</td>
<td>12.8</td>
<td>24</td>
<td>21.4</td>
<td></td>
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<tr>
<td>Total</td>
<td>(133)</td>
<td>(100)</td>
<td>(112)</td>
<td>(100)</td>
<td></td>
<td>0.071</td>
</tr>
<tr>
<td>Pearson’s Chi-Square</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*p values indicate if there is a significant difference between growers and agronomists.

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**Fig. 1.** (a) Map of Australia showing where grower and agronomists who responded to the training needs analysis survey on endemic diseases and high priority pests (HPPs) in grain crops resided based on postcodes. b shows respondents from the Western Australia wheatbelt. c shows respondents from Eastern Australia. The size of the symbols correlates to the number of participants who responded and reside within that locality. ▲ Agronomists [1–8], ▼ Growers [1–9], ◆ Town.
participants were to select the three or four symptoms correctly associated with that HPP (Appendix A). Each correct symptom chosen scored 0.125. Each incorrect symptom not chosen scored 0.125, giving participants a total score of 1 when all answers were correct. In this section, participants who had not answered the question, or selected “don’t know” were treated as missing data and removed from the analysis, thus reducing the sample size. The responses were analysed using crosstabs and Pearson’s Chi-Square test. The Mann-Whitney U test was then used to compare the data collected in 2008 by Hammond (2010) with the data collected in our survey (Table 2).

3. Results

3.1. Response rate

A total of 156 questionnaires were returned by mail, with 54 of these coming from the Birchip Cropping Group and 132 questionnaires were completed online (65 grain growers and 67 agronomists). A total of 248 useable questionnaires were returned. The response rate was 22% for the paper-based questionnaires and 34% of them had achieved vocational education training (VET). The growers (42%) school was the highest education level achieved, and was significantly different (Table 1). For a high proportion of agronomists (80.5%) had completed a university degree. As expected, the education level of growers and agronomists was significantly different (Table 1). For a high proportion of growers (42%) school was the highest education level achieved, and 34% of them had achieved vocational education training (VET). The majority of agronomists (80.5%) had completed a university degree. A significantly higher proportion of females (76%) had a university education compared to males (45%) in the population of growers and agronomists combined (Table 1).

Diversity in age was observed among the participants and there were differences in the age groups between the two occupations (Table 1). There were a higher proportion of agronomists (25%) who were either 30 years of age or younger, compared to growers (11%). A higher proportion of growers than agronomists were older than 51 years of age.

The distribution of gender among the participants was as expected with the majority of respondents being male (87.2% of growers and 78.6% of agronomists) (Table 1).

3.2. Identification of leaf diseases

Powdery mildew was correctly identified by 79% of growers, and stripe rust was correctly identified by 71% of growers. Only 50% of growers correctly identified blackleg on canola while 83% of agronomists correctly identified this disease (\( \chi^2(1, n = 247), = 28.78, p < 0.001 \)) (Fig. 2). The proportion of growers that identified blackleg of canola correctly was less than the benchmark set at 70%.

The ability of growers to identify endemic leaf diseases in their crops was not related to whether they employed an agronomist (\( p > 0.05 \)). The frequency of crop inspection had no impact on whether the correct identification was made (\( p > 0.05 \)). There was no correlation between crops grown and the ability to identify the leaf diseases (\( p > 0.05 \)). Age and length of time working did not correspond with the ability to correctly identify the three leaf diseases (\( p > 0.05 \)).

<table>
<thead>
<tr>
<th>Year data collected 2008</th>
<th>Year data collected 2014</th>
<th>Mann Whitney U</th>
<th>Z</th>
<th>Significance* (p)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Karnal bunt</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grower</td>
<td>0.75</td>
<td>0.75</td>
<td>843</td>
<td>–2.598</td>
</tr>
<tr>
<td>Agronomist</td>
<td>0.75</td>
<td>0.75</td>
<td>218</td>
<td>–2.405</td>
</tr>
<tr>
<td>Total (n)</td>
<td>46</td>
<td>77</td>
<td>154</td>
<td>–0.811</td>
</tr>
<tr>
<td><strong>Khapra beetle</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grower</td>
<td>0.625</td>
<td>0.625</td>
<td>216.5</td>
<td>–0.578</td>
</tr>
<tr>
<td>Agronomist</td>
<td>0.625</td>
<td>0.625</td>
<td>154</td>
<td>–0.811</td>
</tr>
<tr>
<td>Total (n)</td>
<td>33</td>
<td>41</td>
<td>154</td>
<td>–0.811</td>
</tr>
<tr>
<td><strong>Barley stripe rust</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grower</td>
<td>0.875</td>
<td>0.75</td>
<td>1778.5</td>
<td>–2.489</td>
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<tr>
<td>Agronomist</td>
<td>1.00</td>
<td>0.75</td>
<td>366.5</td>
<td>–2.682</td>
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<tr>
<td>Total (n)</td>
<td>48</td>
<td>96</td>
<td>192</td>
<td>–2.682</td>
</tr>
<tr>
<td><strong>Russian wheat aphid</strong></td>
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<tr>
<td>Grower</td>
<td>0.625</td>
<td>0.625</td>
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<td>–1.531</td>
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<tr>
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<td>0.625</td>
<td>162.5</td>
<td>–1.202</td>
</tr>
<tr>
<td>Total (n)</td>
<td>21</td>
<td>23</td>
<td>71</td>
<td></td>
</tr>
</tbody>
</table>

* "p" indicating the level of significant difference between the data in 2008 and 2014.
Education level influenced the ability of participants to identify blackleg in canola correctly; 56% of participants with a university education identified blackleg of canola correctly while 20% of participants with secondary schooling and 24% of participants with VET could correctly identify blackleg ($x^2 (2, n = 247) = 8.631$, $p \leq 0.05$). There was a correlation between gender and disease identification; 61% of males correctly identified blackleg of canola while 83% of females correctly identified this disease ($x^2 (1, n = 244) = 7.131$, $p \leq 0.05$).

A significantly higher proportion of participants from WA (88%) were able to identify powdery mildew in barley compared to participants from EA (76%) ($x^2 (1, n = 240) = 6.268$, $p \leq 0.05$) (Fig. 3). The reverse occurred in the identification of stripe rust on wheat; 72% of participants from WA correctly recognised this disease compared to 88% of participants from EA ($x^2 (1, n = 240) = 9.61$, $p \leq 0.05$). There was no difference between WA and EA participants in their ability to identify blackleg of canola. However, less than 65% of participants correctly identified blackleg of canola overall (Fig. 3), despite it being a very common endemic disease in canola crops across Australia.

Many of the growers and agronomists selected symptoms and signs that were not associated with the four HPPs. For example, for barley stripe rust, 25% of agronomists selected insect feeding damage, and 42% selected pale green aphids. Other incorrect responses included bunted grain (20%), and pink grain (18%), and 20% of agronomists responded that they “don’t know”. In this example, 55% of growers selected the correct response of rust pustules in stripes on leaves while only 35% of agronomists selected this response.

### 3.3. Identification of the four main HPPs for the Australian grains industry

Many growers and agronomists participating in this survey did not answer the four questions on HPPs; they either left the answer blank or ticked “I don’t know”. The response rate (Table 2) varied from 77% ($n = 192$, barley stripe rust) to 24%, ($n = 61$, Khapra beetle), indicating the lack of knowledge of these HPPs.

Growers and agronomists did not differ in their knowledge of symptoms and signs associated with the HPPs ($p > 0.05$) considered except for Karnal bunt ($x^2 (4, n = 143), = 14.901$, $p \leq 0.05$). The percentage of agronomists able to select all of the correct symptoms from the list associated with Karnal bunt was 11.7%, while only 1.5% of the growers were able to correctly identify all of the symptoms associated with Karnal bunt (Fig. 4).

Knowledge of symptoms and signs for the four HPPs were the same for growers and agronomists in WA and EA ($p > 0.05$). The scores for the participants ranged from 0.375 to 1.0 for WA and EA respectively on the entomological HPPs. The participants’ scores for the two fungal HPPs were 0.625 and 1 for WA and EA respectively, indicating a greater level of knowledge by the participants of the symptoms and signs associated with the two fungal HPPs.

Neither gender, age nor education level of the growers and agronomists influenced the knowledge of symptoms and signs associated with three of the four HPPs ($p > 0.05$). However, the education level did influence knowledge of Karnal bunt ($x^2 (4, n = 143), = 14.901$, $p \leq 0.05$). Eighty percent of participants who had a university education identified all symptoms correctly compared to only 20% of those who had completed VET.

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#### 3.3.1. Comparison of data from 2008 to 2014

The knowledge levels of both growers and agronomists differed between the surveys conducted in 2008 and 2014 ($p \leq 0.05$) on the symptoms associated with Karnal bunt and barley stripe rust (Table 2). There was no difference between the median scores of growers and agronomists for Karnal bunt between the two surveys conducted in 2008 and 2014 (Table 2). However, there was a difference between the range of scores between 2008 and 2014 (Fig. 5). The knowledge of the symptoms associated with barley stripe rust by growers and agronomists decreased between the surveys conducted in 2008 and 2014 (Fig. 5 and Table 2).

The median scores (0.625) for growers and agronomists were the same for the entomological HPPs and did not change between 2008 and 2014 (Fig. 5). However, the range of scores varied between 2008 and 2014.

### 3.4. Awareness and usage of diagnostic services

Awareness and usage of the relevant diagnostic services within Australia differed between growers and agronomists (Fig. 6). For example, 40% of agronomists used state diagnostic services 1 to 3 times within the last 12 months while only 20% of the growers used the service in the same time period ($x^2 (3, n = 235), = 33.63$, $p \leq 0.001$). The majority of growers (84%) and agronomists (95%) were aware of the services. For each of the six different diagnostic services, the majority of growers (40–60%) did not submit any crop samples for analysis.

PestFax/PestFacts were the most widely used diagnostic services by agronomists and growers (Fig. 6) with 30% of growers and agronomists submitting at least one report and 48% of agronomists submitting more than four reports in the last 12 months ($x^2 (3, n = 241), = 14.44$, $p \leq 0.05$). A similar observation was made for the influence of education on the use of the PestFax/PestFacts diagnostic services; 27% of participants submitted at least one report and 40% of those who had completed university studies submitted more than four reports in the last 12 months ($x^2 (6, n = 241), = 19.05$, $p \leq 0.05$).

There were no significant differences ($p > 0.05$) between the proportion of growers (36%) and agronomists (32%) who were

![Fig. 3. Percentage of participants located in Eastern or Western Australia who correctly identified the three common endemic leaf diseases in the training needs analysis. The percentage of participants were significantly different at $p \leq 0.05$.](image-url)
unaware of the National Exotic Plant Pest Hotline. Education level influenced use of the National Exotic Plant Pest Hotline; 10% of participants who had completed VET used the service to a greater extent than did participants who had a secondary school or university education ($\chi^2(4, n = 232) = 15.68, p < 0.05$), which was less than 1%. Regardless of education level, 60% of the participants did not submit any samples, while more than 64% of the participants were aware of the service.

Gender and age did not influence the usage or awareness of the six diagnostic services within Australia ($p > 0.05$).

4. Discussion

4.1. Demographics

The demographics collected in our survey indicated that the data collected from participants represented the grains community in Australia very well. The grains industry is a male dominated field and this has not changed over time. In our study, males were the majority of growers and agronomists (87% and 78% respectively). These data are similar to those collected by the ABS; 72% of the farming population were male (Australian Bureau of Statistics (2012)). GRDC conducted a survey of growers in 2013 and found 93% of growers were male and 78.6% of agronomists were male (Watson and Watson, 2014).

The majority of growers had no educational qualifications beyond secondary schooling in this study, which aligns with the ABS data from 2012. However, there is a trend towards formal qualifications as the operations of a farm business become more complex (Australian Bureau of Statistics (2012)).

Growers tend to be part of an ageing workforce; the median age of Australian farmers is 53 years (Australian Bureau of Statistics (2012)); 55% respondents from the GRDC survey were in the 40–59 years of age category (Watson and Watson, 2014) and in our study 42% were older than 51 years of age. Agronomists tend to be younger than growers; for the GRDC survey 55% were aged between 18 and 39 years of age (Watson and Watson, 2014) and in our study 25% were less than 30 years of age.

4.2. Identification of leaf diseases

This is the first training needs analysis of growers and agronomists within the grains industry of Australia. The benchmark for our survey, that 70% of growers and 80% of agronomists should be able to identify common leaf diseases in their crops were met except growers did not meet this benchmark for blackleg in canola. It is important that growers and agronomists have a good knowledge of endemic diseases in their crops, so they can recognise and report symptoms that are different from those caused by endemic pests. This is a vital role in ensuring Australia’s grain industry detects and eradicates or contains emergency plant pests and pathogens (Plant Health Australia, 2015).

The different skill levels of participants in the survey from Western and Eastern Australia in their ability to identify leaf disease was not unexpected because the incidence and severity of these leaf diseases varies across Australia. For example, Murray and...
Brennan (2009a) demonstrated that the proportion of crop area affected by powdery mildew of barley was 40% for EA and 100% for WA respectively. Stripe rust of wheat has the potential to affect 80% of the area planted in EA and 60% in WA (Murray and Brennan, 2009b).

Our study showed that the ability of growers and agronomists to recognise blackleg on the leaves of canola was significantly lower than for the two other leaf diseases. The disease blackleg is prevalent throughout Australia. There is very little difference between the proportions of crop area (93% and 99%) in EA and WA respectively, affected by blackleg of canola (Murray and Brennan, 2012). The lack of recognition of blackleg is of concern, and may be due to the focus of published material on stem cankers and not leaf symptoms in the crop. This lack of recognition also highlights that further training in the recognition of blackleg is required to reduce the possibility of the disease being mistaken for white leaf spot (Mycosphaerella capsellae) as the symptoms are similar and can be confused.

The influence of education in correctly identifying diseases was evident for blackleg of canola. There was a significant difference between growers and agronomists in their ability to correctly identify blackleg of canola. In our survey, there is a correlation between education level and occupation of the participants; agronomists had completed university studies while most farmers had not completed university studies. This may explain why the agronomists met the benchmark for identification of blackleg as they had received more training. Mangano et al. (2011) demonstrated professional experience influenced the ability of participants in recognition and detection of the fictitious high priority pests created for use in their study.

Kunda et al. (2008) reported when knowledge (transmission, clinical features, and diagnosis) of a zoonotic disease in humans is low (<50% correct) reporting of that disease is low and it can remain undiagnosed or be misdiagnosed. This would impact severely on the control of a disease. Although this research on awareness of zoonoses within local communities and medical practitioners was done in Africa, the concepts are similar to those necessary for dealing with plant pests and pathogens. It is essential that participants within the grains industry are able to recognise symptoms of common endemic diseases within their crops. Hammond (2010) and Martin et al. (2015) have both shown that ‘disease awareness’ influences the probability of a HPP being detected both in the plant and animal industry. The recognition of HPPs in our study was low; consequently it is anticipated that reporting of these HPPs will then be low.

### 4.3. Identification of the four main HPPs for the Australian grains industry

Knowledge among growers and agronomists of the symptoms and signs of the top four HPPs in the grains industry was well below the level perceived by members of Plant Health Australia and the GrainGuard Committee in Western Australia. This lack of knowledge was demonstrated by the large number of participants who selected “don’t know” as the answer to the questions, which lead to a decrease in the number of participants (n ranged from 71 to 192).
who were willing to answer these questions compared to the number of participants (n > 240) who answered the questions on endemic leaf diseases. Hammond et al. (2016a) demonstrated there was a significant decrease in the number of participants who were willing to answer the four HPP questions compared to the number who answered the rest of the survey.

The results from our survey showed that demographics gender, education and age of growers and agronomists did not influence knowledge of symptoms and signs associated with the HPPs considered. However, occupation and education did influence the knowledge of symptoms associated with Karnal bunt. This result is not surprising as there is a correlation between the education level and occupation of the participants as shown in the data collected in our survey.

This survey demonstrated that the median agronomists’ knowledge level of barley stripe rust symptoms decreased from 1.00 in 2008 to 0.75 in 2014. This knowledge level should not have decreased as the symptoms of barley stripe rust on barley are very similar to the symptoms of wheat stripe rust on wheat; yellow pustules in stripes along the length of the leaves. The awareness and knowledge level decrease may be due to agronomists having not seen stripe rust of wheat for six years in Western Australia, which had occurred on a regular basis from 2000 to 2009 in WA. The disease did not occur at a yield limiting level in crops again until 2015 (https://www.agric.wa.gov.au/diseases/pestfax-map). For this disease to reoccur after six years indicates that the pathogen was present in crops at a low level or had been misdiagnosed as leaf rust. Another concern is that only 20% of the agronomists correctly identified the symptoms associated with the disease, although 40% correctly recognised the most conspicuous symptom “rust pustules in stripes on leaves”. In the identification of leaf diseases section of our survey, 90% of agronomists correctly identified stripe rust of wheat (Fig. 2), which suggests that a similar number should be able to identify barley stripe rust should it occur. However, this was not the case. Our results from this survey support the work done by other authors that showed that poor knowledge and awareness of symptoms of pathogens can lead to a misdiagnosis of diseases (Bagamba et al., 2006; Hammond, 2010).

Our results from this study indicate that the current methods used to provide information and training to the grains industry participants is not effective. Knowledge and awareness of diseases and pests in crops is dependent upon the extension and training programs used with growers (Bagamba et al., 2006; Levy, 2005; Yang et al., 2008). Information on HPPs in the Australian grains industry is available to all participants through fact sheets and other reading material available from their local grain biosecurity officers (Plant Health Australia, 2015). These officers promote on farm biosecurity and run information booths at local field days. The results from this study’s questions on HPPs indicates that the information is not being taken up by the growers and agronomists, and therefore the method of knowledge transfer needs to be redesigned. In the survey conducted by Hammond et al. (2016a) only 10% of respondents had attended a course focused on the recognition of HPPs. The group in the (Hammond et al., 2016a) study consisted mainly of growers (80%) and the rest were state departmental staff. No agronomists had attended training in this area. Thus the redesign of material on the recognition of HPPs may need to include hands on training, the use of videos and podcasts through social media and web-based training. The sources from which growers and agronomists seek information are a related and
ongoing investigation. The effectiveness of social media as a method to increase awareness and knowledge levels will be assessed in the future.

4.4. Use and awareness of the diagnostic services

The usage and awareness of diagnostic services were investigated, as these services are vital for providing information and data for general surveillance (FAO, 2011). In our study, although the majority of agronomists and growers (95% and 84% respectively) were aware of the services, only a few used the services. Hammond et al. (2016b) and Martin et al. (2015) demonstrated reporting systems and samples submitted to diagnostic services rely upon participants within the industry being able to differentiate between endemic pests and ‘unusual’ pests. Our study showed that growers used diagnostics services less frequently than agronomists and in most cases, except for GrainGuard, were unaware of available diagnostic services.

In our survey, less than 5% of growers and agronomists used a diagnostic service, and the majority of growers and agronomists were unaware available services. The earlier survey conducted in 2008 by Hammond et al. (2016b), similarly showed that the majority of growers and agronomists were unaware of diagnostic services.

In our survey, PestFax/PestFacts were the most frequently used diagnostic services by agronomists. Growers and agronomists were more aware of this service than the other services. The survey conducted in 2008 by Hammond et al. (2016b) had very similar results; that Western Australian respondents were most familiar with PestFax (42.6%), compared to other services available within Western Australia. A possible reason for these services being used more frequently is that they are an interactive service allowing agronomists and growers to send in reports and have them confirmed rapidly through a weekly newsletter sent out to subscribers.

Awareness of the National Exotic Plant Pest Hotline increased from 36% in 2008 (Hammond et al., 2016b) to 70% in 2014. The lack of awareness in 2008 and the lack of usage were most likely due to the service being newly introduced, and a lack of trust by growers (Hammond et al., 2016b).

The use of diagnostic services by growers and agronomists is variable and is very much related to the growing conditions and the presence of pests and diseases in crops in the current season. Climatic conditions in 2013 during the growing season (April–October) in Western Australia were not conducive to high levels of disease being present in crops (G. Thomas pers. Comm 2016) This would explain the small number (<30%) of growers who used a diagnostic service during 2013. These services are vital, as they provide a general surveillance service and are usually the first to detect a biosecurity pest or disease. The lack of awareness of some of these services, such as GrainGuard indicates that promotion of their existence would be beneficial.

5. Conclusion

The Australian grains industry relies upon growers and agronomists to be aware of pest and diseases in their crops and to notify their local State Departments of Agriculture if they see something unusual which may be an incursion of a high priority pest. This study’s training needs analysis showed that growers’ and agronomists’ abilities to identify endemic diseases in grain crops met the benchmarks set for this survey (70% growers, and 80% agronomists). However, their knowledge and awareness of symptoms associated with HPPs did not meet these benchmarks. This indicates that further training in the knowledge and recognition of HPPs is required. In general, age and gender were not related to knowledge level or identification skills of growers and agronomists. However, education levels and occupation of the participants did influence knowledge and identification skills within the industry. The diagnostic services within Australia are an important tool for general surveillance activities, and the availability of these services needs to be promoted so that there is an increase in the awareness and usage of these services amongst growers and agronomists.

Conflicts of interest

Ms Dominie Wright and Nichole Hammond are employed by the Department of Agriculture and Food, Western Australia.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.cropro.2016.07.005.

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