Assessing the “user-friendliness” of biopesticides and their conventional pesticide counterparts: A “proof-of-concept” framework for comparing pesticide groups

T.M. Stewart¹, T. Ramilan¹ and F. Yu²

¹ Massey University, Tennent Drive, Palmerston North 4474, New Zealand

² New Channel, 22 Storey, Huali Building, No.28, Heping North Street, Heping District, Shenyang, Liaoning, China

Corresponding author: t.stewart@massey.ac.nz

Abstract Biopesticides have a number of positive attributes compared with conventional pesticides but direct comparisons are difficult to achieve objectively. Therefore, an indexing method was developed and used to compare the user-convenience and flexibility of spray-applied biopesticides commercially available in the New Zealand with similar conventional pesticides. Relative efficacy was not assessed. Biopesticides scored higher than conventional pesticides when all parameters were considered, particularly for the major fruit crops. Biopesticides had significantly shorter withholding periods, required less resistance management, seldom needed an approved handler, and were registered for more crops than conventional pesticides. However, they were less compatible with other products and some required special storage conditions. There was little difference between the two groups regarding bee toxicity, target range and adjuvant requirements. The methodology used here could potentially be used to compare any individual pesticides or pesticide groups pertaining to a particular measure of interest.

Keywords biopesticides, pesticide comparisons, grower-friendliness, usability, indexing, analytical framework.

INTRODUCTION

Biopesticides, in their broadest sense, are products derived from activities of an agent of natural origin that limit the impact of weeds, pests and pathogens on plants (Glare 2015). While there is no strict definition of the term, the most widely accepted definition comes from the United States Environmental Protection Agency (USEPA) where biopesticides are broken into three groups (United States Environmental Protection Agency 2017). These are: (i) microbial pesticides, where the active ingredient is a microorganism; (ii) plant-incorporated

protectants (PIPS), where genetic material has been added to a plant to produce pesticidal substances; and (iii) biochemical pesticides, which are naturally occurring substances that control detrimental organisms by non-toxic means such as pheromones along with some plant extracts.

Positive features of biopesticides include a lack of persistence in the environment and very low toxicity to non-target organisms. When used on food crops, this translates into either very short withholding periods or none at all.

These products are considered “environmentally friendly” and, as such, can be important tools in integrated pest management (IPM) programmes and sustainable food value chains.

Some biopesticides have a unique niche, such as semiochemicals, many of the *Trichoderma* species used for pathogen biological control, and those applied to soil as growth promoters. However, most are foliar sprays that are used very much like, and compete in the marketplace with, conventional pesticides. Despite their benefits and much research activity over the last 30 years, there are still far fewer biopesticide products compared with their conventional counterparts. For example, 49 biopesticide products were registered for use in New Zealand in 2015 (O’Callaghan et al. 2015). In contrast, over 1000 conventional pesticide products were available that same year (T Stewart, unpublished). There are many reasons for the low numbers of biopesticides, including lower or less reliable efficacy, production difficulties and a more fragmented marketing and customer support infrastructure compared to comparable conventional pesticides. These factors are important from a user’s perspective and, together with price, availability, and export market restrictions, they may influence user choice between a biopesticide or an alternative compound. However, other factors may also have a bearing. For example, key factors for those biopesticides that are applied as sprays are ease of storage and application, and their flexibility as part of an overall management programme compared with conventional products. These factors translate to: whether or not an approved handler is required; whether specific storage conditions are needed for the product; the requirement for an adjuvant for application; toxicity to bees (and other beneficial organisms); the ability to tank mix with other chemicals; whether or not resistance management guidelines restrict use; withholding periods required and how many targets and crops the product can be used on.

Individual biopesticides will differ in these properties. However, it is illuminating to compare and contrast the user-convenience and flexibility

of biopesticides with those of conventional pesticides, for those that are applied as above-ground sprays. As a whole, is one group better than the other in this regard and by how much? To answer this question, examples of each group were scored for various attributes pertaining to user-convenience and flexibility, and the results compared using charts and an indexing system.

Note that compounds with a direct neurotoxic action such as the spinosoids and avermectins were not considered biopesticides for this research. Also, mineral oils, copper and sulphur fungicides along with streptomycin were regarded as conventional pesticides. Bioherbicides were not considered.

MATERIALS AND METHODS

Data collection and scoring

Data relating to different pesticide products were obtained from the 2015 edition of the New Zealand Novachem Agrichemical Manual during the first half of 2016. Products were classified into two groups and loaded into a spreadsheet. The first group included biopesticides that targeted pests or pathogens and could be applied as “sprays” to the above-ground parts of edible crops. Products designed for inundative or long-term release of live arthropod predators or parasites were excluded as were semiochemicals, “plant promoters” designed to be applied to soil, products for trunk injection and products registered for crops not grown for human consumption, such as ornamentals, where withholding periods are unnecessary.

The second group included all conventional pesticide products (either with a single active ingredient or mixtures) that targeted the same problem in the same crops using same mode of application. In essence, they were the direct competitors to the biopesticides selected.

Nine attributes pertaining to convenience and flexibility from a user’s perspective were attributed to each unique formulation per crop and scored using numeric, ordinal or categorical values. The attributes and possible scores are shown in Table 1. The higher the values the more convenient and flexible the product.

Table 1 Product attributes pertaining to user-convenience and flexibility and their possible scores.

Attribute	Possible Score
The necessity for an approved handler	Yes = 1, No = 2
Whether or not the product is toxic to bees	Yes = 1, No = 2
Whether or not refrigeration was needed for storage	Yes = 1, No = 2
Whether or not resistance management was advised	Yes = 1, No = 2
Whether the product was compatible or not with other pesticides in a tank mix	Cannot be used with other products = 1, Compatible with some products = 2, Compatible with most products = 3
The need for an adjuvant	Needs adjuvant = 1, Recommended = 2, No requirement = 3
Withholding period	Long (> 14 days) = 1, Medium (4–14 days) = 2, Short (0–3 days) = 3
Number of crop groups the product could be used in	An integer representing one or more of: avocado, berryfruit, pipfruit, citrus, edible glasshouse crops, grapes, kiwifruit, onion and garlic, pipfruit, stonefruit, strawberry, outdoor tomatoes, vegetable brassicas, cucurbits
Target pests or pathogens	An integer for the number of targets in each crop group above

These attributes were obtained from entries in the New Zealand Novachem Agrichemical Manual, and cross-checked with reputable web sources if the information appeared unclear. The need for an adjuvant, withholding period and target pests or pathogens differed depending on the crop group. Only products that could be applied when bees were foraging in a crop were considered non-toxic to bees.

Individual formulations that were sold as different brands by different companies but were otherwise identical in all attributes above, were counted as a single unique formulation for the purposes of this research.

Data analysis

The scores for each of the five crop-independent attributes listed in Table 1 (first five rows) were counted separately for the two groups (biopesticides and conventional pesticides) so

that the relative proportions of these scores could be compared. Similarly, the relative proportions of the crop-dependent attributes were also compared. In the latter case, the basic unit for analysis was the unique formulation in a particular registered crop. For example, if a pesticide was used in pipfruit, grapes and kiwifruit, then the crop-dependant attributes would be recorded three times, one for each crop.

A more in-depth approach to compare biopesticides and conventional products was also used that involved taking all nine convenience and flexibility attributes, scaling then aggregating them into a number of composite indices whose values ranged from 0 to 10.

Calculations for the composite indexes

The indexing technique is similar to that used by Gomez-Limon & Sanchez-Fernandez (2010). The raw scores were first normalised to produce

indicators within a dimensionless range (0, 1), where 0 corresponds to the worst possible value (in this case the least user-friendly or flexible) and 1 is the best (i.e. the most user-friendly or flexible). Normalisation is a standard procedure when there are multiple variables across different scales as in this case.

The formula for normalisation is:

$$x'_{ai} = \frac{x_{ai} - \text{Min}(x_a)}{\text{Max}(x_a) - \text{Min}(x_a)}$$

where

x'_{ai} - Normalised score of an attribute for each unique pesticide formulation i , with i being a unique pesticide formulation used in a particular crop group.

x_{ai} - Score of an attribute for each unique pesticide formulation in each registered crop group

As the relative importance of each attribute may differ, the analytical framework used was built to be robust enough to accommodate these uncertainties by adding a weighting feature to each attribute. A weighting reflects the fact that some attributes could be more important to users than others, and hence allows for a more precise comparison. Equal weightings were used with each attribute for calculating the primary results reported in this study. However, as the relative importance of these attributes can vary across wide spectrum of people, a small pilot study using variable weightings was carried out as a proof-of-concept exercise. Five people at Massey University familiar with crop production and pesticide use (key informants) were asked to compare the nine attributes in terms of their contribution to user convenience and flexibility by assigning a real number value between 0 and 10 based on rational preferences. However, the sum of the values they proposed for all attributes must equal 10. To assist with the task, key informants typed their values into a provided spreadsheet which allowed them to see a running total. Provisional values were entered, then adjusted

in relation to one another until the total equalled 10 and participants were satisfied that relative distance between values reflected their perceived worth relative to one another. The average weights were then derived for each attribute.

Composite indices for all biopesticides and all conventional pesticides in the study were calculated from these normalised scores and weightings using the following formula.

$$CI_i = \sum_{a=1}^n (wt_a * x'_{ai})$$

CI_i - Composite index for pesticide i , with i being a unique pesticide formulation used in a particular crop group.

n - number of attributes (9)

wt_a - Weighting for each attribute

Once calculated, composite indexes were used to produce various comparative statistics. Averaged composite index scores were compared for significance using Welch's t-test, sometimes called the unequal variances t-test (Ruxton 2006). This test is more reliable than the Student's t-test when the two samples have unequal variances and unequal sample sizes, as in this case.

RESULTS

Comparison of user-convenience and flexibility attributes

The 21 unique biopesticide formulations identified were registered in an average of 3.3 crop types and the 96 unique conventional pesticide formulations were registered in an average of 2.6. Both groups averaged around 2 target species each. By far the majority of conventional pesticides (81%) required an approved handler for application, in contrast to 24% of the biopesticides (Figure 1a). The proportion of each group showing bee toxicity was equal at 33%. Two of the biopesticide products required storage at low temperatures but none of the conventional pesticides required it. Seventy-eight percent of the unique conventional pesticide formulations available came with

Figure 1a A comparison of non-crop related user-convenience and flexibility attributes of above-ground spray-applied biopesticides versus their conventional counterparts.

Figure 1b A comparison of crop-related user-convenience and flexibility attributes of above-ground spray-applied biopesticides versus their conventional counterparts.

guidelines regarding resistance management. This is in contrast to 9.5% of the biopesticides (namely *Bacillus thuringiensis* and kasugamycinas).

Compatibility was more of an issue for biopesticides. Only 48% of biopesticides were very compatible compared to 83% of conventional pesticides. Twenty-eight percent of biopesticides had some compatibility compared to 11% of conventional pesticides and 24% of biopesticides could only be used alone compared to 6% of conventional pesticides.

Scores for the crop-dependant attributes are shown in Figure 1b. Adjuvant requirements were somewhat similar between the two groups. As expected, most (96%) of biopesticides had withholding periods of three days or less compared with only 46% of conventional pesticides.

Composite index scores (equal weightings)

Averaged composite index scores using equal weightings are shown in Table 2.

Table 2 Averaged composite index scores ($\pm$ SD) calculated with equal ratings for above-ground spray-applied biopesticides versus their conventional counterparts

Type of pesticide	Averaged composite index scores
Biopesticides (n=57)	6.80 (1.08)
Conventional (n=254)	5.30 (1.25)

n = sum of all unique formulation-crop combinations

The scores for biopesticides were 1.5 points higher ($P < 0.01$) showing them to be, as a whole, more convenient and flexible than conventional products, although the difference was small in the context of the index range. However, box plots of these scores (Figure 2) showed that some biopesticides were not particularly convenient or flexible to the user as shown by the long bottom whisker in this group. An example would be kasugamycin, which at the time of the study was only registered against PSA (*Pseudomonas syringae* pv. *actinidiae*) in kiwifruit. It had a long withholding period, could not be applied when bees were working in the crop, required an approved handler, and required resistance management. Conversely, some conventional pesticides were very convenient and flexible

particularly fungicides. Thiram for example, was registered for use in 3 of the crop groups for 2 or 3 targets, required no adjuvant in those crops, was safe to bees, had a short or medium withholding period, was compatible with most other products and required no special storage or resistance management plan.

Calculating average index scores for pathogen and pest-active pesticides highlighted two issues (Figure 3). Firstly, biopesticides targeting pathogens were less convenient and flexible than those targeting pests. Secondly, pest-targeted biopesticides had a much higher score (7.3) than pest-targeted conventional pesticides (5.0) in the attributes measured. Also the distribution of scores for biopesticides in the pest-targeted group was less skewed than those targeting pathogens.

Figure 2 Box plots for averaged composite index scores for above-ground spray-applied biopesticides versus conventional pesticides. Numbers in the boxes represent the sum of unique formulations x crop types they are registered in.

Figure 3 Box plots for averaged composite index scores for above-ground spray-applied biopesticides versus conventional pesticides for those targeting pathogens or pests. Numbers in the boxes represent the sum of unique formulations x crop types they are registered in.

Separating out the indexes by crop (Figure 4), it can be seen that averaged scores differ markedly. These results need to be interpreted carefully as there is only one biopesticide available in some cases (for cucurbits and stonefruit). It can be seen that biopesticides rate higher in overall user-friendliness and flexibility except for use on strawberries. This is certainly the case for the three major fruit crops (grapes, kiwifruit and pipfruit) where there are a number of biopesticide options available.

Composite index scores (key-informant derived weightings)

The average weightings for each attribute considered, as determined by the five key-informants, are shown in Table 3.

Given the limited “proof of concept” nature of this part of the research, only the averaged composite index scores are reported (Table 4).

The results (bottom left) show a significant difference between the groups ($P < 0.01$) and are similar to the composite indexes derived using the equally weighted values.

DISCUSSION

Indexes and comparative scores have been developed for rating, ranking and comparing pesticides for a variety of purposes based on a number of parameters and may be used to inform pesticide choice in IPM programmes or policy development (Kovach et al. 1992; Penrose et al. 1994; Walker et al. 1997; Kookana et al. 2005).

Table 3 Averaged key-informant derived weightings ($\pm$ SD) for nine attributes pertaining to user-convenience and flexibility of pesticides

Attributes	Averaged Weightings
The necessity for an approved handler	0.2 (0.23)
Whether or not the product is toxic to bees	1.6 (0.87)
Whether or not refrigeration was needed for storage	1.0 (1.11)
Whether or not resistance management was advised	1.6 (0.46)
Whether the product was compatible or not with other pesticides in a tank mix	1.0 (0.66)
The need for an adjuvant	0.4 (0.48)
Withholding period	1.4 (0.44)
Number of crop groups the product could be used in	1.7 (0.93)
Number of target pests or pathogens	1.1 (0.63)

Table 4 Averaged composite index scores ($\pm$ SD) calculated with key-informant derived weightings for above-ground spray-applied biopesticides versus their conventional counterparts

Type of pesticide	Averaged composite index scores
Biopesticides (n=57)	6.58 (1.04)
Conventional (n=254)	5.22 (1.38)

n = sum of all unique formulation-crop combinations

Figure 4 Box plots for averaged composite index scores for above-ground spray-applied biopesticides versus conventional pesticides arranged by crop. Numbers in the box plots represent the number of unique formulations.

However, the current study is the first known example where user-convenience and flexibility has been the basis of a comparative index. The results obtained here show that, in general and when scored together as a group, biopesticides do appear to outperform conventional pesticides in terms of convenience and flexibility, particularly the ones targeted at arthropod pests.

As explained in the method, user-ranked weightings can make these comparisons more robust, by taking into account the relative importance of the attributes being measured. Our results in regard to variable weightings should be seen as a proof-of-concept exercise only. The number of key informants was small and the respondents scored their ranking for pesticide use generally rather than specifically. In reality, not only would a lot more “users” need to be sampled but, the relative importance of the assessed attributes is likely to depend on the crop concerned. For example, an export pipfruit grower may feel the ability to tank mix a product to be important as single chemical application for a variety of pests and pathogens is common. On the other hand, a grower of fodder brassicas may only be concerned with caterpillar pests, so tank mixes would be uncommon. Each would rank the property of compatibility differently. The same could be said for bee toxicity. In this context indices incorporating user-derived weightings would be more suited to comparison of pesticide groups within crops rather than overall.

It should be mentioned that not all attributes that contribute to user-convenience and flexibility were examined. One such attribute was rainfastness and another was the level of agitation or premixing required. Further work is required to include these attributes as relevant information is not readily available from the New Zealand Novachem Agrichemical Manual.

Despite its limitations, this study brings into focus key differences between two groups of pesticides in the context of user convenience and flexibility. It also provides a methodology for calculating composite indexes for comparing any group of pesticides, against any other group or even individual products using a range of aggregated, weighted properties within a general theme.

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