How do new molluscicide products perform in wet conditions

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Key words

canola establishment, crop protection, integrated pest management, slugs, baits

GRDC codes

DAS 00127 & 00134, MAN2204_001SAX

Take home message

"To manage we must understand."

To prepare for next season's threats, the pest's biology needs to be understood when they are breeding. For slugs, wetter and longer springs extend their breeding period, leading to greater numbers that survive over summer. Summer rainfall is not a good indicator of potential slug threats.

Management needs to choose appropriate crop protection tools based on the context in which they are to be applied. For slugs, late autumn rainfall determines what level of damage occurs: that is, a greater proportion of slugs are active the wetter it is and the slower the crop emerges.

The best product applied at the wrong time will result in poor outcomes. Choose the product based on the context in which it will be applied.

Background

Slugs are particularly damaging to establishing canola, with yield losses in untreated areas of experiments at 60%-80% (GRDC DAS00134 data). One way to estimate the cost of slugs is expenditure on molluscicide baits, which continues to increase in Australia. Bait costs are $30-$120/ha with 95% of canola in the high rainfall zone (>500mm annual rainfall) of western Victoria sown into burnt and/or cultivated ground. Where slugs are a high risk, some growers have shifted away from growing canola, especially where they cannot implement strategic burning and cultivation. That lost opportunity cost is estimated upwards of $270 million annually to the canola industry. A 5% production loss by slug and snail activity would represent a loss of more than $82 million to the Australian canola industry (2012 values).

Slug baits applied at crop establishment are protectants. Cultural methods are required to reduce populations along with the biological function of farming systems (Nash & Pilkington 2016). Baits often perform badly and must be re-applied due to field degradation and/or pest populations not actively feeding.

Slug bait technology has improved past the traditional bran-based dry processed pellets. The need to improve delivery of active ingredients to increase the number of slugs killed, while reducing environmental impacts, has seen the launch of new products with enhanced delivery systems for old active ingredients, resulting in greater return on investment due to a reduction in the kg/ha of product required. For example, new formulations of metaldehyde products kill a greater number of slugs, using less active ingredient under a broader range of conditions.

Industry research continues to focus on improving bait performance. However, the focus by some manufacturers on small pellets to increase the chance of encounter and/or harder pellets to increase rain-fastness may have also increased the chance of delivering sub-lethal doses of metaldehyde. This hypothesis needs testing relevant to Australian conditions.

Previous research (Nash *et al.* 2016) indicated some products commonly used have a limited field life; with the short-window, bran-based metaldehyde products lasting less than 2 weeks; thus, these need to be applied regularly. More expensive, long-window metaldehyde products will last 3-4 weeks when ground temperatures are below 50°C. Temperature, not UV light, reduces the efficacy of metaldehyde baits.

Rainfall not only physically breaks down bran pellets: it causes a reduction in the number of slugs or snails killed (Table 1 Nash *et al.* 2016). Reduction of active ingredient by rainfall (metaldehyde and iron chelate) is the most important factor influencing field life of a product due to individuals being likely to consume a sub-lethal dose. Previous research recommended not to use iron chelate baits when >10mm rain is expected. However, robustness of these baits has recently been improved by the manufacturer.

All products may perform differently to manufacturer claims due to being 'rain-fast'; which is not the same as efficacy after rainfall. That is, hard pellets maintain integrity after rainfall whereas bran-based products do not; yet pellet integrity was found not to influence mortality. In this paper we present data on efficacy of products after exposure to rainfall, not 'rain-fastness'.

Data comparing physical characteristics of commonly available slug bait products (Table 1 Nash 2022[a] Slug Control Fact Sheet) indicates different products have various attributes which differ and influence field performance.

The overall aim of research presented in this paper is to improve decisions on bait applications due to differences in the field life of some products and the variable feeding of the targets; i.e., slugs and earwigs are not always active, thus do not always feed on baits. This paper combines the principles behind improving bait efficacy (Nash 2022[c]) with research on bait degradation. Laboratory assays were used to test causality of factors thought to effect field life, not compare mortality. Field trials and observations are used to support findings presented.

Slugs and other establishment pests can be controlled in no-till, full-stubble systems once growers understand the context of where and when controls are applied and follow a few basic guidelines. Bait needs to be applied when target pests are active and feeding, with the timing varying depending on paddock and seasonal conditions and the species present.

Methodology

Product field life (efficacy after exposure) was determined initially using field cages then laboratory assays run at 22°C ± 1°C, 80-100% RH (Relative Humidity) using field-collected Italian snails (*Theba pisana*). Bait products were weathered by spreading approximately 50g of each on the surface of soil (Warooka red loam) in large planter trays (400 x 300 x 120mm). Trays were placed on benches in an exposed position at Urrbrae, SA (2013-2015), Bairnsdale Vic (2017-2019), or Glen Osmond SA (2022). Baits were exposed to weathering for various intervals resulting in a variety of conditions. Initially, efficacy of three products was assessed by exposing them to weather at 10 day intervals over 0 – 40 days, then comparing different time periods. Then experiments focused on one factor, rainfall, for subsequent results presented in this paper, either exposed with or without rainfall at 14- or 28-day intervals. Rainfall data was collected in situ. All exposure details are provided with the results.

Field cages 2013: Cages consisted of round rings of 15cm wide flat galvanised metal sheeting formed into a 50cm diameter ring giving an enclosed area of 0.2m^2. A black fibreglass insect screen was secured over the open 'top' with taut wire and reinforced cloth tape. After snails were introduced, the cages were secured to the ground with tent pegs and loose soil was pushed up against the edges to form a seal with the ground surface. Bait product and weathering period were randomly allocated to 72 cages (n = 4) containing only dry grass and some eucalyptus tree leaf litter. The site received dappled shade from nearby trees. Cages each received 4L water to moisten the soil prior to placement of eight bait pellets (arrayed in a ring around the central snail release point) and 30 snails.

After 24 hours, 0.5L water was applied to maintain snail activity. After 2-3 days, all snails were retrieved by hand from each cage and returned to the laboratory for mortality assessment.

Lab bioassay: Adult snails were used to test the efficacy of molluscicide baits once they had been exposed to the environment on soil. Five snails were added to each test arena with eight baits as soon as practicable following the completion of weathering periods (usually within one week). Baits were removed three days after initiation of the experiment due to the formation of mould, which was scored as present/absent, and the number and condition of pellets remaining recorded. Snail mortality was assessed 4-5 days after bait was removed. Bait consumption was quantified by drying remaining product at 45^{o}C once removed from arenas and prior to weighing. A subset of each product was used to calculate initial dry moisture content of pellets as the weight for each replicate used in assays was not a dry weight. Replicates varied per assay, with details provided with the results. All assays were fully randomised.

For a list of previously tested products see Table 1 (Nash *et al.* 2016), data is presented but note that some of those products may no longer be available or may have changed pellet properties.

Some changes to products commonly used metaldehyde in Australian broadacre and tested previously include: Metarex® and Metarex Micro® are no longer available, being replaced by METAREX INOV®. Meta® and Slugger® are no longer available, so have been replaced by Snailex as a bran-based product in more recent assays. Products commonly used in broadacre 2022:

Newly registered products: #APVMA Approval Number

- Axcela® Slug and Snail Bait, (2020-07-01) #87576 METALDEHYDE 30g/kg
- METAREX INOV® Slug and Snail Bait, (2020-07-01) #88160 METALDEHYDE 40g/kg
- IMATRADE TRANSCEND® Molluscicide and Insecticide, (2020-07-01) #88733 METALDEHYDE 50g/kg + 1.5g/kg fipronil
- IRONMAX Pro® Slug and Snail Bait, (2021-07-01) #89908 9g/kg Iron present as Iron Phosphate Anhydrous

Products with changed pellet characteristics since registered:

- IMATRADE METAKILL Snail and Slug Bait, #64990 METALDEHYDE 50g/kg
- ERADICATE Snail and Slug Killer, #68634 Iron EDTA Complex 60g/kg
- SlugOut® All Weather Slug and Snail Bait, #49324 METALDEHYDE 18g/kg
- Snailex Slug and Snail Pellets, #68580 METALDEHYDE 15g/kg

Existing products:

- Delicia® SLUGGOFF® lentils, #60931, METALDEHYDE 30g/kg

Results and discussion

What makes a good bait (adapted from Nash 2022[c])

For baits to work, some basic principles are relied upon.

Individuals must first encounter a pellet, which requires:

- Individual activity – slugs must be actively searching for food
- The number of baits to be distributed evenly – pellets/m^2. Pellets need to be evenly applied across the full width of application. Consistent pellet size, weight and density ensure no area is missed. Patchy control can occur when products with high variability are used and/or application equipment is not calibrated
- Attractiveness of bait – individuals display non-random movement towards attractive pellets (true definition of bait). For example, grey field slugs are attracted to bran-based baits from 4cm whereas modern products claim grey field slugs are attracted from 6cm.

Once individuals have encountered a bait, they must consume a lethal dose, which requires:

- Palatability – addition of feeding enhancers ensures individuals consume enough active ingredient to ingest a lethal dose. In the case of metaldehyde; which causes paralysis: consumption of a sub-lethal dose can be an issue with some products because individuals cannot ingest enough to destroy their mucous cells
- Enough bait for the target population – if product does not remain after a couple of days following application, it is usually due to large pest populations consuming it all. Re-application to those 'hot spots' will be required
- Enough toxicant in the bait – the loading of active ingredient determines the amount consumed; hence low loadings require more total product to be applied. In wet conditions, small pellets with greater surface area to volume ratios lose more active ingredient, hence less toxicant will be consumed. For products containing metaldehyde, it is generally recommended that 30–40g/kg is the optimum concentration.

Revisiting old data (adapted from DAS 00127) – Caged field data Italian snail response to baits exposed over time.

Data obtained using field cages indicated that the longer bran-based 15g/kg metaldehyde baits were exposed over the summer / autumn period, the lower their efficacy. This period corresponds with when applications are recommended to control snails in SA. The decline in efficacy fits with local management practices that re-apply 'short-window' bran-based 15g/kg metaldehyde baits in the autumn once snails are active, and before egg laying occurs. Efficacy data was analysed in response to accumulated temperature, accumulated rainfall, and UV exposure (Figure 1). A poor fit to data was observed, due to variance in field data and multiple factors contributing to the response. Further experiments were based on lab data with experiments designed to tease apart individual factors that cause a reduction in the field life, hence efficacy, of snail and slug baits. A summary of these results and recommendations were presented in Nash *et al.* 2016.

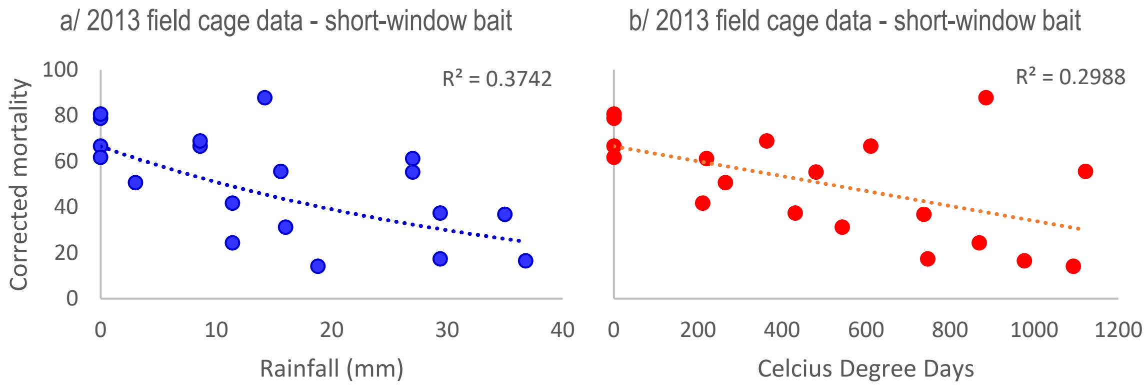


Figure 1. Italian snail response to Meta® exposed to the weather for up to 40 days under different weather conditions in SA. The relationship of mortality with a/ the total amount of rainfall baits were exposed to and b/ the accumulated temperature baits were exposed to, is presented. Weather data was obtained from nearest Bureau of Meteorology weather station.

Revisiting old data (adapted from DAS 00134) - Influence of pellet size on efficacy after rainfall.

Smaller molluscicide baits based on the same product resulted in a greater reduction in efficacy after rainfall, as assessed using snails in laboratory bioassays using a long-window 50g/kg metaldehyde product (2015, Table 1). Similar results were obtained using a short-window 15g/kg metaldehyde product (2016, Table 2).

Consumption data may provide some insights into mechanisms for why efficacy declined after rainfall. All placebo treatment was consumed; as assessed in 2015 by estimating the amount consumed (%) or by quantifying the amount consumed (mg) in 2016; lower amounts were consumed in treatments containing metaldehyde. This result could be due to snails dying, hence they stop feeding. Limited mortality (18%) with a 33% reduction in dead snails compared to the treatment without rainfall in 2016, yet similar consumption (97 vs 87mg) suggests another mechanism is at play. Metaldehyde reduces feeding of slugs and snails by affecting the mucous cells in the target's esophageal crop and causing loss of nerve function. Hence, as metaldehyde concentration increases above 50g/kg, without feeding stimulants in baits, feeding is inhibited. That is why recommendations for metaldehyde concentrations range from 30 – 50g/kg. One hypothesis is consumption of the 50g/kg metaldehyde product increased as the concentration of metaldehyde decreased due to leaching because of rainfall. This was not the case for 15g/kg product, likely due to the lower concentration of metaldehyde not inhibiting feeding in the first place. This work has underpinned the assumption that the greater the surface area to volume ratio, the greater the probability of rainfall leaching active ingredients from baits. This assumption needs to be revisited considering different active ingredients and how they are now incorporated into the pellet matrix of newly-released products.

Table 1. 2015 efficacy after rainfall (> 35mm) of Metarex (60,000 pellets/kg), a long-window bait, compared to the smaller Metarex micro (100,000 pellets/kg). Baits were exposed twice, each time for a period of two weeks, hence the repeated nature of this assay. Treatment ($F_{4,60} = 16.1$; $P < 0.001$) and assay run ($F_{1,60} = 11.7$, $P = 0.001$) caused significant group differences for the number of dead snails. The significance of Reduction in mortality due to rainfall was tested using Tukey's Least Significance Difference ($P < 0.05$) based on the difference in dead snails.

	Rainfall (mm)	*Dead*		*Consumption (%)*		*Mortality*	*Reduction*
2 by 7 reps		*Mean*	*Std. Dev.*	*Mean*	*Std. Dev.*		
Metarex micro	0	2.57	1.34	11%	7%	51%	
	35	1.14	0.86	22%	15%	23%	29%*
Metarex	0	2.14	1.23	6%	10%	43%	
	35	1.93	1.21	25%	19%	39%	4%^{NS}
Placebo	0	0.00	0.00	100%	0%	0%	

Table 2. 2016 efficacy after rainfall (22.5mm) of Pestmaster® 2mm bran-based snail and slug bait (26,000 pellets/kg), a short-window bait, compared to a larger Pestmaster® 4mm dia. Bran-based snail and slug bait made from the same batch by the manufacturer for experiments to compare bait size influence on efficacy. Baits were exposed once for a period of two weeks. Treatment ($F_{4,35} = 12.0$; $P < 0.001$) caused significant group differences for the number of dead snails, hence mortality. The significance of *Reduction* in mortality due to rainfall was tested using Tukey's Least Significance Difference ($P < 0.05$ LSD = 24%) based on mortality.

8 reps	*Rainfall (mm)*	*Dead*		*Consumption (mg/snail)*		*Mortality*	*Reduction*
		Mean	*Std. Dev.*	*Mean*	*Std. Dev.*		
Pestmaster 2mm	0	2.50	1.07	19.44	2.80	50%	
	22.5	0.88	0.64	17.47	2.98	18%	33%*
Pestmaster 4mm	0	2.88	0.99	12.84	2.11	58%	
	22.5	2.00	1.31	13.12	3.23	40%	18%^{NS}
Placebo	0	0.13	0.35	24.92	0.95	3%	

Revisiting old data (adapted from DAS 00134 and various other assays) – amount of rainfall influence on short-window baits efficacy.

As rainfall increases so the efficacy of short-window products declines, however this was difficult to test using snails in bioassays because often mortality in treatments that did not receive rainfall was below 20%. Statistically small effect sizes cannot be tested. For long-window products the amount of rainfall does not seem to affect efficacy, however bioassays used to test this specifically have also been confounded by limited efficacy. Recent research highlights the individual molluscs reproductive state has a greater impact on efficacy than product used (Perry *et al.* 2021) or rainfall. Hence, results from single trials comparing products should be treated with caution due to underlying variation.

Table 3. Short-window products reduction in efficacy due to the amount of rainfall. Only data from assays is presented where a significant reduction in snail mortality was found (LSD P < 0.05). Mortality = dead snails/ total snails. Mortality data presented is from treatments where product did not receive rainfall; reduction in mortality is the difference between treatment with and without rainfall; reduction (ratio) was calculated by mortality no rainfall/100 multiplied by reduction in mortality. That is, the reduction in efficacy was standardised to account for differences in mortality without rainfall.

Exposure date	Product	Mortality	Reduction in mortality	Rainfall (mm)	Reps	Reduction (ratio)
17/10/2016	Pestmaster	47%	33%	22.5	8	70
17/10/2016	Slugger	65%	20%	22.5	8	31
18/09/2015	Meta	29%	20%	35	7	70
9/03/2019	Pestmaster	21%	17%	44	10	80
28/01/2020	Pestmaster	52%	16%	21	5	31

Hard pellets compared to true baits

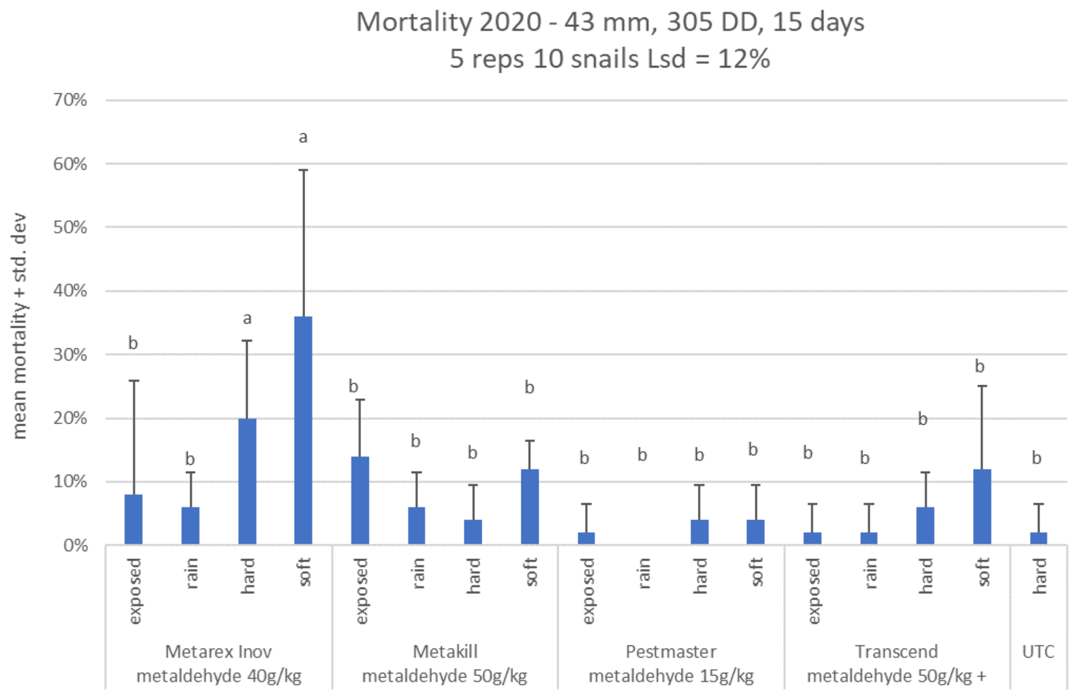
Baits were exposed twice over the summer of 2020 before assays were run in Jan and June 2020. A significant interaction was found between assay and treatment ($F_{16,136} = 4.1$; $P < 0.001$), hence results were analysed and presented separately. For the first assay, baits were exposed for 15 days, received 43mm of rain and 305 DDC (Day Degrees Celsius), with 14.5 hours over 40^{o}C. Low mortality was observed even in the un-exposed treatments (Figure 2a), which were baits either softened by soaking for 2 hours in water (soft) or hard as out of storage (hard). Hence, there were four treatments for each of the four products tested. Treatment was a significant factor ($F_{16,68} = 4.1$; $P < 0.001$), however only two resulted in significantly (LSD $P < 0.05$) greater mortality than the untreated control: Metarex Inov hard and soft un-exposed (Figure 2a).

Mortality was greater for all treatments in the 2nd assay (Figure 2c) where baits were exposed for eight days, received 21mm of rainfall and 175 DDC, without any temperatures over 40^{o}C. Treatment was a significant factor ($F_{16,68} = 7.0$; $P < 0.001$), with all except one treatment (exposed Pestmaster) resulting in significantly (LSD $P < 0.05$) greater mortality than the untreated control (Fig. 2c). There was a significant reduction in mortality where the small Metakill pellets were exposed to rain compared to those exposed only to temperature (LSD $P < 0.05$).

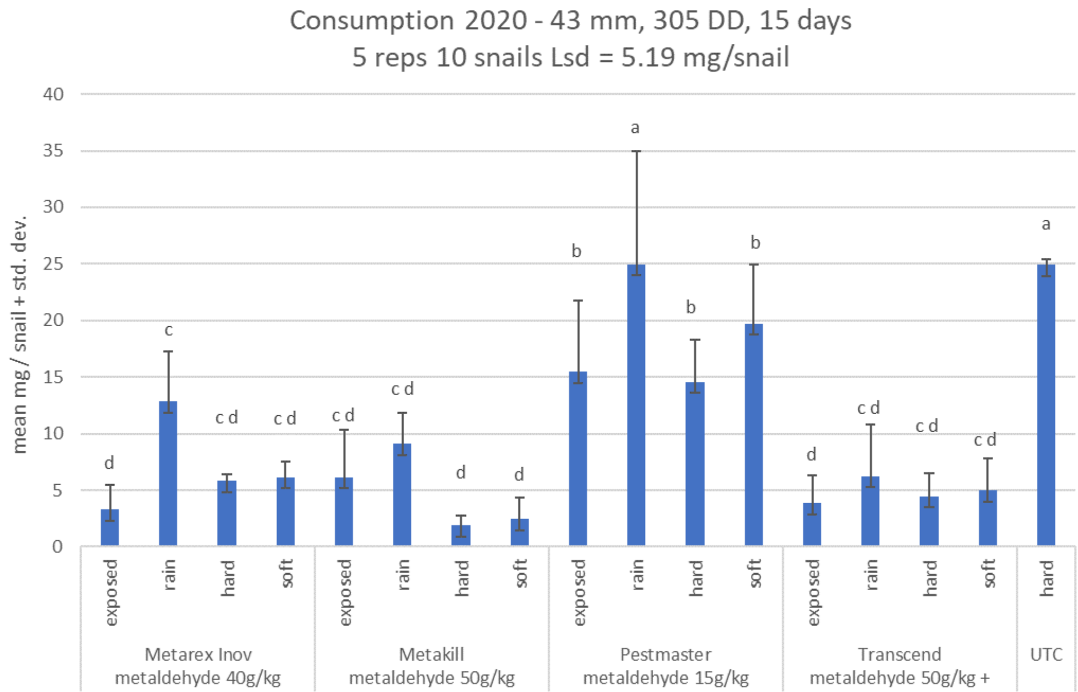
Feeding was reduced in the 1st assay which, along with the low mortality observed, highlights the influence of 'when snails are collected', on the results obtained. This observation aligns with previous findings that demonstrate life stage influences efficacy (Perry *et al.* 2021)

Consumption between treatment groups was significantly different for both assays (1st $F_{16,68} = 17.1$; $P < 0.001$: 2nd $F_{16,68} = 93.9$; $P < 0.001$). Significantly (LSD $P < 0.05$) greater consumption of all softened products was observed in the 2nd assay (Fig 2d). These results suggest some products when applied may require some moisture for them to soften somewhat to increase bait consumption.

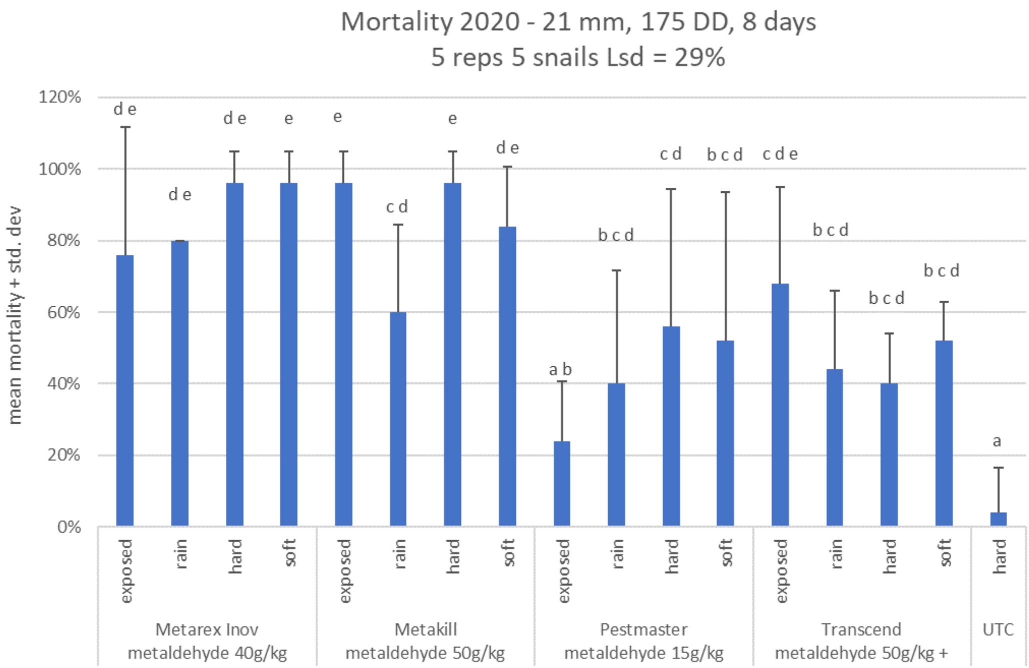
a)


Mortality 2020 - 43 mm, 305 DD, 15 days
5 reps 10 snails Lsd = 12%
mean mortality + std. dev
70%
60%
50%
40%
30%
20%
10%
0%
a
b
b
a
a
b
b
b
b
b
b
b
b
b
b
b
b
b
b
b
exposed
rain
hard
soft
Metarex Inov
metaldehyde 40g/kg
Metakill
metaldehyde 50g/kg
Pestmaster
metaldehyde 15g/kg
Transcend
metaldehyde 50g/kg +
UTC

b)


Consumption 2020 - 43 mm, 305 DD, 15 days
5 reps 10 snails Lsd = 5.19 mg/snail
mean mg / snail + std. dev.
40
35
30
25
20
15
10
5
0
d
c
c d
c d
c d
c d
d
d
b
a
b
b
d
c d
c d
c d
a
exposed
rain
hard
soft
Metarex Inov
metaldehyde 40g/kg
Metakill
metaldehyde 50g/kg
Pestmaster
metaldehyde 15g/kg
Transcend
metaldehyde 50g/kg +
UTC

c)



d)

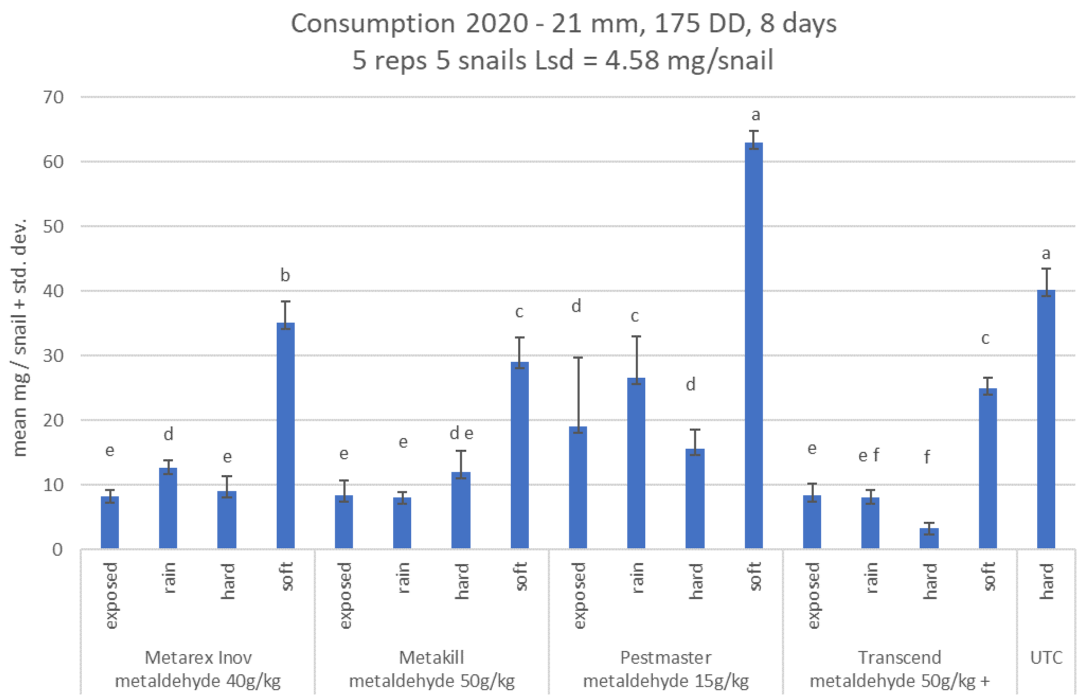


Figure 2. Results from bioassays testing four different slug and snail bait products efficacy after being exposed on wet soil to rainfall (rain) or without rainfall (exposed) and pellets from storage that were either soaked for 2 hours (soft) or not (hard). Data is presented separately as exposure, population of snails used, mortality and consumption results were all different. a) 1st assay mortality, b) 1st assay consumption, c) 2nd assay mortality d) 2nd assay consumption. Different superscript letters indicate a significant (LSD P < 0.05) different between groups.

Conclusions

Multiple factors, such as rainfall, soil moisture, and temperature, not only influence individual pest activity but also product performance in the field. The interaction between environment, target and product dictates the success of baiting to limit crop losses. Physical integrity of slug and snail baits, referred to as rain-fastness, is not associated to efficacy.

Treat one-off trial data on slug and snail bait efficacy data with caution, as individual results can be extremely variable and dependent on target pest individuals' activity / state. Comparisons of product data requires updating as manufacturers continue to improve the delivery of molluscicides.

Having a persistent bait that individual pests will consume to receive a lethal dose allows for application before individuals are active. This timing often coincides with rainfall. Bran-based products, which have low initial loadings of active ingredient, need to be reapplied after heavy rainfall. Modern long-window products continue to be effective for up to a month after application and rainfall. However, some products achieve rain-fastness by including glue in the pellet matrix, which can reduce palatability.

Combining what is known about the factors that improve bait efficacy, such as attractiveness, palatability, ballistics, persistence, has led to the delivery of some products that deliver faster and more efficient mortality. The continued improvement of delivery technologies has seen less of the active ingredients applied; hence lower environmental loadings, yet better crop protection and slug control; leading to better return on growers' investment in slug bait.

How will the latest products affect management strategies and packages?

Conclusions from laboratory assays indicate there is an interaction between bait hardness to achieve rain-fastness, concentration of metaldehyde in individual baits, pellet composition and rainfall that influences the amount of active consumed, hence target mortality. Field results from small plot trials in canola comparing products support these laboratory findings. That is, small hard pellets only focused on delivering an increased number of pellet points increase the chance of delivering a sub-lethal dose. This is due to decreased palatability, especially in dry conditions, and increased chance of active leaching in wet conditions and an increase in product consumed. By applying larger baits with enhanced attractiveness, the chance of encounter is maintained while maintaining delivery of a lethal dose across a range of environmental conditions.

Product choice when applying early in the season; when conditions are dry; may warrant a softer bran-based short-window product, whereas once soil moisture has increased that not only favours slug activity but ensures long-window products are palatable, hence these would be a better option. These long window-baits, having a greater loading of the active ingredient metaldehyde also ensure enough active is available for consumption. Hard glue-based pellets are best applied before substantial rainfall. Although not recommended due to settling and different ballistic characteristics of different pellet size and density, mixing short- and long-window products for application after seeding does occur with successful protection of seedlings from slugs achieved.

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