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Insecticide Resistance Management for Diamondback Moth in Georgia

Contents

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Insecticide Resistance Management

For Diamondback Moth in Georgia

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The Diamondback Moth (DBM)

The diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae), is a common pest of *Brassica* crops including cabbage, collards, turnip greens, mustard greens, broccoli, cauliflower and other leafy greens. The eggs are laid on the leaves of these crops; then larvae hatch out and develop through four instars while feeding on the leaf (Photo 2). The larvae will then pupate in a cocoon on the leaf or the stem, usually after extensive leaf damage has occurred (Photo 1).

The life cycle of DBM changes with temperature (Koshihara 1986) from over two months in cool periods to as little as two weeks during the summer in Tifton, Georgia (Figure 1). This means that the population can build rapidly during the months in late spring, summer and early fall but slows down in winter. Understanding the generation time of diamondback moth is important for proper insecticide rotation within a resistance management program, since the selection for resistance occurs in each generation.

Photo 1. Diamondback moth, *Plutella xylostella* L., damage to a leaf of collard greens with numerous spinosad-resistant larvae and pupae on the leaf.

History of DBM Resistance To Insecticides

For our discussion here, resistance is defined by Sawicki (1987) as "a genetic change in response to selection by toxicants (i.e., insecticides) that may impair control (of DBM) in the field." The first report of DBM resistance to an insecticide was to DDT in 1953 in Indonesia. By 1981 DBM had become resistant to more than 36 insecticides across multiple chemical classes including chlorinated hydrocarbons, carbamates, organophosphates and pyrethroids (Miyata et al., 1986). By 1990 resistance to abamectin, benzophenyl ureas, and various strains of *Bacillus thuringiensis* had been reported in many parts of the world (Sun 1990). It is interesting that even the overuse of *Bacillus thuringiensis kurstaki* resulted in resistance in the field in Hawaii (Tabashnik et al. 1990) despite this pesticide having multiple modes of action and preserving beneficial arthropods. Thus even over-use of biorational insecticides can lead to resistance. Most recently, resistance to newer

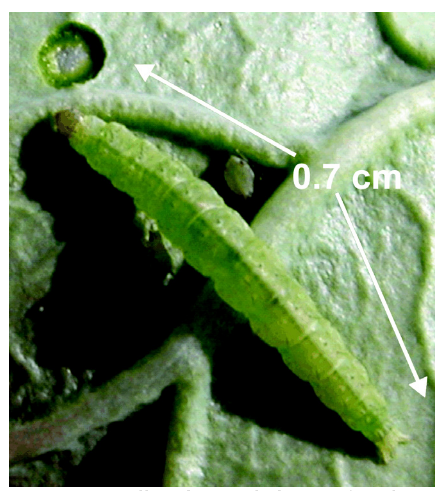

Photo 2. Diamondback moth larva feeding on cabbage leaf.

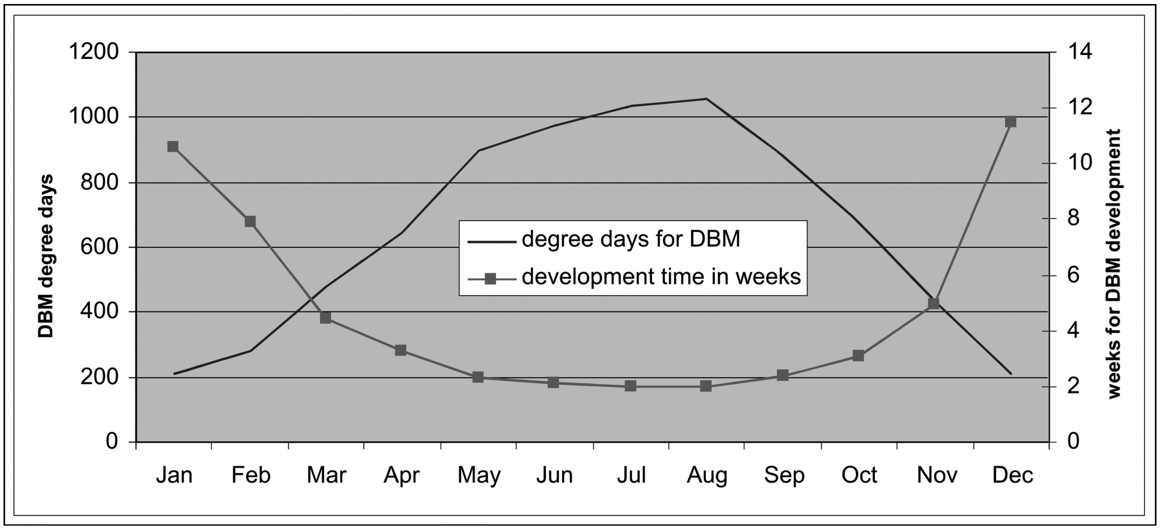

Figure 1. Development time for diamondback moth in Georgia.

insecticide chemistries, including spinosad, indoxacarb and emamectin benzoate, has also been reported (Zhao et al. 2006).

The mechanisms of resistance within the DBM are also diverse (Sun 1990), including acetylcholinesterase insensitivity, reduced penetration, nerve insensitivity and detoxification of insecticides. The presence of these multiple mechanisms of resistance suggests that DBM is likely to become resistant to any class of insecticide given enough time, consistent selection pressure, and a large enough DBM population for selection to occur. Thus any new insecticide chemistries being developed face similar resistance selection problems beginning with their first use. Without proper insecticide resistance management, DBM will continue to overcome insecticides when used as a solitary control tactic.

Resistance Selection

The first step to managing insecticide resistance is to understand how the problem develops. It is important to realize that the genotype for resistance can be present before a new insecticide is ever used, but it typically occurs in a very low frequency in the population. An individual insect does not become resistant but, through multiple applications of an insecticide over multiple generations of the pest, susceptible individuals are removed from the population and resistant individuals remain to reproduce, resulting in a population of insects that can no longer be controlled with that insecticide.

This process does not develop a resistant insect, it simply selects for a population of that insect that is resistant. For example, starting with a population that has 0.01 percent of the individuals with resistance, after a single application of an insecticide that provides 95 percent control of susceptible individuals, roughly 0.2 percent of the individuals within the population will be resistant. After a second application of the same insecticide to this population, 3.85 percent of the individuals in the population will be resistant. A third application would result in 44.5 percent of the population with resistance, and a fourth application would result in 94.1 percent resistant insects. Fortunately a variety of factors usually retards this process in field populations, but this demonstrates the general process of resistance selection and emphasizes the necessity of repeated selections (multiple applications) for resistance to develop.

Genetics of Resistance

As previously discussed, resistance develops at the population level, not within an individual. It is an inherited trait. The genetics of resistance plays a major role in both the potential and stability of resistance. As illustrated in Figure 2, a resistance can be genetically dominant “R” (Figure 2 A) or recessive “r” (Figure 2 B). If dominant, then only one copy of the allele is needed for the expression of resistance; if recessive, two copies of the allele are needed.

The stability of resistance is also affected by the genetics and mechanism of resistance. While dominant genes are more readily expressed in a population, the resistance in the Rr individual helps maintain susceptible alleles in the population. Frequently, resistance also has a physiological cost to the indivi-

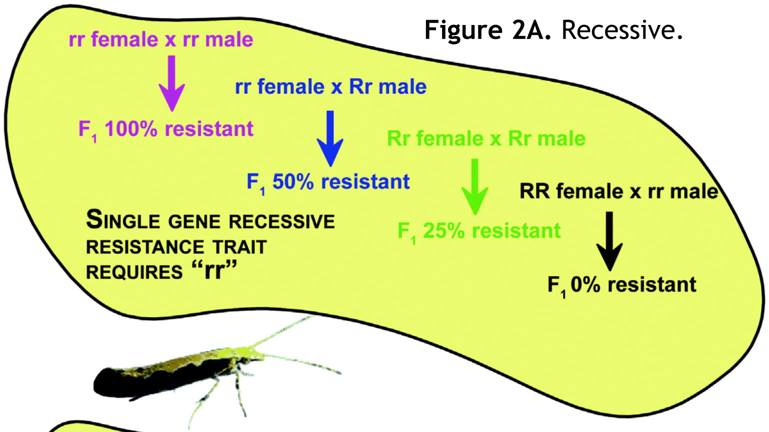

Figure 2A. Recessive.

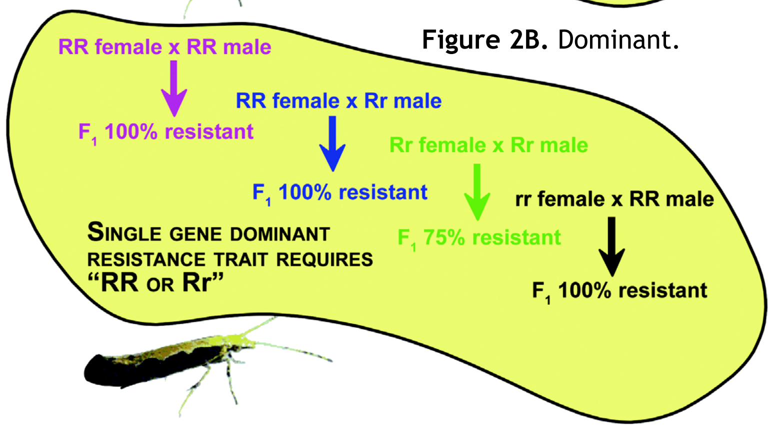

Figure 2B. Dominant.

dual, making it less fit than a susceptible individual in the absence of the insecticide and aiding reversion to susceptibility in the absence of selection pressure.

Actually, the genetics of resistance is much more complicated than we can address here, but our purpose is simply to indicate that resistance has a genetic basis and it is the frequency of resistance in a population that we attempt to manage in a resistance management program. While the genetics of resistance plays a major role in the potential and stability of resistance, from a grower standpoint, all types of resistance are managed similarly. Growers cannot influence the genetics of resistance. Our greatest potential for managing insecticide resistance is in crop management and insecticide selection and use.

Recipe for Resistance

Before presenting recommendations for managing resistance, let us first look at a worst-case approach for developing resistance in a population. This would be to expose as much of the population as possible to a selected insecticide as frequently as possible while maintaining a pest population.

The first step would be year-round production of a favored host plant to maintain pest populations and resistance selection year-round. This would require sequential plantings of hosts, which would be placed within easy reach of one another. Crops would also be left in the field after harvest to allow resistant populations to reproduce. If transplants were used, transplant production would be placed near field production, and resistance selection would be started in the greenhouse or plant house with use of the same insecticide in the field and transplant production (Figure 3). Transplants would also be treated shortly after transplanting in the field to ensure elimination of the "natural" field population and maintenance of the "purity" of the selected strain. Finally, the selected insecticide would be sprayed on a schedule or with the use of a very low threshold, again to maintain the high frequency of the selected genes for resistance in the population.

This process would place year-round production of the crop and year-round selection for resistance within a small area, resulting in heavy selection pressure on an isolated population with minimal opportunity for introduction and establishment of susceptible insects. If this production system sounds

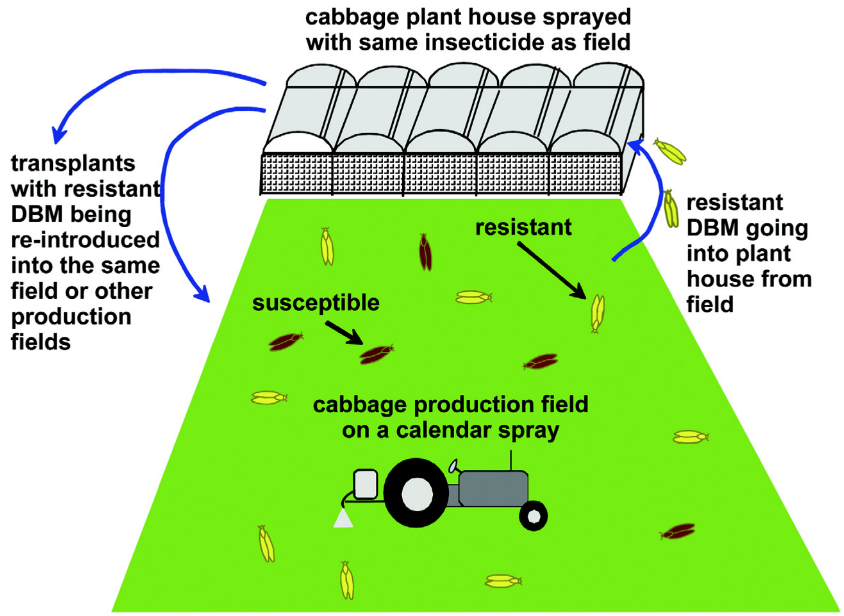

Figure 3. Worst-case scenario for creating resistance.

a little too familiar, you may want to consider the following resistance management recommendations.

Diamondback Moth Resistance Management Recommendations

Resistance management for DBM, as with any insect, centers on minimizing exposure of the pest population to a single insecticide or a single class of insecticides, thereby maintaining susceptible individuals within the population or minimizing the number of resistant individuals within a population.

Crop Management

One of the most important non-insecticide control options for management of insecticide resistance in DBM populations is a crop host-free period. A host-free period functions to reduce the overall DBM population, with assumed equal reduction in both susceptible and resistant individuals. This also forces the pest onto wild host plants, which typically support much lower populations, and, hopefully, increases the potential for resistant individuals to mate with susceptible individuals as they move about searching for scarce resources. Obviously, the host-free period eliminates resistance selection during this period. The host-free period would further impact resistance selection in that crops produced shortly after this period would experience reduced pest pressure, resulting in less pesticide use and less resistance selection.

For Georgia, the best host-free period would likely be a two-month period of no cabbage or leafy greens crops in the middle of the summer. This time frame would minimize the presence of volunteer crop hosts and related weeds (which generally grow better in the cooler times of the year) at a time of year when DBM are developing through a generation in about two weeks. A two-month host-free period at this time of year would maximize the mortality associated with a lack of large host acreage, maximize the number of host generations for crossing between susceptible and resistant insects, and maximize the number of generations developing without resistance selection.

During the production season, resistance management should start in transplant production. Separate greenhouses and any other plant houses used for transplant production from field production as far as possible. Do not use pesticides used in field production in transplant production (see Figure 3 for a worst case example). When possible, use insect screens on plant houses to prevent migrating DBM from infesting new transplants. Also, the microbial insecticide *Beauvaria bassiana* can effectively be used in humid greenhouses against DBM.

While sequential plantings are necessary for meeting market demands, separate sequential plantings as far as possible. While a separation of a few miles will not prevent DBM from finding fields, it will hopefully reduce the number of moths moving into fields and increase the “mixing” of moths from different locations. This mixing of moths will introduce more susceptible genes into a population than would occur with a large population of moths moving across a small area into a nearby field.

The final step of crop management is sanitation. Once a crop is finished, thoroughly destroy the crop as soon as possible. While these crop residues allow for reproduction without selection pressure, generally by the end of harvest, any DBM populations remaining in the field have undergone extreme selection pressure and are likely to contain an elevated level of resistant individuals. It is probably best not to allow these populations to increase.

Insecticide Selection and Use

The first rule in integrated pest control and resistance management is to minimize insecticide use. From an insecticide resistance viewpoint, every time a pest population is treated with an insecticide, selection for resistance is occurring. This selection is not evident at first because so few individuals survive. As the resistant population increases, survival of larvae and plant damage becomes obvious and intensified spray programs usually follow.

Intensified spray programs can exacerbate the problem by putting even more resistance selection pressure on the DBM, which maintains high levels of resistance. Ideally, growers should work with set thresholds and spray with insecticides only when these thresholds are exceeded. Trying to produce a crop with a zero tolerance for damage may work in the short term but leads to increased insecticide use, insecticide resistance and, ultimately, loss of pest control and increased crop loss.

Selective use of insecticides should start in transplant production. Although producers want “clean” transplants, excessive use of insecticides in transplant production is likely more damaging than excessive use in the field. In transplant production, DBM populations are typically more confined, a larger proportion of the population is exposed, and, although the length of production is shorter, sequential plantings over time and insecticide use on these plantings maintains strong selection pressure on the DBM population. Resistant individuals, therefore, can be concentrated in the enclosed area, maximizing the inbreeding for insecticide resistance. Finally, any resistant individuals that survive on the transplants are then distributed with the transplants.

Shipping infested plants out with these selected DBM greatly increases the distribution of resistance in field populations. If similar insecticides are then used on these field populations, resistance is easily maintained and distributed over a wide area. For this reason, many insecticides are not labeled for use in transplant production. It is critical to follow these label restrictions, because this is one way companies are trying to assist in resistance management efforts.

In addition to minimizing insecticide use, producers should rotate insecticides to minimize resistance selection. Proper rotation should take into account the life cycle of the insect, the mode of action of the pesticide, and label restrictions. Use the life cycle to establish the time frame for insecticide class rotation. The basic approach is not to use the same or similar insecticide on two sequential generations of a pest. So in the summer when DBM generation time is about two weeks, use a specific insecticide class for a maximum of two weeks and then avoid it for a minimum of two weeks. The more generations that can be skipped between exposures, the better.

For example, with three efficacious insecticides, the first would be used for two weeks, the second for the next two weeks, and then the third for two weeks. With this simple rotation, each insecticide would benefit from two generations (four weeks) of non-selection prior to repeated exposure.

Within a use cycle for a specific insecticide class (the two weeks of use in the example above), closely follow label restrictions, including rates of application, application intervals and maximum number of applications. If additional applications are needed within a use cycle (heavy pest pressure or poor control), then substitute a product in the same class that is still effective in the field. If a different mode of action becomes necessary, make an additional substitution; however, if this is done, insecticides in either class used should then be avoided for the next two weeks. Obviously, continued substitutions are not a sustainable resistance practice, since only one class of insecticide should be used per DBM generation. So avoid production of susceptible host crops when DBM pest pressure is so severe that it causes problems with the insecticide rotations.

B.t. insecticides are a good option for this “within cycle” rotation early in the cropping season. Note than B.t. insecticides come in different strains, such as Dipel (B.t. var. kurstaki) versus Xentari (B.t. var. aizawai), which can be rotated if efficacy against DBM is low for one strain. One point of interest with

B.t. insecticides is their short residual control. Also, as with any insecticide that requires ingestion by the insect, tank mix applications can have a negative impact on efficacy, particularly if the tank mix partner has any repellency action (as is the case with pyrethroid insecticides). **In general, tank mixes of insecticides are not recommended.**

In selecting insecticides for rotation, consider the mode of action of an insecticide. Addition of the IRAC Mode of Action to most insecticide labels should aid this greatly. Insecticides with similar modes of action generally express cross-resistance (selection for resistance to one product selects for resistance to all products with the same mode of action). Thus, in rotation of insecticides, a producer would select products from multiple mode of action groups for rotation. Examples of common insecticides used in cole crops and their modes of action are listed in Table 1.

Key Points in Resistance Management

While we have presented a worst-case scenario for resistance development, a few points need added emphasis. The very worst insecticide approach is to find something that works and "stick with it." If you have one or more products that work well, use these sparingly and only when the best control is needed. Basically, save these products for when they are really needed.

If a product seems to fail, the very last thing to do is re-apply the same product. If there is an explanation for the failure other than resistance (poor coverage, rain during application, etc.), re-application may be justified. If resistance is suspected, re-application simply intensifies the selection pressure and assures a minimum number of susceptible individuals survive, ensuring more stable resistance. And finally, acceptance of some level of damage will be a necessity for managing insecticide resistance in DBM.

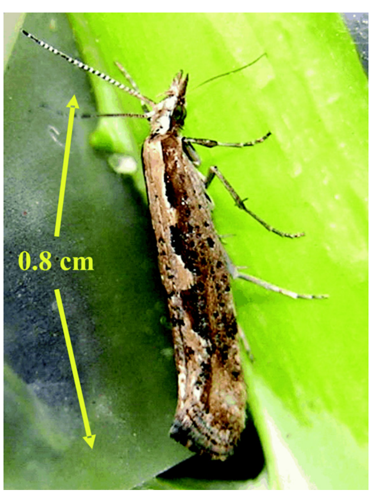

Photo 3. Diamondback moth.

DBM Resistance Management Recommendations

- ❑ **Establish a host-free period to reduce pest populations and reduce selection.**
- ❑ **Spatially separate sequential plantings as much as possible.**
- ❑ **Spatially separate transplant production and field production.**
- ❑ **Eliminate crop residues immediately after harvest.**
- ❑ **Use insecticides only as needed (use thresholds; tolerate some damage).**
- ❑ **Do not use of the same type of insecticides in transplant and field production.**
- ❑ **Rotate insecticides with different modes of action as in Table 2 (rotation based on insecticide category [Table 1], pest life cycle and label restrictions).**
- ❑ **Use B.t.s when populations are low or some damage can be tolerated (i.e., early season; they can also be rotated with synthetic insecticides within a DBM generation).**
- ❑ **Avoid tank mixes of insecticides, i.e., one insecticide at a time.**
- ❑ **Older chemistries (i.e., carbamates, organophosphates, endosulfan) may work if the population has not been exposed for an extended period, but resistance is likely to reappear rapidly if rotations are not followed.**
- ❑ **Follow label restrictions for all products; most labels now contain specific instructions for resistance management.**
- ❑ **If you spray and suspect resistance to insecticide, do not re-apply the insecticide.**

Table 1. List of insecticides by IRAC group with potential DBM efficacy.

IRAC Insecticide Category (groups 1 to 28 followed by letter designated subgroup)	Some Commercial Labels with DBM Control	Comments
Group 1A, Carbamates	Lannate Larvin Sevin	Possible cross-resistance with organo-phosphates; resistance less stable than pyrethroid resistance.
Group 1B, Organophosphates	Naled Diazinon	Possible cross-resistance with carbamates; resistance less stable than pyrethroid resistance.
Group 2A, Cyclodiene	Thiodan	Possible cross-resistance with pyrethroids.
Group 3, Pyrethroids	Danitol Mustang Max Warrior	Resistance relatively stable even in absence of selection.
Group 5, Spinosyns	SpinTor	Incomplete recessive resistance.
Group 6, Chloride Channel Activator	Proclaim	
Group 11, Bt Microbials	Bta - Xentari Btk - Dipel	Complex — primarily recessive genetic components.
Group 15, Chitin Inhibitor	Rimon	Completely recessive.
Group 21, Sodium Channel Blockers	Avaunt	

Table 2. Example rotation schemes for insecticides in different classes (letter designation) for late spring to early fall (two-week life cycle for DBM is represented between the double lines).

Week	Very light pressure	Light to moderate pressure	Moderate to heavy pressure	Heavy pressure
1 - early	Insecticide D	Insecticide A	Insecticide A	Insecticide A
1 - late			Insecticide D	Insecticide B
2 - early		Insecticide A	Insecticide A	Insecticide A
2 - late			Insecticide D	Insecticide B
3 - early	Insecticide A	Insecticide B	Insecticide B	Insecticide C
3 - late			Insecticide E	Insecticide D
4 - early		Insecticide B	Insecticide B	Insecticide C
4 - late			Insecticide E	Insecticide D
5 - early	Insecticide E	Insecticide C	Insecticide C	Insecticide A
5 - late			Insecticide D	Insecticide E
6 - early		Insecticide C	Insecticide C	Insecticide A
6 - late			Insecticide D	Insecticide B
7 - early	Insecticide B	Insecticide A	Insecticide A	Insecticide C
7 - late			Insecticide E	Insecticide D

* The above examples assume insecticides in classes A, B and C are relatively efficacious. Insecticides in classes D and E would represent older chemistries or a less efficacious insecticide.

** **This is NOT intended as a spray schedule but as a potential rotation for applications that are required based on pest abundance.** Attempting to produce crops under the heavy pressure situation is not sustainable and attempts to produce a perfectly clean crop when pressure is high will lead to heavy resistance selection pressure when pest populations are at their peak, which provides the greatest potential for resistance selection.

Key Considerations for DBM Resistance Management

Failure to employ sound DBM resistance management strategies jeopardizes the cole crop industry in Georgia as well as the continued availability of effective insecticides.

Detailed resistance management strategies (provided in this circular) include:

- ❑ A host-free period
- ❑ Proper field sanitation with crop residue destruction
- ❑ Separation of plant house and field DBM populations
- ❑ Spacial separation of sequential plantings of host crops.
- ❑ Minimizing overall insecticide use
- ❑ Accepting commercially insignificant crop damage
- ❑ Eliminating off-label use of insecticides in transplant production
- ❑ Reserving the use of the "most effective" insecticides until required
- ❑ Rotating insecticides (with different modes of action)

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