Current Problems and Future Potential for Herbicide Resistance in Vegetable Production.

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Abstract. **Weed resistance to triazine herbicides was first reported in 1968. Since then, herbicide resistance has been observed in over 100 weed species. There are reports of resistance to most major herbicides and most herbicide classes. Most early reports of weed resistance involved a single herbicide. Recently, cross resistance to several herbicides and other classes of herbicides has been reported in several weeds. Most weed resistance has occurred in field crops, forage crops, and perennial tree crops. The primary cause is the continued use of the same or similar herbicides in a cropping system for many years. To this date, there are few reports of weed resistance in vegetable crops. Recently, resistance to the sulfonylureas and imidazolinones has occurred after only 5-6 years of use. These herbicides are not often used in vegetables, but with new registrations their use will increase. Resistance to graminicides, which are widely use in vegetable production, has been reported. Most weed resistance has developed as a result of specific, heritable traits which exist in a small segment of the population. The percentage of resistant plants has increased after many years of control of the susceptible biotypes. However, discovery of resistance as a result of enhanced herbicide metabolism by mixed function oxidases creates concerns about the occurrence or resistance to a large number of very diverse herbicides. Vegetable growers may soon face resistance problems unless management techniques are used to avoid it.**

INTRODUCTION

One of the first published reports of weed resistance reported a wild carrot (*Daucus carota L.*) resistant to 2,4-D in Canada (26). Although some researchers predicted serious weed resistance problems in the future, weed resistance was considered to be a curiosity until resistance to simazine in common groundsel (*Senecio vulgaris L.*) appeared in an ornamental nursery in Washington state in the mid 1960s (21). Since 1970, triazine resistance has been reported in over 40 species of broadleaves and 15 species of grasses in various countries around the world (12). As of 1991, an additional 55 weed species had been reported to be resistant to over 15 other herbicides or herbicide families (11, 25). Resistance has been reported from most areas in the United States, Canada, many European countries, Australia, Japan, and several other countries around the world (18). There have been a few published reports of resistance from Latin America (8, 24). Resistance is undoubtedly present in many places in Latin America, but it may not be widely recognized or reported yet.

At least one weed species has been reported to be resistant to the following herbicide families: triazines (e.g., atrazine), bipyridyliums (e.g., paraquat), sulfonylureas (e.g., chlorsulfuron), imidazolinones (e.g., imazaquin), phenylureas (e.g., linuron), phenoxy acids (e.g., 2,4-D), aryloxyphenoxypropionates (e.g., fluazifop), cyclohexanediones (e.g., sethoxydim), dinitroanilines (e.g., trifluralin), amides (e.g., propanil), triazoles (e.g.,aminotriazole), uracils (e.g., terbacil), carbamates (e.g., phenmedipham), nitriles (e.g., bromoxynil), and pyridines (e.g.,picloram) (10). There have been a few, but unconfirmed, reports of resistance to acetanilides, diphenylethers, glyphosate, and the thiocarbamates (12).

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CHARACTERISTICS OF WEED RESISTANCE

Most weed resistance has been discovered in fields under continuous cultivation of field crops (e.g., maize, wheat, cotton, rice), orchards, or ornamental nurseries. In all these crops, one herbicide or others in the same chemical family have been used for a long period of time. Differences in the number of years of herbicide use before weed resistance appears is a function of the number of naturally resistant plants in the wild population. Use of low rates of the herbicide may result in an increase in the percentage of resistant plants because the low rates will not control moderately resistant individuals.

For example, triazine resistance appeared after about 20 years of use, but acetolactase synthase (ALS) inhibitor resistance appeared after only 5 years of continuous use. Evidently, there were a larger number of weeds naturally resistant to ALS inhibitors. The loss of whole classes of older herbicides due to regulatory action will eliminate alternatives, and result in more intense use of new classes of herbicides with higher specific activity. This will probably result in more rapid development of resistance in the future.

Several factors contribute to the development of weed resistance to herbicides (17). The greatest contributing factor appears to be herbicide sensitivity at a single site of action. Herbicides that interfere with only one biochemical process are more susceptible to development of resistance since a single-gene alteration may affect susceptibility. For instance, most triazine resistance is the result of an altered binding site (serine to glycine) of the D-1 protein in Photosystem (PS) II which results in the failure of the herbicide to bind to the altered site (1). The resistant biotype does not bind the herbicide, and becomes almost immune to its activity. In addition, the resistant biotype carries the gene for resistance maternally, so it is not diluted by cross pollination with the susceptible biotype (13).

Herbicides that are not as specific in their mode of action, or that affect several plant functions, do not elicit resistance rapidly. For example, the acetanilides continue to be effective on a wide range of weeds even after more than 30 years of use, with few reports of resistance. These herbicides appear to have multiple sites of action which are not clearly defined, but which result in inhibition of shoot elongation.

Resistance to a herbicide with a single site of action may result in cross resistance to other herbicides with the same site of action. For example, triazine resistance often results in cross resistance to other PS II inhibitors, such as the phenylureas and uracils. Most weeds resistant to the sulfonylureas are also resistant to the other ALS inhibitors, the imidazolinones. Moreover, there appears to be some cross resistance within the acetyl-CoA carboxylase (ACCase) inhibitors (postemergence grass herbicides): the aryloxyphenoxypropionates (APPs) and cyclohexanediones (CHDs). However, cross resistance is not universal, and some resistant weeds respond differently to various herbicides with the same mode of action or even within the same chemical family, since the actual binding sites may not be identical (7).

Non-target site cross resistance and multiple resistance (resistance to herbicides with different modes of action) may pose the ultimate threat to herbicide effectiveness. Non-target site resistance may involve several mechanisms, including reduced uptake and translocation, compartmentation, and enhanced detoxification (20).

Multiple resistance may arise from metabolism of the herbicide by a mixed function oxidase (MFO) catalyzed by cytochrome P450 (10). In this situation, the resistant plants have an MFO not found in the susceptible plants. This MFO may metabolize herbicides unrelated in their mode of action (7). Multiple resistance in rigid ryegrass *(Lolium rigidum Gaudin)* and blackgrass (*Alopecurus myosuroides Huds.*), reported in Australia and U.K., appears to be a result of MFO metabolism (8). MFO metabolism of toxins is a well known phenomenon in insects, and it may become a source of serious resistance in weeds. However, it currently is relatively rare.

Biotype 'fitness' refers to the relative ability of one biotype to compete with another biotype of the same species under normal growing conditions (19). Evidence of fitness may include greater biomass production, larger plant size, more rapid germination rate, and greater photosynthetic efficiency. In the case of triazine resistance, the herbicide resistant biotype is less fit and occurs naturally as a very low percentage of the population. However, the resistance is genetically stable, and as the susceptible (more fit) biotype is controlled by the herbicide, the resistant (less fit) biotype begins to predominate.

WEED RESISTANCE IN VEGETABLE CROPS

Most weed resistance has developed in cropping systems in which there are few changes from year to year. Continuous use of the same herbicide is the primary factor in weed resistance. Other cultural factors that tend to increase resistance include multiple applications of the same herbicide each year, lack of tillage, lack of crop rotation, and rotation to crops with similar cultural and weed control practices. These practices are characteristic of highly mechanized field crop production, small grains, pastures, and tree crops.

Reports of weed resistance in vegetable production have been published only recently. In 1987, Stall, et al. (22) reported difficulty controlling American black nightshade (*Solanum americanum Mill.*) with paraquat in tomato fields in southern Florida. At first it appeared that the lack of weed control was caused by an interaction with the fungicide cupric hydroxide which is also routinely applied to tomatoes. Field and greenhouse experiments indicated that the nightshade was resistant to 12X the normal paraquat rate, but the addition of cupric hydroxide increased the resistance to 14X (2). Subsequent research indicated that the paraquat resistant nightshade was also slightly tolerant of diquat (3).

The paraquat-resistant biotype has now spread to central and northern Florida and is also found in pepper and eggplant fields. The resistance to diquat which was originally only marginal, is now increasing (William Stall, Univ. of Florida, personal communication.).

Several other weeds have been reported to be resistant to paraquat in field, forage, and tree crops (4). Paraquat is one of the most widely used herbicides in vegetable production worldwide, and there will be more reports of resistance in vegetable crops in the future.

Masabni, et al. (14) found a linuron-resistant biotype of common purslane (*Portulaca oleracea L.*) growing in a carrot field in Michigan. The field had been planted to carrots and sprayed with at least 2.24 kg/ha linuron annually for over 25 years. Subsequent experiments demonstrated that this linuron-resistant biotype is also highly resistant to atrazine and terbacil, which are also PS II inhibitors (15). Greenhouse and laboratory experiments revealed that the linuron-resistant common purslane had lighter seed weight, slower germination, less fresh and dry weight, and fewer leaves than the susceptible biotype (16). This fits the classical scenario of a less fit, less competitive, resistant biotype appearing after many years of control of the mixed weed population. The culture of carrots on this farm is similar to field crop production, with limited rotation and few changes in agronomic practices.

In 1993, Wiederholt and Stoltenberg (28) reported that they had identified three accessions of large crabgrass (*Digitaria sanguinalis (L.) Scop.*) from a carrot-onion-maize rotation which were resistant to sethoxydim and fluazifop. In 1994, they reported that they had also identified a giant foxtail (*Setaria faberi Herrm.*) accession from the same cropping system that was also resistant to both sethoxydim and fluazifop (29). Fluazifop and sethoxydim had been applied to carrots and onions for about 5 years before the resistance was reported. Greenhouse experiments indicated that the resistant giant foxtail was also moderately resistant to diclofop, quizalofop, and fenoxaprop. However, it was only slightly resistant to clethodim (23).

Redroot pigweed (*Amaranthus retroflexus L.*) and common lambsquarters (Chenopodium album L.) resistance to triazines is widely reported in maize and other crops. It has recently become a problem in potatoes in Wisconsin which are grown in rotation with maize and soybean (Larry Binning, Univ. of Wisconsin, personal communication.) Both weeds are also highly resistant to linuron, which is applied to both potatoes and soybeans.

There are undoubtedly many other occurrences of weed resistance in vegetable production that have not been verified or reported yet. After a resistant biotype begins to emerge in a cropping system, it often takes 5-7 years for it to become obvious. If there is no change in the cropping system, the resistant biotype will predominate in about 8-10 years (5).

PROSPECTS FOR THE FUTURE OF WEED RESISTANCE IN VEGETABLE CROPS

Several factors indicate that there will be increased reports of weed resistance in vegetable crops. The number of herbicides registered for use in vegetable production is very limited. In many crops there may be only one or two preemergence herbicides registered. In some crops only paraquat is registered for postemergence broadleaf weed control. Many of the herbicides most commonly used in vegetable production are reported to have resistant weeds in other crops.

These include: atrazine, bromoxynil, 2,4-D, fluazifop, linuron, paraquat, pyrazon, sethoxydim, and trifluralin (12, 26). We are currently developing vegetable registrations for several sulfonylurea and imidazolinone herbicides, which already have extensive resistance problems in other crops.

IDENTIFYING WEED RESISTANCE IN THE FIELD

Weeds survive and persevere under many cultural and environmental conditions. They adapt readily to any particular cropping system. Those that can not adapt tend to disappear and are replaced by more vigorous competitors. Their adaptability indicates a broad genetic base which helps the weeds survive under many conditions. Therefore, we can expect weed resistance to herbicides to eventually occur in most intense cropping systems. Recognizing and verifying resistance is an important first step in dealing with it at an early stage (5).

Poor weed control may be the result of many factors, so it is important to carefully evaluate and document the situation if resistance is suspected. If you suspect resistance, consider these questions:

1. Are other weeds being controlled as expected with the herbicide?
   Usually only one weed develops resistance at the same time and place.

2. Has the herbicide been ineffective against the same weed in previous years?
   Does the number of resistant plants appear to be increasing?

3. Has the same, or a similar herbicide been used for many years with little change in cultural practices?

If the answer is yes to any or all of these questions, you may have weed resistance (5).

Knowledge of weed characteristics that tend to enhance development of resistance will help in early identification of resistance. For instance, weeds that are prolific seed producers, are genetically diverse, and produce several generations per year, are especially vulnerable to development of resistance. Redroot pigweed and common lambsquarters are good examples of such weeds. When resistance is suspected, seeds are collected from resistant and susceptible biotypes and evaluated with whole plant bioassays under controlled conditions to verify actual resistance (9).

If it appears that resistance has developed, change cultural practices as soon as possible. Select another herbicide with a different mode of action. Mechanical cultivation will help control emerged weeds and interrupt their reproductive cycle. In subsequent cropping season, grow other crops on which different herbicides may be used. Make every effort to keep the resistant population from going to seed.

AVOIDING RESISTANCE

The most important factor in avoiding resistance is change. For example, rotate crops and herbicides as often as possible. Since several herbicides are used on many vegetable crops (e.g., trifluralin, fluazifop, and sethoxydim), it may be difficult to avoid using a herbicide suspected of promoting resistance. In such cases, it may be wise to rotate from vegetables to field crops on a regular basis. When rotating crops, be sure to select a herbicide with a different site of action (6). Since all the postemergence grass herbicides (APPs and CDHs) are ACCase inhibitors, it will be difficult to avoid the same site of action for grass control. In that case, at least rotate between the APPs and CHDs if there is an alternative.

The appearance of resistance is directly related to intensity of weed pressure. Therefore, use an application rate that is high enough to kill all the target weeds. A low rate will only increase selection pressure in favor of the resistant biotype. If a resistant weed develops in a field, avoid its spread to other fields by cleaning equipment between fields and by using weed-free crop seed. Finally, be aware of your weed population, and monitor it regularly. Keep a log book of weeds present in an area, and any changes in the weed population in the field. You will then be better able to identify changes early and respond quickly to any resistance that occurs.

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