Research Progress on Toxicity and Residues of Commonly-used Plant Growth Regulators in Vegetables

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Abstract This paper reviewed the toxicity, maximum residue limits (MRLs) and current residue status of commonly used plant growth regulators in vegetables, including 2,4-dichlorophenoxyacetic acid (2,4-D), naphthaleneacetic acid (NAA), ethephon, gibberellin, and paclobutrazol. Methods for reducing residues of plant growth regulators in vegetables were discussed, and recommendations and strategies for their application were proposed.

Key words Vegetables; Plant growth regulator; Toxicity; Residue

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Types of Plant Growth Regulators Commonly Used in Vegetables

Commonly-used plant growth regulators in vegetable production include 2,4-dichlorophenoxyacetic acid (2,4-D), naphthaleneacetic acid (NAA), ethephon, gibberellin, and paclobutrazol. These regulators serve different purposes in vegetable cultivation. 2,4-D is cost-effective and widely applied. It has the effects of promoting fruit setting, reducing flower and fruit drop, inducing seedless fruit development, and minimizing leaf abscission. NAA promotes root formation in cuttings, fruit development, bolting, and flowering. Ethephon accelerates fruit ripening and enhances the formation of female flowers in cucurbit vegetables. Gibberellin stimulates stem and leaf growth, breaks dormancy, and improves fruit setting. Paclobutrazol is primarily used to prevent excessive seedling elongation, promote dwarfing, enhance root development, and deepen leaf color[1].

Toxicity, Maximum Residue Limits (MRLs) and Residue Status of Common Plant Growth Regulators in Vegetables

In China, the *Pesticide Management Regulations* promulgated in 1997 and revised in 2001 classify plant growth regulators as pesticides for unified regulation. Pesticides are categorized into six classes based on their oral median lethal dose (LD_{50} per kg of body weight): extremely high toxicity, extreme toxicity, high toxicity, moderately toxicity, low toxicity, slight toxicity. Plant growth regulators are a type of pesticide that regulates plant growth and development, rather than targeting the elimination of harmful organisms. As such, they are generally classified as low toxic or slightly toxic. Residues of plant growth regulators refer to the remaining quantities of their toxic and active components in plants and soil[2-3]. Under normal usage conditions, plant growth regulators entering vegetables will gradually degrade through metabolism, with their effects diminishing over time. The residual levels in vegetables remain very low, and even trace amounts are further reduced to varying degrees during cooking.

2,4-Dichlorophenoxyacetic acid (2,4-D)

It is classified as a low-toxicity pesticide, with an oral LD_{50} of 500 mg/kg in rats. Prolonged exposure to 2,4-D in mice can lead to skeletal deformity, and increased morbidity and mortality. Daily administration of 21.5 mg/kg 2,4-D to rats showed no tumor formation, indicating no carcinogenic effects. 2,4-D exhibits acute neurotoxicity and can irritate the skin and eyes. Its acute toxicity primarily manifests as neurotoxic effects upon inhalation or contact. Chronic toxicity includes hematotoxicity, hepatotoxicity, nephrotoxicity, inhibition of certain enzyme activities, and suppression of protein synthesis. Embryological studies in animals have not provided direct evidence of adverse effects on human reproductive function[4].

Maximum residue limits (MRLs): International regulations on 2,4-D residue are relatively stringent. The Codex Alimentarius Commission (CAC) sets residue limits for 2,4-D in 25 agricultural products, ranging from 0.01 to 400 mg/kg. In China, the mandatory national standard specifies a maximum residue limit (MRL) of 0.2 mg/kg for 2,4-D in vegetables.

NAA

It is a low-toxicity pesticide with an acute oral LD_{50} ranging from 1 000 to 5 900 mg/kg in rats. It may irritate human eyes, skin, mucous membranes, and the upper respiratory tract. Inhalation can cause coughing, wheezing, laryngitis, shortness of breath, headache, nausea, and vomiting. Ingestion may lead to

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poisoning and cause damage to the liver and kidneys[5].

Maximum residue limits (MRLs): Japan sets the maximum residue limit for NAA in vegetables at 0.1 mg/kg. China currently has no national safety standard for NAA residue limits.

Ethephon

It is a low-toxicity pesticide with an acute oral LD_{50} of 4 000 mg/kg in rats and 4 229 mg/kg in mice. Ethephon can cause genetic damage to somatic and germ cells in mice, increasing the micronucleus rate in bone marrow cells and the malformation rate in male germ cells. It interferes with the normal production and maturation of sperm, leading to chromosomal aberrations in somatic cells and gene mutations in germ cells. Ethephon poses potential risks to humans, including carcinogenic, teratogenic, and other hazardous effects. For example, in May 1997, 47 cases of food poisoning were reported after consuming watermelons contaminated with ethephon. Symptoms such as dizziness, headache, blurred vision, numbness of the lips and tongue, chest tightness, palpitations, excessive sweating, nausea, vomiting, abdominal pain, and diarrhea appeared within 20 – 40 min of exposure. Ethephon also irritates the skin, as evidenced by four reported cases of skin irritation in California, USA, between 1980 and 1986. Excessive exposure to ethephon can accelerate aging, corrode the digestive tract, and cause damage to the brain and kidneys[6].

Maximum residue limits (MRLs): In recent years, foreign countries have put forward strict residue limits for ethephon in vegetables. The United States sets the maximum residue limit at 2 mg/kg for tomatoes and 0.1 mg/kg for cucumbers. New Zealand specifies a limit for tomatoes at 1 mg/kg. Japan's new regulation for Chinese agricultural imports specifies a limit of 2 mg/kg for tomatoes. There is currently no internationally unified standard for the maximum allowable residue level of ethephon. China's national regulation sets the maximum residue limit for ethephon in tomatoes at 2 mg/kg.

Gibberellin

It is a slightly toxic pesticide with no significant toxic reactions in acute toxicity tests on animals. The intravenous LD_{50} in mice exceeds 6 300 mg/kg, and oral administration of doses over 25 000 mg/kg showed no toxic effects. Carcinogenicity tests in mice showed negative results. However, some studies have found that gibberellin can affect the endocrine system, significantly increasing the weight of endocrine glands such as the thyroid, ovaries, and adrenal glands in test animals. This leads to alterations in certain hormone levels, potentially disrupting growth and development or even inducing carcinogenesis[7].

Maximum residue limits (MRLs): The United States, Japan and other countries have set the maximum residue limit for gibberellin in vegetables at 0.2 mg/kg. China currently has no established national standard for gibberellin residue.

Paclobutrazol

It is a low-toxicity pesticide with an acute oral LD_{50} of 1 500 mg/kg in rats. High doses of paclobutrazol may damage male reproductive organs in animals, reduce offspring body weight and reproductive indices, and cause liver damage, suggesting potential carcinogenicity and thus requiring cautious use. The powder form of paclobutrazol can cause mild to moderate irritation to the skin and eyes[8].

Maximum residue limits (MRLs): Neither CAC standards nor the European Commission have established MRLs for paclobutrazol. Countries including Japan, New Zealand, South Korea and Australia have set the MRL at 0.5 mg/kg. China's regulations specify maximum residue levels for potatoes, onions, and rapeseed oil and other products at 50, 15, and 0.5 mg/kg, respectively.

Methods for Reducing Residues of Plant Growth Regulators in Vegetables

Use of biopesticides

The application of biopesticides in vegetable production represents a major direction in the development of plant growth regulators. For example, gibberellin, secreted by *Gibberella* fungi, exhibits extremely low toxicity, while triacontanol, found in plant wax, beeswax, fruit peel wax, and bran wax, is relatively safer compared with other plant growth regulators. These natural plant growth regulators, derived from natural sources, play a significant role in producing green food and promoting sustainable agricultural development.

Selecting plant growth regulators with fast degradation, short residue period and low toxicity

With increasing public demand for vegetable quality and safety, as well as growing environmental awareness, highly efficient, short-residue, non-toxic (or low-toxic) and broad-spectrum plant growth regulators are receiving more and more attention. For example, ethephon, which has a residue period of only a few days, has been widely used in vegetable production. Under the premise of achieving the same effect, plant growth regulators with short residual periods and low toxicity should be selected. For example, uniconazole can be used instead of paclobutrazol to cultivate robust rapeseed seedlings. Uniconazole has the same physiological functions as paclobutrazol but exhibits higher activity, broader application range, and lower required dosage. Additionally, uniconazole has a shorter residual period and is safer for humans, livestock, and the environment[9].

Grasping correct concentrations, application frequency and periods

Plant growth regulators are generally used at low concentrations. The dosage should be minimized as much as possible without compromising biological effects. Too-high concentrations can not only cause phytotoxicity in vegetable crops but also increase residues in both the vegetables and the soil. The same plant growth regulator may require different concentrations for different vegetables or even different varieties of the same vegetable. Therefore,

it is advisable to conduct concentration tests before application to determine the appropriate dosage. Additionally, a safe interval period should be established, and the times of spray applications should be minimized. It is strictly prohibited to use plant growth regulators with strong toxicity or long residual period near and after harvest, so as to reduce the residual amouns in vegetables.

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(Continued from page 46)

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