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Degradation and distribution of imidacloprid in potatoes

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Abstract. The problem of translocation of the systemic pesticide imidacloprid in potato plants is addressed. The aim of the study was to investigate the pathways of movement, the dynamics of accumulation, and the degradation of the active substance in different plant parts. The field experiment was conducted in the Leningrad Region on the potato variety *Udacha*, with sampling of aboveground biomass from different parts of whole plants and tubers after treatment. Chemical analysis was performed using an in-house method based on the QuEChERS methodology with HPLC-UV detection. The results confirmed the predominantly xylem-mediated transport of imidacloprid, with maximum concentrations found in the upper foliage. A retrograde redistribution of the active substance downward along the foliage was observed 24 hours after treatment, which may be attributed to reverse flow in the xylem associated with nocturnal root pressure and guttation. Accumulation of imidacloprid residues in tubers was detected, with a peak concentration of 0.074 mg/kg on day 7, exceeding the established maximum residue limit (MRL) of 0.05 mg/kg. This finding suggests a possible downward (basipetal) transport, which is atypical for classic xylem-mobile compounds. The novelty of this study lies in the comprehensive experimental identification of the possible translocation pathways of imidacloprid and the assessment of its redistribution and degradation within the plant. The practical significance is demonstrated by the proven need for strict adherence to the pre-harvest interval for this pesticide on potatoes, as a temporary but significant exceedance of the MRL poses a potential toxicological risk.

Keywords: pesticides, pesticide degradation, QuEChERS, pesticide translocation

Author contributions: Alekseev E.Y. — methodology, study implementation, manuscript drafting and editing; Dolzhenko V.I. — study conceptualization and supervision. All authors read and approved the final manuscript. All authors contributed equally to this manuscript.

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Introduction

The movement of active substances of pesticides is an important and poorly understood area. Plant morphology and physiology, as well as the chemical properties of individual pesticide active substances, are highly variable, and the mechanisms underlying translocation processes are often insufficiently studied [1]. Field experiments show that neonicotinoids generally possess good systemic properties [2, 3]. Imidacloprid, one of the most popular neonicotinoids, exhibits clear xylem translocation, meaning it is found primarily in shoots and leaves [3, 4]. The upward movement of imidacloprid is determined by its chemical properties. Imidacloprid is expected to be detected in xylem rather than phloem. This is because it is a weak acid (present in non-dissociated form) and has a low transpiration stream concentration factor (TSCF) of 0.6 (ratio of concentration in xylem sap to concentration in the initial solution) [3]. However, in practice, when studying imidacloprid degradation dynamics, residual amounts are found in tubers, suggesting the possibility of limited phloem transport or a mechanism different from classical phloem mobility [3, 5, 6]. The maximum residue limit (MRL) for potatoes in Russia is 0.05 mg/kg[1].

The aim of the study was to assess degradation and distribution of systemic insecticide imidacloprid based on quantitative determination of its residual amounts in potato foliage and tubers.

Materials and methods

The study was conducted in 2020 in the Leningrad region by treating with an insecticide (suspension concentrate, SC) containing imidacloprid at an application rate of 0.28 L/ha, corresponding to 8.4 g/ha of imidacloprid active ingredient. The spray volume was 300 L/ha. The potato variety was *Udacha*. Sampling was performed daily for two weeks (except weekends), then every third day until harvest maturity. The study was conducted comprehensively, collecting foliage at different levels and root crops. The first sample was taken 2 hours after treatment. Collected potato samples were frozen at –18 °C and stored at the same temperature until analysis. Imidacloprid determination was performed according to the authors' method, based on extraction of the target component from samples with an organic solvent, extract

[1] Resolution of the Chief State Sanitary Doctor of the Russian Federation of January 28, 2021 No. 2 (as amended on December 24, 2025) "On approval of sanitary rules and regulations SanPiN 1.2.3685–21 'Hygienic standards and requirements for ensuring the safety and (or) harmlessness of environmental factors for humans'". Available from: https://www.consultant.ru/document/cons_doc_LAW_375839/ (Accessed 27th May 2026).

purification using the modified QuEChERS Original method, and subsequent analysis of the extract by high-performance liquid chromatography (HPLC) with an ultraviolet (UV) detector [7]. Imidacloprid identification was performed by retention time, and quantitative determination by the absolute calibration method.

Results and discussion

Accumulation and degradation of imidacloprid in different parts of potato shoots (Fig. 1). It was observed that the concentration of imidacloprid throughout the experiment was always higher in the upper part of the plant, despite the growth of new foliage. This further confirms the xylem nature of systemic imidacloprid transport. However, 24 hours after treatment, a clear redistribution of imidacloprid from the upper part to the middle and lower parts was evident. This may be explained by retrograde transport.

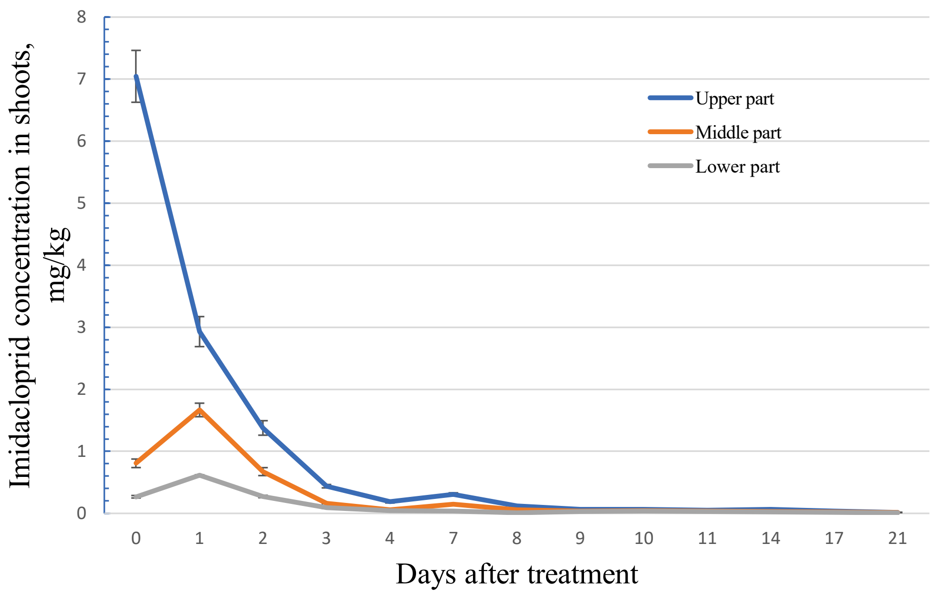

Fig. 1. Dynamics of imidacloprid accumulation and degradation in various parts of potato shoots
Source: compiled by E.Y. Alekseev.

During the day, the plant actively loses water through leaf stomata (transpiration). Upper, young leaves typically have the highest transpiration activity. The concentration of imidacloprid immediately after treatment and in the first hours during the day will be higher in zones of active transpiration (the top).

At night, stomata close, and transpiration sharply decreases or ceases. However, roots continue active absorption of water and mineral salts from the soil. This creates positive osmotic pressure (root pressure) in the xylem [8].

If the soil is sufficiently moist and root pressure is strong, excess water with dissolved substances cannot be lost through transpiration [9, 10]. The pressure pushes dissolved xylem substances upward through the vessels. However, since the upward path is partially closed by stomata, the pressure finds an exit through specialized structures — hydathodes (water stomata), located primarily at the tips and edges of leaves, and often in lower (older) leaves [11, 12]. Liquid is released outward as droplets (guttation) [8, 12]. The process of fluid movement under pressure upward and its release through hydathodes can cause local reverse currents (retrograde flows) in the xylem. Substances (including imidacloprid) that were transported to the upper and middle parts of the plant during the day may be captured by this upward but subsequently "reflecting" flow and carried back downward toward the hydathodes of lower leaves. A portion of imidacloprid may be released with the droplet [13–15]. The pesticide originally located in the upper parts was "pushed" downward by retrograde flows under the influence of nocturnal root pressure.

Accumulation and degradation of imidacloprid in tubers (Fig. 2). Despite the apparent movement of imidacloprid through the xylem, residual amounts were present in tubers. The detection of imidacloprid in tubers may indicate the possibility of imidacloprid movement through the phloem or a similar mechanism.

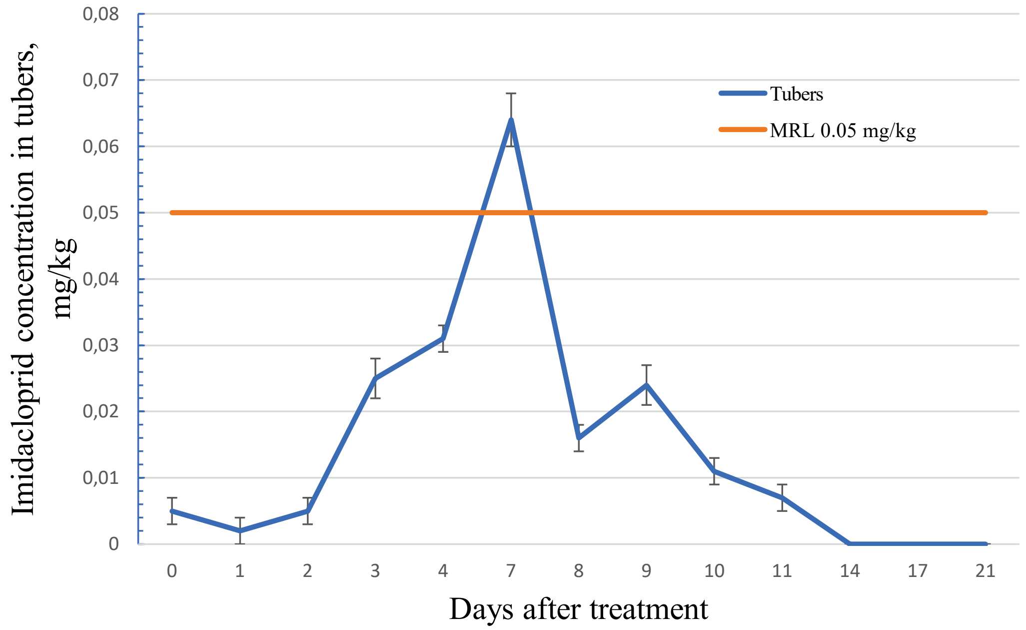

Fig. 2. Dynamics of imidacloprid accumulation and degradation in potato tubers
Source: compiled by E.Y. Alekseev.

Notably, the peak accumulation was reached on day 7, exceeding the maximum residue limit (MRL). Although the concentrations of imidacloprid residues found in tubers are relatively low compared to those in the shoots, they may be toxicologically significant. This indicates that adherence to pre-harvest intervals is critically important for this insecticide.

Conclusion

Various parts of the potato plant were analyzed. The xylem nature of imidacloprid translocation was confirmed. In addition, atypical accumulation of imidacloprid in the middle and lower parts of the shoots was detected 24 hours after treatment, which may be explained by retrograde transport, root pressure, and guttation during the night. It was also shown that, atypically for a systemic neonicotinoid, residual amounts accumulated in potato tubers, indicating a downward mechanism of imidacloprid movement. The maximum peak of imidacloprid accumulation in tubers exceeded its MRL, which is toxicologically significant. However, at the end of the experiment (after expiration of the pre-harvest interval), no residual amounts were detected**.**

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Деградация и распространение имидаклоприда в картофеле

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Аннотация. Рассмотрена проблема транслокации системного пестицида — имидаклоприда — в картофеле. Цель — изучить пути движения, динамику накопления и деградации исследуемого действующего вещества в различных частях растения. Эксперимент проводился в полевых условиях Ленинградской области на сорте Удача с отбором проб ботвы из разных частей целого растения и клубней после обработки. Анализ выполнялся по авторской методике на основе методологии QuEChERS с использованием ВЭЖХ-УФ детектирования. Результаты подтвердили преобладающий ксилемный транспорт имидаклоприда с максимальными концентрациями в верхней ботве. Обнаружено ретроградное перераспределение действующего вещества вниз по ботве через 24 часа, что возможно объясняется обратными потоками в ксилеме, связанными с ночным корневым давлением и гуттацией. Установлено накопление остатков имидаклоприда в клубнях с пиковой концентрацией (0,074 мг/кг) на 7-е сутки, превысившей установленный максимально допустимый уровень (МДУ) 0,05 мг/кг. Это указывает на возможный нисходящий транспорт, не характерный для классической ксилемной мобильности. Уникальность исследования заключается в комплексном экспериментальном выявлении возможных путей движения имидаклоприда и оценке его перераспределения и деградации в растении. Практическая значимость заключается в доказанной необходимости строгого соблюдения сроков ожидания для данного препарата на картофеле, поскольку временное, но значимое превышение МДУ создает возможный токсикологический риск.

Ключевые слова: пестициды, деградация пестицидов, QuEChERS, транслокация пестицидов

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