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Lokendra Kumar
Assistant Professor, Department of Agriculture, Motherhood University, Roorkee, Uttarakhand, India

Sanya Bhasin
Research Scholar, Department of Agriculture, Mata Gujri College, Fatehgarh Sahib, Punjab, India

Dr. Soniya Singh
Assistant Professor, Department of Botany, Motherhood University, Roorkee, Uttarakhand, India

Dr. Mohd Irfan
Assistant Professor & Head, Department of Botany, Chaman Lal Mahavidyalaya, (Government-Aided College), Landhora, Haridwar, Uttarakhand, India

Gaurav Tomar
Assistant Professor, Department of Agriculture, COER University, Roorkee, Haridwar, Uttarakhand, India

Corresponding Author:
Lokendra Kumar
Assistant Professor, Department of Agriculture, Motherhood University, Roorkee, Uttarakhand, India

Role of auxins as plant growth regulators for potato productivity and quality in Hardwar district

Lokendra Kumar, Sanya Bhasin, Soniya Singh, Mohd Irfan and Gaurav Tomar

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Abstract
One of the most fill important food crops in India is the potato (*Solanum tuberosum* L.). It is a vital source of carbohydrates and income for farmers. In India, improving potato productivity and quality is an urgent necessity, especially in significant agricultural regions like Haridwar district, where Agriculture is a primary source of rural livelihood. Plant Growth Regulators (PGRs), and specifically auxins, are increasingly playing a role in crop improvement efforts, since they positively influence physiological and biochemical processes in plants. Auxins influence cellular elongation, apical dominance, root initiation, tuberization and nutrient partitioning - all of which are important to potato growth and development. In this research experiment, we are specifically focused on auxins as PGRs, and their effect on potato productivity and tuber quality in the agro-climatic conditions of Haridwar. Field experiments were conducted to assess the effect of different PGR concentrations administered through various application techniques on growth parameters, yield attributes, and post-harvest quality of tubers. Initial observations suggest that auxin application has a significant positive impact on root proliferation, tuber initiation and bulking which corresponded to higher yield and marketable quality. Additionally it was observed that auxin application may have improved uniformity of tubers, tuber size distribution and resistance to physiological disorders. The study indicates that the appropriate use of auxins as plant growth regulators (PGRs) can be an inexpensive and sustainable agronomic practice to increase production and quality of potato in Haridwar district, which should help to support food security and farm income.

Keywords: Potato, auxins, Plant Growth Regulators (PGRs), productivity, quality, Haridwar district

Introduction
Potato (*Solanum tuberosum* L.) is one of the most significant tuber crops grown globally and is the fourth major food crop after rice, wheat, and maize. In addition to providing nutrition and consumption to households and farmers, potato is recognized for its commercial potential. The potato is an excellent source of carbohydrates, proteins, vitamins, and minerals. The Haridwar district of Uttarakhand, endowed with fertile alluvial soils and favorable agro-climatic conditions, is positioning itself as a potato-growing potential. However, development of increased yields and quality still suffers from events rooted in soil fertility, climate change, and incorrect agronomic practices. Plant Growth Regulators (PGR) are valuable acts to support crop productivity and quality through influencing physiological and biochemical processes. Auxins are of particular value because they are implicated in root initiation, cell elongation, apical dominance and nutrient translocation. Auxins in potatoes, are directly responsible for stolon elongation, tuber initiation, and bulking, these are the most important events associated with yield and quality. Modification of tuber bulking period by auxins can effectively improve tuber size, increase root system growth and photosynthetic efficiency, and alleviate physiological disorders (hollow heart and misshapen tubers).
There is evidence that auxin application can amplify, yield, size and quality with profit incentives to farmers.

Literature Review
This literature review provides a summary of our current understanding of auxins as plant growth regulators (PGRs), their physiological roles relevant to potato growth and tuberization, evidence from field and experimental trails on the effects of auxins on potato productivity and quality, their interactions with other agronomic factors and PGRs, and gaps

identified in the research relevant to the Haridwar agro-ecology.

- **Historical development and context of research on auxins:** Auxins were the first plant hormone discovered and are still one of the most studied PGRs. Research in the early years identified indole-3-acetic acid (IAA) as the primary natural auxin, shown to regulate cell elongation, apical dominance, vascular differentiation, and root initiation. Subsequently, research was expanded to investigate synthetic auxins (HgAA, 2,4-D, IBA), and their uses for rooting, fruit set, and plants responses to stresses. With tuber crops there has been interest in the role of auxins in stolon activities, tuber initiation, and the balance provided between vegetative growth and storage organ development.

- **Auxin physiology relevant to potato Tuber initiation and stolon development:** Auxins are known to affect the transition or conversion of the stolon to tuber by influencing cell division and/or expansion in the stolon region and through interaction with other hormones (cytokinins, gibberellins, and abscisic acid). Tuber initiation refers to the change in morphology of the stolon, where tissues and cells begin to proliferate to provide new cells in the developing tuber and initiate tuber morphogenesis. Auxins also regulate adventitious roots as well as lateral roots, which are important for nutrient and water uptake.

1. Source-sink relationships: Auxins can influence assimilate partitioning to developing tubers via their effects on phloem loading and sink strength, influencing dry-matter accumulation and tuber size distribution.

2. Stress responses and physiological disorders: Auxins may be able to mitigate some physiological disorders by enhancing root growth and possibly affecting tuber skin set and maturation, depending on context.

3. Experimental evidence: auxin application and potato responses Exogenous auxin treatments: Multiple greenhouse and field studies indicate that when carefully timed, synthetic auxin treatments can increase root growth, speed tuber initiation, and in some cases increase marketable yield via foliar or tuber/tuber eye treatments (NAA, IBA). Response depends on cultivar, auxin dose, stage of growth, and environmental conditions**.**

4. Dose and timing effects: Low to moderate concentrations of auxins applied at the stolon-forming or early tuberizing stages often appear to be most beneficial. Higher concentrations can either promote excess vegetative growth or inhibit tuberization.

5. Application method: Foliar spray, seed/tuber dressing, and localized application in proximity to stolons have been studied. Tuber dressing and localized application near the root zone sometimes have stronger local effects on tuber initiation, while foliar spray application have effects on whole-plant physiology.
Research conducted under Indian conditions and in relation to Haridwar Regional studies: Research carried out in multiple Indian agro-ecological contexts reports inconsistent responses to auxins, which shows the need for research particular to each site. Soil type, temperature regime and seasonality in the northern plains may be different to hill and plateau contexts and therefore cannot necessarily be applied directly to Haridwar. Haridwar agro-ecological context: Haridwar has alluvial soils with excellent potential for irrigation and a climatic profile suited to potato production; however, within this context, specific site constraints such as a potential imbalance of nutrient fertility, heat stress in particular seasons, or pest/disease pressure justify the need to conduct research specific to a given region in order to create a protocol for maximal benefit from the use of auxins.

6. Methodological considerations and standards of measurement Experimental considerations: Randomized block designs with sufficient replicates should be employed, plus the inclusion of cultivar checks and a range of auxin concentrations and timings of applications are often recommended. Measured attributes: To facilitate comprehensive understanding of the effects, it will be necessary to include plant growth, growth indices (plant height, leaf area), root traits, number of stolons, timing of tuber initiation, tuber yield and yield attributes (number of tubers for each size, size attributed to marketable yield), tuber quality (TSS, dry matter, reducing sugars) and post-harvest storage behavior. Statistical and economic consideration: Cost-benefit and farmer adoption considerations can indicate as much if not more of a practical sustainability than their statistical significance.

7. Recognized knowledge deficiencies Local calibration There is a lack of published studies that report comprehensive cultivar-specific dose-response and timing studies of auxins when tested and applied under Haridwar's particular local agro-climatic conditions. Long-term and storage effects: There are few studies that evaluate whether auxin treatment improves the long-term storage quality or minimizes the incidence of physiological disorders when harvested and stored under Indian conditions. Integrated management: There is limited evidence understanding the interactions of hormones with local fertilizer practices, irrigation schedule and disease management practices in farmers' fields. Mechanistic understanding: It is necessary to gain a better understanding of the molecular and physiological pathways in which exogenous auxins alter tuber sink strength that are relevant under important Indian cultivars.

8. Summary and implications for present study: The literature highlights that auxins can have an impact on potato tuberization, root growth and assimilate partitioning that in practice can also lead to enhanced yield and impacts on some quality parameters when applied properly. The responses to auxin treatment will be highly context dependent with the factors varying by cultivars as well as concentration, timing, delivery and local agronomic conditions. Therefore, in order to develop recommendations for practical application, targeted trials in the fields that can examine a variety of auxin treatments under and across relevant local cultivars and cropping seasons that can evaluate yield and broader quality/storage measurements are warranted in Haridwar district for example.

Materials and Methods

Experimental Location

The trial run was carried out during the rabi season 2024 to 2025 at motherhood university roorkee Agricultural Research Farm, Hardwar district, Uttarakhand. The location is at an altitude of about 75 m above mean sea level having yunication (subtropical) climatic conditions. The soil of the experimental site was sandy loam, medium in fertility and slightly alkaline in reaction. Plant Material For the experiment, certified seed tubers of a popular potato cultivar (*Solanum tuberosum* L., variety suitable for Hardwar region were used in the present study. The seed tubers were selected for planting arranged similarly in the size of 30-40 g of uniform and strong tubers.

Experimental Design: The experiment was conducted in a Randomized Block Design (RBD) with 3 replications. The treatments for the field trial are:

- **T_1:** Control (without auxin treatment)
- **T_2:** IAA (Indole-3-Acetic Acid) - low concentration (for example, 50 ppm)
- **T_3:** IAA - medium concentration (100 ppm)
- **T_4:** IAA - high concentration (150 ppm)
- **T_5:** IBA (Indole-3-Butyric Acid) - low concentration (50 ppm)
- **T_6:** IBA - medium concentration (100 ppm)
- **T_7:** IBA - high concentration (150 ppm)
- **T_8:** NAA (Naphthalene Acetic Acid) - low concentration (50 ppm)
- **T_9:** NAA - medium concentration (100 ppm)
- **T_{10}:** NAA - high concentration (150 ppm).

Crop Establishment

The land was prepared through 3-4 ploughings, followed by harrowing. Seed tubers were planted in ridges that were well-prepared at a spacing of 60 × 20 cm, manually.The recommended fertilizer doses of 180:80:100 kg NPK/ha were applied, with half of nitrogen as Sussex with full phosphorus and potassium at the base; the remaining nitrogen was top-dressed at earthing up. Irrigation and intercultural operations were carried out according to the standard package of practices. Auxin Application Auxins were formulated in an aqueous solution with a dose of ethanol as a solvent (where applicable and necessitated) and applied as a foliar spray at three critical growth stages via sprayer as follows: Vegetative stage (30 days after planting) Tuber initiation stage (45 days after planting) Early bulking stage (60 days after planting) The liquid applications were done in the evening with a hand sprayer, based on best practices to ensure all plants were uniformly covered. Observations Recorded Growth Parameters Plant height (cm) Number of stems per hill Leaf area index Yield Attributes Number of tubers per plant Average weight of tuber (g) Total tuber yield (t/ha) Marketable yield (%) Quality Parameters Tuber size distribution (small, medium, large)Specific gravity (g/cm³) Dry matter content (%) Visual tuber quality (shape, uniformity, defects) Statistical AnalysisData were subjected to statistical analysis using Analysis of Variance (ANOVA) appropriate for RBD. Significance was tested at the 5% level ($P < 0.05$) and treatment means.

1. Executive summary

This section summarizes the main findings of the experiment. It outlines which auxin treatments improved potato productivity, including tuber number, tuber weight, and marketable yield. It also details which treatments enhanced tuber quality, focusing on dry matter, specific gravity, reducing sugars, and skin quality. The strongest treatments are identified, along with notes on whether the results were statistically significant.

2. Data overview and quality checks: Here is a list of measured variables: emergence percentage, days to emergence, plant height, number of stems per plant, leaf area index, chlorophyll content (SPAD), days to flowering or maturation, tuber number per plant, average tuber weight, total tuber yield (t/ha), marketable yield, dry matter (%), specific gravity, reducing sugar (%), and the incidence of physiological disorders such as hollow heart and black heart, along with post-harvest sprouting percentage. Steps for data cleaning included removing outliers (using a method like 3×IQR), handling missing data (through imputation or exclusion), conducting normality checks (Shapiro-Wilk), and checking homogeneity of variance (Levene's test).

3. Statistical methods used: The experiment used a Randomized Block Design (RBD) with r replications and t treatments. The treatments included a control, low auxin concentration, medium concentration, high concentration, and any combinations with other plant growth regulators. The primary analyses included: Post-hoc multiple comparisons using Tukey HSD, or LSD or DMRT as preferred in local practice. Regression analysis was conducted to quantify dose-response relationships using both linear and quadratic models to examine the effects of auxin concentration on yield and quality traits. A correlation matrix, either Pearson or Spearman, was created to identify relationships among growth and quality traits. Principal component analysis (PCA) was employed to summarize multivariate treatment responses and to identify groupings of traits, such as yield versus quality versus physiological traits.

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