Synergy of Polyphosphates and Orthophosphates: An Advanced Strategy for Root Nutrition and Bioactive Stability

Parra, J.; Quirós, J.; Barrantes, D. Formulaciones Químicas S.A.: Puntarenas, Costa Rica.

■ ABSTRACT

The present study analyzes the chemical configuration of a complex NPK fertilizer (approximate grade 10-21-5) that integrates a dual phosphorus release strategy through the combination of polyphosphate and orthophosphate salts. This formulation not only guarantees immediate nutrient availability but also establishes a macromolecular reservoir that resists soil fixation, while enabling the stable coexistence of steroidal phytohormones and essential micronutrients.

■ INTRODUCTION

The efficiency of phosphate fertilization is one of the greatest challenges in agricultural chemistry due to the high rate of phosphorus insolubilization in the presence of metallic cations. The NPK formula with brassinosteroids, developed by Formulaciones Químicas S.A., addresses this issue through a molecular design that optimizes systemic mobility and nutrient longevity in the rhizosphere.

The stability of a phosphated multimineral concentrate is justified by fundamental properties of coordination compounds and other physical properties. In contrast, the structural efficiency of the mixture is justified through the use of complementary growth hormones and large molecules that constitute long-term nutrients, resistant and compatible with other nutrients such as potassium and nitrogen.

■ EXPERIMENTAL

A 500.00 mL sample of the described multimineral concentrate was prepared in triplicate according to the following characteristics.

Table I. Nutritional Summary of the NPK Fertilizer with Brassinosteroids

Nutritional Component	**Approximate Concentration (% w/v)**	**Main Function**
Total Nitrogen (N)	10.0–11.5	Vegetative development and protein synthesis
Total Phosphorus (P_2O_5)	21.0–22.5	Energy (ATP) and dual root development
Soluble Potassium (K_2O)	5.0–6.0	Osmotic regulation and crop vigor
Total Sulfur (S)	1.8–2.3	Biosynthesis of essential amino acids
Micronutrients (Zn, Mn)	0.05–0.10	Enzyme activation and chlorophyll synthesis

Bioactive Compounds*	Traces (< 0.005)	Hormonal stimulation and anti-stress activity

* Includes steroidal phytohormones and primary fatty alcohols (Triacontanol).

■ RESULTS DISCUSSION

To regulate the quality of chemical formulations in agriculture, the references cite the joint FAO and WHO manual (specifically the 2004 edition aligned with CIPAC standards), which establishes that formulations must undergo critical physical tests to ensure stability. The following table details the results obtained from these physicochemical properties for the NPK fertilizer with brassinosteroids.

Table II. Physical Properties Obtained in the NPK Fertilizer Sample with Brassinosteroids.

Parameter	Control Range	Measurement Conditions
Hydrogen Potential (pH)	6.0–7.0	Measured at 25 °C
Relative Density	1.270–1.295 g/mL	Measured at 20 °C
Appearance	Concentrated liquid	Compatible with artificial blue dyes
Phase Stability	Homogeneous	No precipitates present

The core of this technology is the balanced combination of monoammonium phosphates and ammonium polyphosphates. Orthophosphate provides immediately available phosphorus in the form of $H_2PO_4^-$, while polyphosphate, formed by condensed phosphorus units, functions as a gradual-release reserve. This inorganic polymer exhibits greater resistance to adverse conditions such as precipitation with iron and aluminum in acidic soils. As its chains hydrolyze, it releases phosphorus in a sustained manner into the root system, extending its contribution beyond that of conventional fertilizers.

The stability of the formula is based on the thermodynamic balance provided by a 50/50 mixture of orthophosphates and ammonium polyphosphates. Within the density range of 1.270 to 1.295 g/mL, the liquid matrix reaches a saturation level at which polyphosphate macromolecules favor dispersion and increase the overall solubility of the system. Unlike mixtures composed solely of orthophosphates, which tend to crystallize at these densities, the controlled hydrolysis and polymeric structure of polyphosphate maintain a high ionic strength without exceeding the solubility product constant (Ksp), thereby preventing unwanted salt precipitation.

Verification of the pH range is important, as this physicochemical property constitutes a fundamental component of fertilizer stability. pH values below 6.0 would favor phosphorus fixation with iron and aluminum, whereas values above 7.0 would induce the formation of insoluble calcium phosphates. The inclusion of potassium thiosulfate provides a dual benefit: it supplies ionic potassium for osmotic regulation and enzymatic activation, while also incorporating sulfur as an essential micronutrient. Sulfur is important for the biosynthesis of amino acids such as cysteine and methionine, fundamental components of plant proteins.

A disruptive scientific contribution of this formula is its physicochemical stability for hosting low-concentration growth regulators, specifically brassinosteroids. These hormones are steroidal chemical messengers possessing a four-ring structure. The liquid matrix, stabilized with chelating agents such as EDTA to protect cations such as Zn^{2+} and Mn^{2+}, maintains a pH and ionic strength that prevent degradation of these bioactive compounds, enabling them to effectively stimulate cellular development and resistance to physiological stress. In the prepared samples, no precipitation or phase separation resulting from the mixture of brassinosteroids or zinc and manganese salts was observed under normal storage conditions: 22–28 °C, 80% relative humidity, and pressure close to 1 atm.

The stability of these micronutrients (Zn^{2+} and Mn^{2+}) within this high-density matrix is explained through coordination chemistry. EDTA acts as a strong-field ligand (electron-density-accepting ligand), leading to a large octahedral field splitting parameter (Δo). As a high-field ligand, EDTA forms extremely stable chelated complexes that protect metallic cations such as zinc and manganese from direct interaction with phosphate anions. This strong-field stabilization ensures that micronutrients remain in solution and are fully bioavailable to the root system.

■ CONCLUSION AND RECOMMENDATION

The NPK formula with brassinosteroids represents a significant contribution to agronomic engineering in the development of liquid fertilizers. By combining short- and long-term phosphate nutrition with a mineral base rich in sulfur and stable phytohormones, a product with superior functionality is achieved for stimulating functional and vigorous roots, indispensable during critical crop growth stages.

■ REFERENCES

(1) Navarro Blaya, S.; Navarro García, G. Agricultural Chemistry: Soil and Essential Chemical Elements for Plant Life, 2nd ed.; Ediciones Mundi-Prensa: Madrid, 2003; pp. 233–247, 321–336.

(2) Masís Meléndez, F.; Hernández Chaverri, R.; Piedra Marín, G. Agricultural Chemistry; Editorial Universidad Estatal a Distancia (EUNED): San José, Costa Rica, 2017; pp. 249–288.

(3) Chang, R. Chemistry, 10th ed.; McGraw-Hill: Mexico, 2013; pp. 952–978.

(4) Carbonero Zalduegui, P. Soil and Fertilizer Chemistry; Department of Biotechnology, Polytechnic University of Madrid: Madrid, Spain; pp. 95–108.

(5) Housecroft, C. E.; Sharpe, A. G. Inorganic Chemistry, 4th ed.; Pearson: Harlow, England, 2012.

(6) Subbarao, Y. V.; Ellis, R. Phosphorus Reactions as Affected by Concentrated Polyphosphate Fertilizer. J. Agric. Food Chem. 1975, 23 (4), 740–744.

(7) Martell, A. E.; Smith, R. M. Critical Stability Constants, Vol. 1: Amino Acids; Plenum Press (ACS Monograph): New York, 1974.