



“Optimizing Macro–Micro Nutrient Regimes And Plant Spacing For Enhanced Seed Yield And Profitability Of Bari Kalozira-1 And Rz-19 Varieties”

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ABSTRACT

Spice seed crops such as black cumin (kalozira) and cumin contribute substantially to smallholder income and national spice supply in South Asia. This research paper presents an experiment-ready framework to optimize macro- (N, P, K) and micro-nutrient (S, Zn, B, etc.) regimes together with plant spacing to maximize seed yield and profitability of two commercially important varieties: BARI Kalozira-1 and RZ-19. Drawing on varietal descriptions and recent agronomic studies, we propose a split-plot field experiment with nutrient regime as the main plot and plant spacing as subplots, factorially tested on both varieties across two seasons. Expected outcomes include identification of economically optimal fertilizer packages and spacing combinations that increase seed yield, harvest index and net returns while maintaining seed quality.

Keywords: Bari kalozira-1, rz-19, black cumin, cumin, plant spacing.

I. INTRODUCTION

The cultivation of spice crops such as cumin (*Cuminum cyminum*) and black cumin or nigella (*Nigella sativa*) has long been an integral component of agricultural systems in South Asia and beyond, where they hold not only culinary significance but also medicinal and economic importance. These crops are valued for their seeds, which are used as condiments, flavoring agents, and in traditional medicine due to their essential oil content and therapeutic properties. In recent decades, the demand for cumin and black cumin has steadily increased in both domestic and international markets, placing greater emphasis on strategies that enhance productivity and profitability while ensuring sustainability. Among the improved varieties of these crops, BARI Kalozira-1 developed by the Bangladesh Agricultural Research Institute (BARI) and RZ-19, a widely cultivated cumin variety adapted to semi-arid regions of India, have demonstrated significant promise for farmers. Despite their genetic potential, yields in farmer's fields often remain suboptimal due to inadequate nutrient management, inappropriate plant spacing, and limited adoption of integrated agronomic practices. Therefore, optimizing macro–micro nutrient regimes in conjunction with plant spacing is a critical area of investigation to unlock the yield potential of these varieties and to improve farmer profitability [1].

Plant nutrition represents one of the fundamental pillars of crop productivity. The macronutrients nitrogen (N), phosphorus (P), and potassium (K) are required in relatively large quantities to sustain plant growth and development. Nitrogen is central to vegetative growth, chlorophyll formation, and protein synthesis; phosphorus is essential for root growth, energy transfer, and reproductive development; and potassium plays a vital role in osmoregulation, enzyme activation, and stress tolerance. In crops such as cumin and black cumin, the balance of these macronutrients determines not only the magnitude of biomass production but also the efficiency of flowering, seed setting, and ultimately, seed yield. However, macronutrient application alone is not sufficient, particularly in soils that are inherently deficient in essential micronutrients such as zinc (Zn) and boron (B). Micronutrients, though required in much smaller quantities, perform critical physiological and biochemical functions, including hormone regulation, pollen viability, seed development, and enzyme activation. Research has shown that deficiencies in zinc and boron can result in poor seed set, reduced seed weight, and compromised seed quality, all of which directly impact economic returns. Hence, the synergistic management of macro- and micronutrients offers a pathway to maximize seed yield and quality in cumin and black cumin production systems [2].

Alongside nutrient management, plant population density regulated through appropriate plant spacing is another critical factor influencing productivity. The spacing between plants dictates the degree of intra-specific competition for light, water, and nutrients, and it significantly affects branching, canopy architecture, and seed yield components. Very narrow spacing results in overcrowding, which can lead to competition for resources, reduced individual plant growth, and susceptibility to pest and disease outbreaks due to microclimatic changes in the crop canopy. Conversely, very wide spacing reduces the number of plants per unit area, leading to underutilization of land resources and lower yields on a per-hectare basis, despite potentially robust individual plant growth. The challenge, therefore, lies in identifying an optimal spacing that balances plant density with per-plant productivity to achieve the highest seed yield per unit area. In spice crops such as cumin and black cumin, where seed size and seed weight are highly influenced by nutrient availability and space, the interaction between spacing and nutrient management becomes particularly important [3].

The varieties BARI Kalojira-1 and RZ-19 present unique opportunities for examining these interactions. BARI Kalojira-1, developed and released by BARI, has been reported to exhibit improved adaptability, moderate plant height, and higher yield potential compared to local landraces of black cumin. It matures within 135–145 days and has shown positive responses to balanced nutrient application in field trials. RZ-19, on the other hand, is a cumin variety widely adopted in Rajasthan and neighboring regions of India, known for its stability, adaptability to arid conditions, and moderate seed yield potential under rainfed and irrigated conditions. Although both varieties have distinct agro-ecological adaptations, they share common physiological needs that make nutrient and spacing optimization equally relevant. Comparative studies involving these varieties can shed light on varietal differences in response to agronomic management, enabling more tailored recommendations to farmers.

Past research on cumin and black cumin has highlighted the significance of nutrient management and plant spacing in shaping yield outcomes, but the majority of studies have been conducted in isolation. Fertilizer trials often focus exclusively on macronutrient levels without considering the role of micronutrients, while spacing trials tend to neglect the interaction between spacing and nutrient availability. Yet, crop productivity is seldom influenced by a single factor; it is rather the cumulative effect of multiple interacting factors that defines yield potential and profitability. A factorial approach that evaluates the combined effects of nutrient regimes and plant spacing, especially across different varieties, is therefore essential. Such an approach not only identifies the best agronomic practices but also helps in understanding whether certain varieties respond better to intensive management than others [4].

Beyond biological yield, economic considerations are equally critical in determining the viability of agronomic practices for farmers. Fertilizers represent one of the major input costs in cumin and black cumin cultivation, and their overuse not only increases production costs but also poses environmental risks such as nutrient leaching and soil degradation. Similarly, adjusting plant spacing often involves changes in seed rate, labor for sowing, and subsequent weeding or irrigation practices, all of which influence cost of cultivation. The ultimate measure of success for any agronomic intervention lies not in yield alone but in profitability, expressed as net return and benefit-to-cost (B:C) ratio. Hence, research aimed at optimizing nutrient and spacing regimes must integrate economic analysis to ensure that the recommendations are not only agronomically sound but also financially attractive to resource-constrained farmers [5].

II. NUTRIENT MANAGEMENT EFFECTS

Nutrient management plays a decisive role in determining the growth, yield, and profitability of spice crops such as cumin (*Cuminum cyminum*) and black cumin (*Nigella sativa*). Both crops are nutrient-demanding despite being cultivated in relatively low-input systems by smallholder farmers in South Asia, particularly in Bangladesh and India. Among the macronutrients, nitrogen, phosphorus, and potassium are the most influential in shaping crop productivity. Nitrogen serves as the driving force for vegetative growth, chlorophyll synthesis, and enzyme activity, directly contributing to biomass accumulation and branching, which are crucial in crops like cumin and black cumin where seed yield is largely dependent on the number of umbels or capsules produced per plant. Phosphorus enhances root development, energy transfer, and reproductive efficiency, ensuring timely flowering and improved seed set. Potassium, often referred to as the “quality nutrient,” regulates water balance, improves disease resistance, and enhances seed filling, ultimately increasing thousand-seed weight and seed quality parameters. Together, these macronutrients determine the foundation of growth and yield, and their balanced application is far more effective than individual or skewed use [6].

Micronutrients, although required in smaller quantities, exert profound effects on yield and quality. Zinc (Zn) is essential for auxin synthesis, enzyme activation, and pollen development, and deficiencies often lead to poor seed set and reduced seed weight. Boron (B) plays a pivotal role in cell wall formation, sugar transport, and reproductive processes such as fertilization and seed development. In cumin and black cumin, boron deficiency has been linked to reduced capsule formation, lower seed numbers per capsule, and ultimately diminished yields. Studies from related oilseed and spice crops indicate that supplementation with zinc and boron significantly enhances seed set, seed weight, and essential oil content, thereby improving both biological yield and market value. Thus, integrated management that combines macronutrients with key micronutrients is vital to exploit the genetic potential of improved varieties such as BARI Kalozira-1 and RZ-19 [7].

However, nutrient management is not only about maximizing yield but also about optimizing economic efficiency and sustainability. Excessive application of nitrogen, for example, can lead to lodging, delayed maturity, and reduced seed quality, while increasing input costs and causing environmental risks through leaching and volatilization. Similarly, imbalanced nutrient application—such as using nitrogen without adequate phosphorus and potassium—results in inefficient nutrient use and depressed yields. The challenge lies in determining the optimum dose and combination of nutrients that produce the highest yield without compromising profitability or soil health. Integrated approaches that blend chemical fertilizers with organic amendments such as farmyard manure or compost are increasingly recommended, as they improve soil structure, enhance nutrient use efficiency, and sustain yields over time.

For farmers cultivating BARI Kalozira-1 and RZ-19, adopting an evidence-based nutrient management strategy can translate into substantial yield gains and higher net returns. Recommended doses of NPK, when supplemented with zinc and boron, are expected to improve seed yield per hectare and raise the benefit-to-cost ratio, especially when applied in combination with appropriate plant spacing. Ultimately, nutrient

management effects extend beyond immediate yield benefits, influencing long-term soil fertility, input-use efficiency, and the sustainability of spice crop cultivation in diverse agro-ecological regions [8].

III. NPK & SPACING EVIDENCE

The interplay between nutrient management and plant spacing is a critical determinant of seed yield and crop profitability in spice crops such as cumin (*Cuminum cyminum*) and black cumin (*Nigella sativa*). Field experiments and agronomic studies have consistently demonstrated that the response of these crops to NPK fertilization is closely influenced by the spatial arrangement of plants, and vice versa. Nitrogen, phosphorus, and potassium collectively regulate vegetative growth, flowering, and seed development, but their efficiency depends on the number of plants per unit area and the competition for light, water, and nutrients. Experimental evidence indicates that applying recommended doses of NPK enhances the number of branches per plant, umbel or capsule formation, seed number per capsule, and thousand-seed weight, resulting in higher overall yields. For instance, trials with BARI Kalozira-1 have shown that moderate nitrogen application (80–100 kg N ha⁻¹) combined with balanced phosphorus and potassium promotes vigorous vegetative growth without inducing excessive vegetative biomass, which can delay flowering or increase susceptibility to lodging. Similarly, studies on RZ-19 have demonstrated that optimal NPK rates improve both seed yield and quality, particularly under irrigated conditions where nutrient uptake is more efficient [9].

While macronutrients alone significantly influence productivity, their effects are modulated by plant density, which is determined by row-to-row and plant-to-plant spacing. Narrow spacing tends to increase plant competition, leading to reduced branching, smaller capsule size, and fewer seeds per capsule, despite high nutrient availability. Conversely, very wide spacing allows individual plants to develop larger canopies and more branches, but the reduced number of plants per unit area can limit total seed yield per hectare. Evidence from factorial field experiments on cumin and black cumin has shown that intermediate spacing often provides the best balance between per-plant growth and population-level yield. For example, inter-row spacing of 20–30 cm combined with intra-row spacing of 10–15 cm has been found optimal for both BARI Kalozira-1 and RZ-19, maximizing light interception and nutrient utilization while avoiding excessive competition [10].

The interaction of NPK rates with spacing further illustrates that fertilizer efficiency is highly context-dependent. Studies indicate that high nitrogen doses are most effective under optimal spacing because overcrowded plants cannot utilize additional nutrients efficiently, leading to diminishing returns. Similarly, the positive effects of phosphorus and potassium on flowering and seed setting are more pronounced when plants have sufficient space to develop a healthy canopy and root system. Field data also show that the addition of micronutrients such as zinc and boron amplifies the benefits of NPK fertilization, particularly under intermediate spacing, as these nutrients improve pollen viability, seed set, and thousand-seed weight. The combined effect of balanced macronutrients, targeted micronutrients, and optimal spacing has been reported to increase seed yield by 20–35% compared with control plots where only basic NPK or wider/narrower spacing was applied [11].

Economic analyses of these experiments further emphasize the importance of integrating nutrient and spacing strategies. While higher fertilizer doses may increase gross yield, the net profitability is maximized when intermediate plant spacing is combined with moderate NPK and micronutrient application. This approach ensures efficient input use, minimizes wastage, and enhances the benefit-to-cost ratio, making it more suitable for smallholder farmers who face constraints on fertilizer availability and land resources. Overall, the evidence underscores that neither NPK application nor plant spacing should be considered in isolation; their interaction is central to achieving both high biological yield and economic returns in BARI Kalozira-1 and RZ-19 cultivation.

IV. BARI KALOZIRA-1 AND RZ-19 VARIETIES

The selection of appropriate crop varieties is a fundamental component of modern agronomic research, particularly when the goal is to optimize yield and profitability under variable nutrient and spacing regimes. In the context of cumin (*Cuminum cyminum*) and black cumin (*Nigella sativa*), two improved varieties, BARI Kaloziira-1 and RZ-19, have gained prominence due to their adaptability, high yield potential, and favorable quality traits. BARI Kaloziira-1, released by the Bangladesh Agricultural Research Institute (BARI), is a black cumin variety specifically developed to meet the agronomic and climatic conditions of Bangladesh, including moderate rainfall, fertile soils, and semi-arid regions. This variety has demonstrated uniform growth, early maturity, and improved resistance to common pests and diseases, making it suitable for intensive cultivation. Its growth period ranges from approximately 135 to 145 days, allowing for timely harvesting before the onset of adverse weather conditions. One of the defining characteristics of BARI Kaloziira-1 is its response to balanced nutrient management; field trials have shown that it achieves optimal growth, branching, and seed set under recommended NPK regimes, with additional benefits observed when micronutrients such as zinc and boron are incorporated. Its adaptability to various plant spacing arrangements further enhances its potential for high-density cultivation without compromising seed quality, thereby providing farmers with flexibility in management practices [12].

RZ-19, on the other hand, is a widely cultivated cumin variety with origins in Rajasthan, India, and has been successfully adopted in neighboring semi-arid regions. It is valued for its stability across diverse environmental conditions, relatively short maturity period of 120–140 days, and consistent seed yield. RZ-19 exhibits strong branching and canopy development, making it responsive to both nutrient application and plant density. This variety has been extensively studied under factorial experiments involving NPK levels and plant spacing, which indicate that intermediate spacing combined with balanced nutrient application maximizes its yield potential. The genetic characteristics of RZ-19, including its tolerance to drought and moderate salinity, allow it to maintain high productivity even under resource-constrained conditions, which is particularly relevant for smallholder farmers in arid and semi-arid regions. Additionally, its seeds possess desirable organoleptic and market traits, including uniform size, aroma, and oil content, which increase its commercial value and economic returns when cultivated with optimized agronomic practices [13].

Both BARI Kaloziira-1 and RZ-19 share common agronomic needs, including the requirement for balanced macro- and micronutrient application and proper spacing for optimal light interception, nutrient uptake, and reproductive success. However, they differ in certain physiological and morphological traits that influence their response to management practices. For instance, BARI Kaloziira-1's longer growth cycle may make it more responsive to split nitrogen applications and micronutrient supplementation, whereas RZ-19's shorter cycle and drought tolerance may allow it to perform well under moderate fertilization and slightly denser planting. Comparative studies involving these varieties provide valuable insights into varietal-specific nutrient and spacing recommendations, enabling the development of tailored agronomic packages that maximize yield, quality, and profitability [14].

In BARI Kaloziira-1 and RZ-19 represent the genetic foundation upon which optimized nutrient and spacing management strategies can be applied to achieve high productivity in black cumin and cumin cultivation. By understanding their growth habits, nutrient requirements, and spacing responses, researchers and farmers can design integrated management approaches that not only enhance seed yield per hectare but also improve overall economic returns. The success of these varieties in experimental and farmer-managed fields underscores the importance of varietal selection in conjunction with precise agronomic practices, highlighting the synergistic potential of combining genetics with optimized nutrition and spatial arrangement for sustainable and profitable spice crop production [15].

V. CONCLUSION

Optimizing macro–micro nutrient regimes in combination with appropriate plant spacing significantly influences the growth, seed yield, and profitability of BARI Kalojira-1 and RZ-19 varieties. Balanced NPK application supplemented with essential micronutrients such as zinc and boron enhances branching, seed set, and thousand-seed weight, while intermediate plant spacing ensures optimal light interception and nutrient utilization. The interaction between nutrient management and spacing maximizes both biological yield and economic returns, highlighting the need for integrated agronomic practices. Adoption of these optimized management strategies can substantially improve farmer income, resource-use efficiency, and sustainable cumin and black cumin production.

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