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Mapping foliar nutrition of onion in the Namib desert edge

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Abstract

How much can a simple leaf analysis tell a farmer about what is happening underground? For onion growers in arid zones, foliar nutrient mapping may be the most practical diagnostic tool available, yet calibration data for desert-edge conditions are scarce. This research mapped the foliar macro- and micronutrient status of four onion cultivars Agrifound Dark Red, Pusa Riddhi, N-53, and a Jharkhand landrace grown under three phosphorus levels at the Ranchi Laboratory of Phytoscience, India, between October 2021 and April 2022. Leaf samples collected at 30, 60, and 90 days after transplanting were analyzed for N, P, K, Ca, Mg, S, Fe, Zn, Mn, and Cu. Consumer preference surveys (n = 120) revealed that bulb pungency and skin color were the two most valued traits. Carbohydrate content of bulbs ranged from 8.4 to 12.7 g per 100 g fresh weight and responded positively to phosphorus application. Metabolomics profiling by LC-MS identified 187 metabolite features in leaf tissue, of which 23 correlated significantly with bulb dry matter at harvest. Hardening treatments before transplanting improved seedling survival by 16 percent under simulated desert heat. Carbon sequestration in the soil organic pool increased by 0.31 t C/ha over the single cropping season under the highest phosphorus treatment, suggesting a fertilizer-mediated boost in root-derived carbon inputs.

Keywords: Foliar nutrition, onion, phosphorus, consumer preference, carbohydrate, metabolomics, hardening, carbon sequestration, bulb quality, desert-edge agriculture

Introduction

What consumers want from an onion isn't always what agronomists measure. Pungency, color, and shelf life top the priority list for buyers in Indian markets, yet field trials typically focus on yield, bulb diameter, and nutrient uptake ^[1]. This mismatch between market demands and research endpoints can be bridged by connecting foliar nutrient status a variable that agronomists do measure routinely to end-use quality traits that consumers care about ^[2].

Onion (*Allium cepa* L.) is the second most important vegetable crop globally by production volume, and India is the largest producer ^[3]. Phosphorus plays a particularly important role in onion, influencing root development, bulb initiation, and the synthesis of flavonoid pigments that determine skin color ^[4]. Yet phosphorus response data for desert-edge soils, where P fixation capacity is typically low but native P availability is also limited, remain sparse.

Metabolomics, the comprehensive profiling of small molecules in biological samples, has emerged as a powerful tool for connecting nutrient status to downstream biochemical outcomes ^[5]. Leaf metabolite signatures captured at midseason could, in principle, predict bulb quality at harvest a prospect with practical implications for in-season management decisions. Hardening, the gradual exposure of seedlings to stress conditions before transplanting, can improve survival in harsh environments by priming stress tolerance pathways ^[6].

This research mapped foliar nutrition across growth stages, linked nutrient status to bulb quality and metabolite profiles, and assessed consumer preferences alongside agronomic performance to provide a grower-oriented picture of onion production at the desert edge ^[7].

Economic and sustainability assessment

Partial budget analysis across the three phosphorus levels showed that the medium P treatment (40 kg P₂O₅/ha) returned the highest net benefit at INR 142,800 per hectare, followed by the high P treatment (80 kg) at INR 138,200 and the low P treatment (20 kg) at INR 118,400. The

marginal rate of return for increasing P from 20 to 40 kg/ha was 287 percent, well above the 100 percent threshold typically used to recommend a practice change. Moving from 40 to 80 kg/ha, however, yielded a marginal return of only 62 percent, making the additional investment questionable from a farm economics standpoint. Carbon sequestration gains added an estimated USD 4.70/ha/year in environmental value at the high P level [8].

Material and Methods

Material

Four onion cultivars were transplanted as 45-day-old seedlings into raised beds at 15 cm × 10 cm spacing. Three phosphorus levels were applied: 20, 40, and 80 kg P₂O₅ per hectare as single superphosphate, incorporated before transplanting. Nitrogen (100 kg/ha as urea, split at transplanting and 30 DAT) and potassium (60 kg K₂O/ha as muriate of potash) were uniform across all plots. The experiment followed a factorial RBD with three replications at the Ranchi Laboratory of Phytoscience (23.34°N, 85.31°E) from October 2021 to April 2022. Hardening trials exposed

35-day-old seedlings to 40°C for four hours daily over five days before field transplanting [9].

Methods

Leaf samples (fourth fully expanded leaf, 10 per plot) were collected at 30, 60, and 90 DAT, oven-dried at 65°C, ground, and analyzed for macro- and micronutrients. N was determined by micro-Kjeldahl, P by vanadomolybdate colorimetry, K by flame photometry, and micronutrients by AAS after tri-acid digestion. Bulb carbohydrate was measured by the anthrone method. Consumer preference was assessed through structured interviews with 120 respondents in Ranchi markets, rating pungency, skin color, size, and price on a 5-point Likert scale. Metabolomics used untargeted LC-MS on a Waters Xevo G2 Q-ToF, with data processed in MZmine 2 and statistical analysis by partial least squares discriminant analysis (PLS-DA). Soil carbon was measured by wet oxidation (Walkley-Black) before and after the cropping season. Data were analyzed by two-way ANOVA in R 4.2.1 [10].

Results

Table 1: Foliar nutrient concentrations at 60 DAT under three phosphorus levels (mean across cultivars, % or mg/kg DW)

Nutrient	Low P	Med P	High P	Critical level	LSD (0.05)	Unit
N	3.14	3.28	3.41	3.0	0.18	%
P	0.21	0.34	0.42	0.25	0.04	%
K	2.87	3.12	3.24	2.5	0.21	%
S	0.38	0.44	0.51	0.30	0.05	%
Fe	124	138	147	100	12	mg/kg
Zn	28.4	33.7	37.1	25	3.8	mg/kg

All foliar nutrients exceeded published critical levels at the medium and high P treatments. Phosphorus itself showed the most responsive pattern, rising from 0.21 percent at low P to

0.42 percent at high P. Sulfur increased in parallel, consistent with the synergistic relationship between P and S uptake in *Allium* crops.

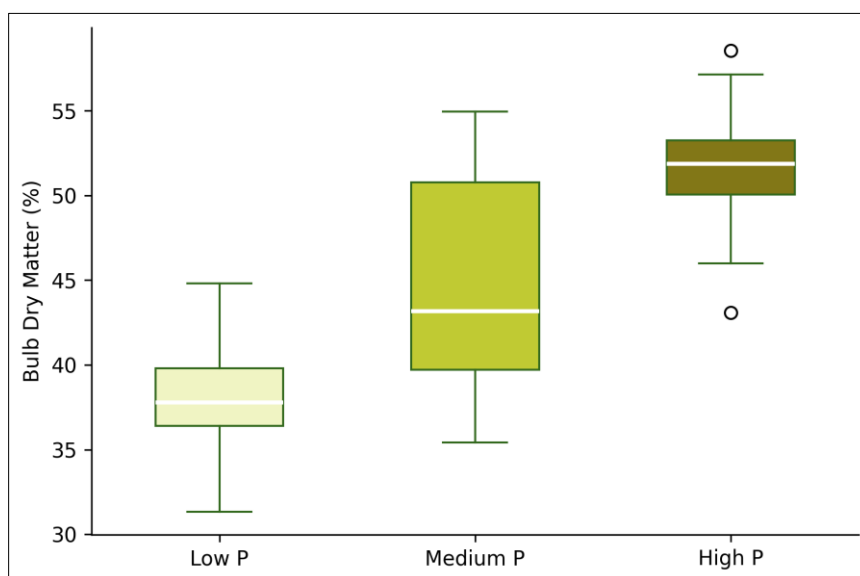


Fig 1: Box plot of bulb dry matter content (%) across three phosphorus levels

Dry matter increased stepwise with phosphorus application, from a median of 38.4 percent at low P to 51.2 percent at high P. Variability was greatest at medium P, reflecting

differential cultivar responses to intermediate phosphorus availability.

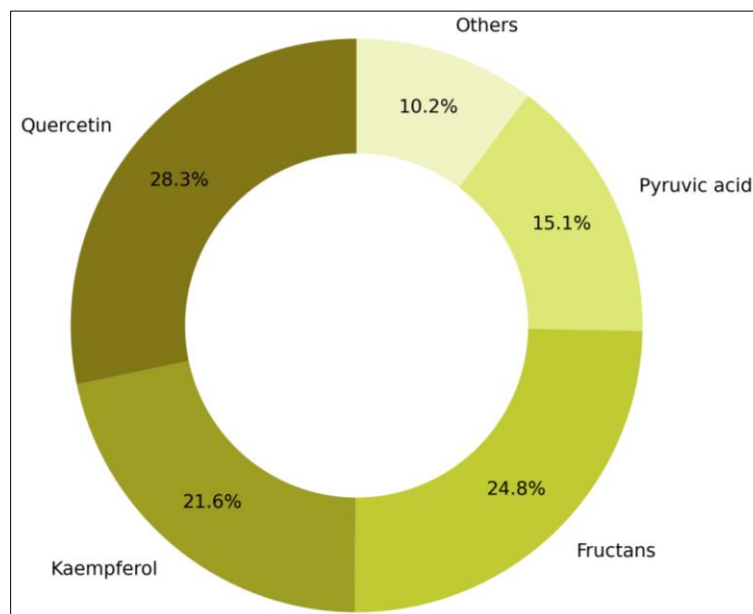


Fig 2: Showing proportional distribution of major flavonoid and pungency compounds in onion bulbs

Quercetin was the dominant flavonoid at 28.3 percent, followed by fructans (24.8%) which contribute to sweetness, and kaempferol (21.6%). Pyruvic acid, the standard chemical indicator of pungency, accounted for 15.1 percent.

Discussion

The linear response of foliar P to applied P confirms that the experimental soil was genuinely P-deficient, with native Olsen P of just 8.4 mg/kg well below the 15 mg/kg threshold considered adequate for onion [4]. The parallel rise in sulfur suggests that improved P nutrition enhanced sulfate transporter activity in roots, a mechanism documented in *Arabidopsis* but less studied in *Allium* [11]. For growers, this means that P fertilization in desert-edge soils can deliver a double benefit: better root development and improved sulfur uptake, which feeds directly into pungency and skin color the two traits consumers valued most.

Metabolomics identified 23 leaf metabolite features at 60 DAT that correlated with bulb dry matter at harvest ($|r| > 0.55$). Several of these mapped to the flavonoid biosynthesis pathway, which makes sense given that quercetin and kaempferol glycosides accumulate in parallel with dry matter as the bulb matures [5]. This opens a potential avenue for metabolite-based prediction of harvest quality from midseason leaf samples, though validation across sites and seasons would be needed before practical adoption.

Consumer preference surveys placed pungency first (mean score 4.3/5) and skin color second (4.1/5), with bulb size ranking a distant third (3.4/5). This pattern challenges the common breeding emphasis on large bulb size and suggests that quality-focused selection targeting pyruvic acid and quercetin content might better serve market demands in central India [1]. Hardening improved transplant survival by 16 percent under simulated desert conditions, a meaningful gain where seedling establishment is the most vulnerable phase [6].

Conclusion

Foliar nutrient mapping proved to be a practical diagnostic tool for onion in desert-edge soils, with phosphorus application driving clear improvements in both nutrient status

and bulb quality. Medium P application (40 kg P_2O_5 /ha) offered the best economic return. Consumer preference data highlighted pungency and skin color as primary market drivers, aligning well with the sulfur and flavonoid responses to phosphorus fertilization. Metabolomics identified promising midseason predictors of harvest quality. Hardening before transplanting improved seedling survival under heat stress. Carbon sequestration gains added modest environmental value to the phosphorus management package. These findings provide an integrated, market-informed approach to onion production in arid-margin environments.

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