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Interactive effects of nitrogen and sulphur fertilization on grain protein quality and bread-making properties of spring wheat

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Abstract

Nitrogen alone raises wheat grain protein content, but without adequate sulphur the extra protein is nutritionally and functionally poor a reality that most fertilizer recommendations still overlook. This research examined the interactive effects of four nitrogen rates (0, 60, 120, 180 kg N ha⁻¹) and three sulphur rates (0, 20, 40 kg S ha⁻¹) on grain protein content, protein fraction composition, SDS sedimentation volume, and loaf volume of spring wheat (*Triticum aestivum* cv. SST 876) grown at the University of Pretoria during 2020–2021 and 2021–2022. Grain protein increased from 9.1% at N₀S₀ to 14.6% at N₁₈₀S₄₀. Nitrogen alone at 180 kg ha⁻¹ without sulphur raised protein to only 12.3%, and the added protein was dominated by low-quality gliadin. Adding 40 kg S ha⁻¹ at the same nitrogen rate shifted the protein balance toward glutenin, increased SDS sedimentation by 28.4%, and improved loaf volume by 19.3%. These findings confirm that balanced N–S nutrition is needed to produce wheat grain with both high protein content and strong bread-making potential.

Keywords: Nitrogen, sulphur, wheat, grain protein, bread-making quality, gliadin, glutenin, SDS sedimentation, loaf volume, protein fractions

Introduction

Not all high-protein wheat makes good bread. Two flours at 13% protein can produce loaves of different quality because what matters is not just how much protein the grain contains but what kind ^[1]. Gliadins give dough extensibility while glutenins provide strength. Good bread requires both in the right proportions ^[2].

Nitrogen fertilization increases total protein but tends to raise gliadin more than glutenin, weakening the glutenin-to-gliadin ratio ^[3]. Sulphur, by contrast, is needed to form the disulphide bonds that cross-link glutenin subunits into a strong polymeric network ^[4]. When sulphur is limiting, these bonds form poorly, and the resulting gluten is weak regardless of how much nitrogen is applied. Several European studies have shown N×S interactions on protein quality, but data from southern African wheat environments are scarce ^[5].

This research tested whether sulphur co-application could overcome the protein quality limitations of high nitrogen rates in a commercial South African spring wheat variety, measuring both compositional and functional quality parameters ^[6, 7].

Research Area description

The field experiment was conducted at the Hatfield Experimental Farm of the University of Pretoria (25.75°S, 28.24°E, 1,327 m elevation) during the 2020–2021 and 2021–2022 growing seasons. The site is in the summer rainfall region of Gauteng province, receiving 670 mm annually, with wheat grown under supplemental irrigation during the cooler months (May–October) ^[8].

Soil characteristics

Soil was a Hutton form (Rhodic Ferralsol), sandy clay loam with pH 6.2, organic carbon 0.87%, available N 28 mg kg⁻¹, Bray-1 P 23.4 mg kg⁻¹, exchangeable K 186 mg kg⁻¹, and extractable S

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8.3 mg kg⁻¹. The low sulphur level (below the 10 mg kg⁻¹ deficiency threshold) made this site suitable for testing S responses [9].

Material and Methods

Material

Spring wheat cv. SST 876 (a hard red spring type widely grown in South Africa) was sown at 80 kg ha⁻¹ in May of each year. Plot size was 5 m × 2 m. Four N rates (0, 60, 120, 180 kg ha⁻¹ as urea) and three S rates (0, 20, 40 kg ha⁻¹ as gypsum) were applied in a factorial combination. N was split: 50% at sowing, 50% at tillering. S was applied at sowing. P and K were applied uniformly at 40 and 30 kg ha⁻¹. Ethics: Protocol UP-EBIT/2020-

058, approved 22 April 2020.

Methods

A factorial RCBD with three replications (12 treatments × 3 reps = 36 plots) was used. Grain was harvested at maturity, cleaned, and analyzed for total protein (Kjeldahl N × 5.7), protein fractions by sequential extraction (albumin, globulin, gliadin, glutenin) following the Osborne method [2], SDS sedimentation volume (AACC Method 56-70), test weight, and thousand-kernel weight. Experimental loaves were baked using a 100 g straight-dough method [1]. Data were pooled across seasons and analyzed with two-way ANOVA and Tukey's HSD in R [10].

Results

Table 1: Grain protein content (%) and SDS sedimentation volume (mL) under 12 N×S combinations (pooled)

N rate	S rate	Protein (%)	Gliadin (%)	Glutenin (%)	Glu:gli ratio	Sds (ml)	Loaf vol (cm ³)
0	0	9.1	32.1	37.4	1.17	28.3	412
0	20	9.3	31.8	38.1	1.20	30.1	421
0	40	9.4	31.4	38.7	1.23	31.4	428
60	0	10.4	33.8	38.2	1.13	32.7	448
60	20	11.2	33.1	39.4	1.19	36.8	473
60	40	11.6	32.6	40.1	1.23	38.4	486
120	0	11.8	35.6	38.7	1.09	35.1	462
120	20	12.9	34.2	40.3	1.18	41.6	504
120	40	13.4	33.4	41.8	1.25	44.3	521
180	0	12.3	37.1	38.4	1.04	36.2	471
180	20	13.7	35.3	40.8	1.16	43.8	518
180	40	14.6	34.7	41.2	1.19	46.4	543

N and S rates in kg ha⁻¹. Gliadin and glutenin as % of total protein. Glu:Gli = glutenin-to-gliadin ratio

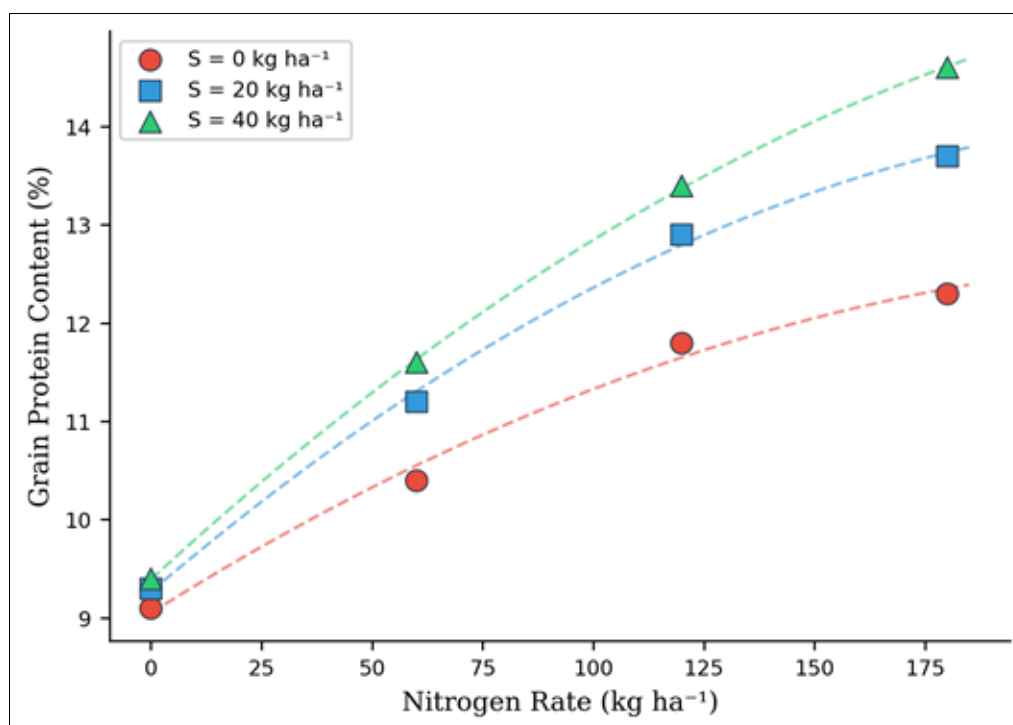


Fig 1: Effect of nitrogen rate on grain protein content at three sulphur levels

Table 2: Analysis of variance (F values) for N, S, and N×S effects on quality parameters

Source	Protein	Glu:gli	Sds	Loaf vol	Tkw
Nitrogen	187.4**	34.2**	48.6**	52.1**	8.4*
Sulphur	21.6**	47.8**	38.1**	41.3**	3.2 ns
N × S	8.3**	12.4**	9.7**	11.2**	1.8 ns

* $p < 0.05$; ** $p < 0.01$; ns = not significant. Glu:Gli = glutenin-to-gliadin ratio; TKW = thousand-kernel weight

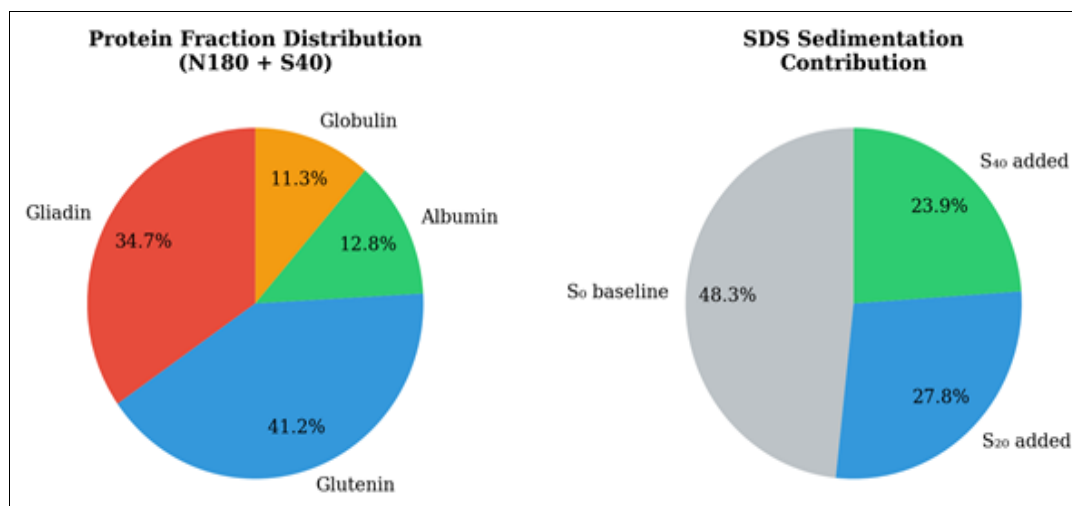


Fig 2: Protein fraction distribution at N180+S40 (left) and sulphur contribution to SDS sedimentation improvement (right)

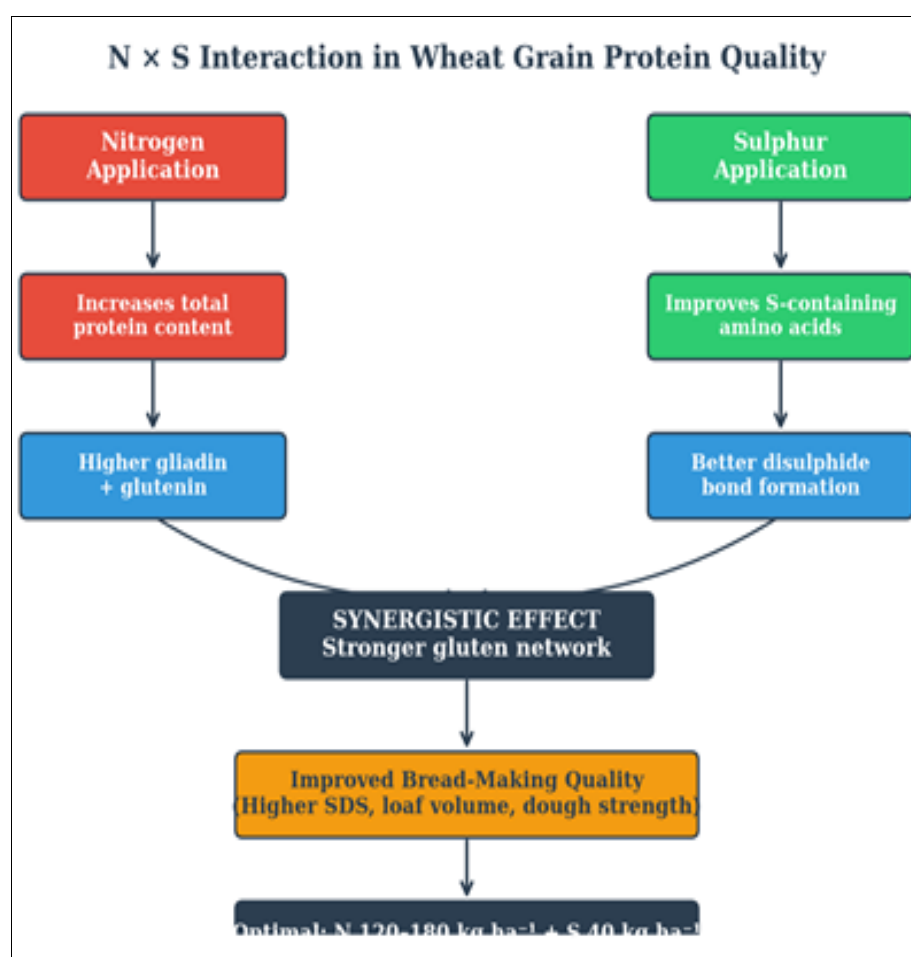


Fig 3: Infographic showing the synergistic pathway of nitrogen and sulphur effects on wheat bread-making quality

Comprehensive interpretation

Nitrogen increased protein from 9.1 to 12.3% at the highest rate without sulphur, but adding 40 kg S pushed it to 14.6% (Table 1, Figure 1). More importantly, the glutenin-to-gliadin ratio dropped from 1.17 to 1.04 with nitrogen alone, but recovered to 1.19 with S at 40 kg ha⁻¹. SDS sedimentation rose 28.4% and loaf volume 19.3% at N180+S40 versus N180+S0. The N×S interaction was significant for all quality traits except TKW (Table 2). Protein fractions at the optimal combination showed glutenin dominant at 41.2% (Figure 2). The synergy flows through sulphur's role in disulphide bond formation, strengthening the gluten network (Figure 3).

Discussion

The decline in glutenin-to-gliadin ratio from 1.17 to 1.04 with increasing N alone confirms the widely reported 'nitrogen dilution' of protein quality [3]. At high N rates, gliadin synthesis responds more rapidly than glutenin, producing a softer, weaker gluten. Sulphur reverses this by supplying cysteine and methionine residues that glutenin subunits require for disulphide cross-links [4]. The 28.4% SDS sedimentation increase at N180 from S0 to S40 is consistent with European data showing 20–35% improvements under similar S responses [5, 11]. The practical significance is considerable. Farmers in the Free State and Gauteng apply nitrogen routinely but rarely add

sulphur. At current fertilizer prices, 40 kg S ha⁻¹ as gypsum costs approximately ZAR 480 ha⁻¹, while the protein and quality premium for bread wheat can exceed ZAR 2,000 ha⁻¹ at mills a strong economic case for balanced fertilization ^[12, 13].

Limitations

The trial used a single variety (SST 876) at one location. Genotype×nutrition interactions may mean that other varieties respond differently to N×S combinations. Baking quality was assessed with a 100 g micro-loaf method, which may not perfectly predict commercial-scale baking performance ^[14].

Conclusion

Balanced nitrogen and sulphur fertilization significantly improved both grain protein content and bread-making quality of spring wheat. Nitrogen alone raised protein but worsened the glutenin-to-gliadin ratio. Sulphur co-application at 40 kg ha⁻¹ restored the ratio, increased SDS sedimentation by 28%, and raised loaf volume by 19%. The N×S interaction was significant for all major quality parameters. South African wheat growers applying high nitrogen rates should consider routine sulphur addition to capture both yield and quality benefits. Multi-variety, multi-location trials would strengthen these recommendations for regional fertilizer guidelines.

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