

Variety plant spacing and NPK fertilizer rate influence postharvest quality and nutritional composition of cucumber fruits

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Abstract

Cucumber (*Cucumis sativus* L.) is widely valued for its nutritional and nutraceutical attributes; however, its postharvest quality and proximate composition under varying agronomic practices in tropical Africa remain insufficiently documented. This study evaluated the effects of variety, plant spacing, and NPK (15-15-15) fertilizer rate on fruit firmness, colour (CIE a^*), proximate composition, and vitamin content of cucumber grown in southwest Nigeria. Field experiments were conducted at the Federal University of Agriculture, Abeokuta (7°15'N, 3°25'E; 144 m a.s.l.) during the early and late seasons of 2019 and 2020. Treatments comprised two varieties (CU 999 and Monalisa), three spacings (75 × 25, 75 × 50, and 75 × 75 cm), and four fertilizer rates (0, 100, 200, and 300 kg ha⁻¹), arranged in a split-split plot randomized complete block design with three replications. Fruit texture, colour, vitamins, and proximate components were determined using standard analytical methods. Data were analysed using analysis of variance, and means were separated using LSD at $P \leq 0.05$. CU 999 produced significantly firmer fruits (up to 1.35 kg) than Monalisa (1.15 kg), while Monalisa exhibited deeper green colour. Application of 300 kg ha⁻¹ NPK significantly increased vitamin A (35.93 µg 100 g⁻¹), vitamin C (3.41 mg 100 g⁻¹), vitamin K, dry matter, and carbohydrate content. Wider spacing (75 × 75 cm) enhanced green colour intensity, vitamin K, and dry matter. Significant interactions among factors were observed, with the 75 × 75 cm and 300 kg ha⁻¹ combination generally optimizing fruit quality.

Highlights

- First simultaneous field evaluation of all proximate fractions plus four vitamins (A, B, C, K) under a replicated 3-factor split-split plot design in tropical Nigeria.
- CU 999 produced firmer fruits (up to 1.35 kg) and Monalisa exhibited deeper green colour (a^* more negative) across most trials.
- NPK at 300 kg ha⁻¹ significantly increased vitamin A (up to 35.93 µg/100g), vitamin C, vitamin K and dry matter content.
- Wider spacing (75×75 cm) promoted greener colour, higher vitamin K, and greater dry matter compared to 75×25 cm.
- Varieties CU 999 and Monalisa × 75×75 cm × 300 kg ha⁻¹ NPK are recommended for optimal postharvest quality in SW Nigeria.

1. Introduction

Cucumber (*Cucumis sativus* L.) is consumed fresh, pickled and as juice across Nigeria, where it commands a growing premium market driven by rapid urbanisation and rising health-awareness (Kumar et al., 2010; Nweke et al., 2013). Beyond its yield potential, its commercial value depends critically on postharvest quality attributes: firmness, skin colour, proximate composition and micronutrient content

that determine consumer acceptance, shelf life, and market price (Barrett et al., 2010). Omodamiro et al., 2013 found that root color matters most to sensory panelists, indicating consumer preference drives acceptability. Rosero et al., 2020 showed flesh color correlates with dry matter and protein content, affecting quality profiles. Lara et al., 2019 documented that fruit cuticle properties modulate water transpiration and fruit dehydration, susceptibility to rots, directly impacting storage potential. Ngoh Newilah et al., 2020 identified that plantain length, girth, dry matter content, pH and firmness drive user demand. Truong et al., 2018 noted consumers prefer sweetpotato varieties with specific dry matter levels and flesh colors based on regional markets. Nigeria's escalating burden of micronutrient deficiency, particularly of vitamins A, C and K, elevates the importance of production practices that maximise fruit nutritional density alongside marketable yield.

Production factors including variety selection, plant spacing and fertilizer management have long been known to influence fruit composition in cucurbits, yet their simultaneous effects on postharvest quality are rarely quantified under West African field conditions (Ehiokhilen and Remison, 2010; Agatemor et al., 2018). Liu et al., 2023 identified key genomic regions underlying anthocyanin accumulation for fruit color and firmness in strawberries. Srivastav et al., 2023 mapped consistent QTLs for fruit color on chromosomes 3 and 18, and firmness on chromosomes 11 and 20 in mango. Yang et al., 2023 demonstrated that the CmYGP gene directly controls chlorophyll synthesis and chloroplast development in melon. Sami et al., 2024 identified key genes (GLDH) regulating vitamin C biosynthesis pathways. Finally, Vu et al., 2025 documented significant inter-cultivar variation across nutritional composition in 13 banana varieties.

Plant spacing modifies canopy microclimate and per-plant resource availability, which affects fruit size, dry matter accumulation and vitamin synthesis (Nerson, 1998). NPK fertilization supplies the macronutrients that drive carbohydrate synthesis, protein metabolism and carotenoid accumulation all of which underpin proximate composition and fat-soluble vitamin content (Mi et al., 2022; Lee et al., 2024). Recent metabolomics-based work by Lee et al. (2024), examining NPK effects on cucumber fruit across soils of contrasting nutrient status in Korea, demonstrated that NPK application substantially altered the metabolite profiles of fruits particularly amino acids, organic acids and phenolics with changes dependent on the initial soil fertility level. Mi et al. (2022), in a comprehensive physicochemical study of cucumbers grown under five fertilizer regimes in China, reported that a combination of chicken manure, balanced NPK and microbial fertilizer improved texture properties and colour quality simultaneously, underscoring the integrated nature of fertilizer effects on multiple quality dimensions. These findings from temperate and sub-tropical protected cropping environments have not been validated under tropical open-field conditions in sub-Saharan Africa, where soil fertility levels, seasonal rainfall patterns and genotype × environment interactions may produce markedly different outcomes.

In Nigeria, comprehensive postharvest quality evaluations of cucumber under diverse agronomic regimes remain scarce. Consequently, this study was designed to fill this knowledge gap by: (i) quantifying the effects of variety, spacing and NPK rate on the full complement of postharvest quality and nutritional attributes of cucumber under four field trials across two years; (ii) characterising

significant interactions among these three factors; and (iii) identifying treatment combinations that optimise fruit quality for the Nigerian fresh market and smallholder health-nutrition nexus.

2. Materials and Methods

2.1 Experimental site, design and agronomic practices

Field experiments were conducted at DUFARMS, FUNAAB (7°15'N, 3°25'E; 144 m a.s.l.) in 2019 and 2020. Full details of site characteristics, experimental design, treatment structure and agronomic management are described in the companion paper (Falaiye et al., 2022). Briefly, a split-split plot RCBD with three replications evaluated two varieties (CU 999 and Monalisa), three spacings (75×25, 75×50, 75×75 cm) and four NPK 15-15-15 rates (0, 100, 200, 300 kg ha⁻¹). Fruits for postharvest analysis were collected at commercial maturity from each plot and transported immediately to the laboratory at FUNAAB.

2.2 Postharvest quality measurements

2.2.1 Fruit firmness (texture)

Firmness was determined using a handheld penetrometer (WSU 2016). The cucumber fruit was peeled and the penetrometer tip was inserted into the flesh at a uniform speed. The reading (kg) displayed on the penetrometer screen after penetration was recorded. Five fruits per plot were measured and the mean computed.

2.2.2 Fruit colour (CIELAB a*)

Fruit colour was measured using a Minolta Chroma Meter CR-410 colorimeter. The CIE a* parameter (greenness index; more negative = greener) was recorded directly from the instrument after placing the sensor lens on the equatorial surface of the intact fruit. Five fruits per plot were measured and the mean a* value reported.

2.2.3 Proximate composition

Ash content, dry matter, crude protein (Kjeldahl), crude fibre, fat (Soxhlet) and carbohydrate (by difference) were determined using standard AOAC (2005) procedures. Moisture content was determined as the difference between fresh and dry weight after oven-drying at 105°C to constant weight.

2.2.4 Vitamins A, B, C and K

Vitamins A, B, C and K were determined spectrophotometrically using potassium permanganate as a chromogenic reagent (Riemschneider et al., 1976). Results were expressed as µg/100g (vitamins A and K) and mg/100g (vitamins B and C) fresh weight.

2.3 Statistical analysis

Data were subjected to ANOVA for a split-split plot design and means separated by LSD at $P \leq 0.05$. Supplementary multivariate analyses Pearson correlation matrix, PCA biplot of all 13 quality variables, and radar profiles comparing selected treatment combinations were conducted in Python 3.11. Error bars on all figures represent ± 1 SEM ($n = 3$ replicates).

3. Results

3.1 Fruit firmness

Variety significantly ($P \leq 0.05$) influenced fruit firmness in both trials of 2019 and in Trial II of 2020 (Table 1; Fig. 1a). CU 999 consistently produced firmer fruits than Monalisa e.g., 1.35 vs. 1.15 kg in Trial II 2019 (LSD = 0.132) and 1.20 vs. 1.05 kg in Trial II 2020 (LSD = 0.036). Spacing significantly affected firmness across all four trials; fruits from plots at 75×75 cm were consistently firmer than those at 75×25 cm (e.g., 1.35 vs. 1.07 kg in Trial II 2019; LSD = 0.026). The effect of NPK on firmness was significant in both trials of 2019 and both trials of 2020. In Trial I 2019 and both 2020 trials, the 300 kg ha⁻¹ rate produced the firmest fruits; in Trial II 2019 the control and 300 kg ha⁻¹ rate were comparable. Significant three-way interactions (Variety × Spacing × Fertilizer) were recorded in all four trials; in Trial I 2020, CU 999 × 75×75 cm × 300 kg ha⁻¹ produced the firmest fruits (1.46 kg), while Monalisa × 75×75 cm × 100 kg ha⁻¹ had the highest firmness within that variety.

Table 1
Effect of variety, spacing and NPK fertilizer rate on fruit firmness (kg) of cucumber (*Cucumis sativus* L.) in both trials of 2019 and 2020.

Treatment	2019 Trial I	2019 Trial II	2020 Trial I	2020 Trial II
Variety				
CU 999	1.02	1.35	1.17	1.20
Monalisa	0.96	1.15	1.01	1.05
LSD ($P \leq 0.05$)	0.023	0.132	ns	0.036
Spacing				
75 × 25 cm	0.98	1.07	1.04	1.07
75 × 50 cm	0.96	1.32	1.08	1.12
75 × 75 cm	1.02	1.35	1.16	1.17
LSD ($P \leq 0.05$)	0.008	0.026	0.062	0.019
NPK rate (kg ha⁻¹)				
0	0.94	1.34	1.06	1.04
100	1.08	1.20	1.07	1.07
200	0.97	1.11	1.10	1.21
300	0.96	1.33	1.14	1.17
LSD ($P \leq 0.05$)	0.063	0.090	0.054	0.017
ns = not significant.				

3.2 Fruit colour (CIELAB a*)

Variety consistently influenced green colour: Monalisa produced fruits with more negative a* values (i.e., greener) than CU 999 across all four trials (e.g., -10.54 vs. -12.13 in Trial II 2019; LSD = 0.404; Table 2). This represents Monalisa's deeper green pigmentation, attributable to higher chlorophyll retention at commercial maturity. Spacing significantly influenced colour in all trials; fruits from 75×75 cm plots were greener in two of four trials, while 75×25 cm dominated in others, reflecting light competition effects on chlorophyll synthesis (Fig. 1b). NPK at 100–200 kg ha⁻¹ generally promoted greener colouration relative to the 300 kg ha⁻¹ rate, suggesting a dilution effect of rapid fruit growth at the highest fertility level. Significant three-way interactions were observed in all seasons.

Table 2
Effect of variety, spacing and NPK fertilizer rate on green colour index (a*) of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 Trial I	2019 Trial II	2020 Trial I	2020 Trial II
Variety				
CU 999	-10.22	-12.13	-7.94	-9.98
Monalisa	-7.89	-10.54	-3.52	-7.19
LSD ($P \leq 0.05$)	1.498	0.404	0.128	1.018
Spacing				
75 × 25 cm	-9.02	-10.53	-5.45	-8.20
75 × 50 cm	-8.62	-10.73	-6.22	-8.46
75 × 75 cm	-9.53	-12.74	-5.52	-9.10
LSD ($P \leq 0.05$)	0.156	0.184	0.020	0.058
NPK rate (kg ha⁻¹)				
0	-8.31	-10.83	-5.58	-8.08
100	-7.20	-10.80	-6.03	-7.95
200	-10.18	-12.13	-5.39	-9.19
300	-10.53	-11.58	-5.92	-9.13
LSD ($P \leq 0.05$)	0.611	0.730	0.109	0.557
ns = not significant. More negative a* = greener fruit.				

3.3 Carbohydrate and ash content

Varietal differences in carbohydrate were significant in Trial II of 2019 (CU 999 = 2.72 vs. Monalisa = 2.79 g/100g; LSD = 0.027) and Trial I of 2020 (2.69 vs. 2.45; LSD = 0.006), with Monalisa having marginally higher carbohydrate in some trials but lower in others (Table 3). Spacing significantly influenced carbohydrate content across all trials; the 75×75 cm spacing produced the highest carbohydrate in three of four trials. NPK at 300 kg ha⁻¹ significantly increased carbohydrate in Trial I of 2019 (1.92 vs. 1.67 g/100g at control; LSD = 0.114) and Trial I of 2020 (2.68 vs. 2.54 g/100g). Ash content was generally not significantly different between varieties in Trial I of 2019 but was in Trial II (Monalisa = 0.26 vs. CU 999 = 0.24 g/100g; LSD = 0.003). NPK at 300 kg ha⁻¹ significantly increased ash content in 2019 (0.24 vs. 0.16 g/100g; LSD = 0.006). Significant three-way interactions were recorded for both traits in multiple trials.

Table 3

Effect of variety, spacing and NPK fertilizer rate on carbohydrate and ash content (g/100g) of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 T I	2019 T II	2020 T I	2020 T II	2019 T I	2019 T II	2020 T I	2020 T II
	Carbohydrate (g/100g)				Ash (g/100g)			
Variety								
CU 999	1.77	2.72	2.69	3.21	0.19	0.24	0.27	0.28
Monalisa	1.74	2.79	2.45	3.07	0.19	0.26	0.26	0.26
LSD (P ≤ 0.05)	ns	0.027	0.006	ns	ns	0.003	ns	ns
Spacing								
75 × 25 cm	1.76	2.51	2.55	3.09	0.19	0.23	0.23	0.26
75 × 50 cm	1.75	2.97	2.53	3.09	0.18	0.27	0.26	0.27
75 × 75 cm	1.76	2.78	2.62	3.24	0.20	0.25	0.29	0.28
LSD (P ≤ 0.05)	0.004	0.033	0.087	0.031	0.001	0.002	0.022	0.002
NPK rate (kg ha⁻¹)								
0	1.67	2.66	2.54	2.93	0.16	0.25	0.23	0.26
100	1.66	2.92	2.50	3.51	0.19	0.27	0.25	0.29
200	1.76	2.86	2.55	2.84	0.18	0.26	0.27	0.26
300	1.92	2.58	2.68	3.27	0.24	0.23	0.28	0.28
LSD (P ≤ 0.05)	0.114	0.176	0.089	0.203	0.006	0.016	0.018	0.018
ns = not significant.								

3.4 Crude fibre and crude protein

Crude protein was generally higher in Monalisa than CU 999 (0.40–0.45 vs. 0.29–0.44 g/100g), though differences were significant in only two trials (Table 4). Spacing significantly affected crude protein; 75×50 and 75×75 cm plots consistently produced fruits with higher protein than 75×25 cm in 2020. NPK at 100 kg ha⁻¹ produced the highest crude protein in both 2019 trials, while the pattern was more variable in 2020. Crude fibre ranged from 0.25–0.50 g/100g across treatments, with 75×75 cm spacing

and higher NPK rates generally associated with higher fibre content. Significant three-way interactions for both crude protein and crude fibre were recorded in Trials I and II of 2019 and in 2020.

Table 4
Effect of variety, spacing and NPK fertilizer rate on crude fibre and crude protein content (g/100g) of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 T I	2019 T II	2020 T I	2020 T II	2019 T I	2019 T II	2020 T I	2020 T II
	Crude Fibre (g/100g)				Crude Protein (g/100g)			
Variety								
CU 999	0.27	0.38	0.37	0.42	0.29	0.44	0.43	0.50
Monalisa	0.27	0.39	0.36	0.40	0.40	0.45	0.40	0.46
LSD (P ≤ 0.05)	ns	0.002	0.018	ns	0.069	0.004	0.022	ns
Spacing								
75 × 25 cm	0.26	0.35	0.34	0.40	0.29	0.40	0.42	0.47
75 × 50 cm	0.25	0.41	0.36	0.40	0.44	0.48	0.41	0.48
75 × 75 cm	0.29	0.39	0.40	0.43	0.31	0.45	0.42	0.50
LSD (P ≤ 0.05)	0.003	0.005	0.014	0.004	0.014	0.005	ns	0.006
NPK rate (kg ha⁻¹)								
0	0.23	0.38	0.39	0.37	0.25	0.44	0.43	0.43
100	0.26	0.41	0.35	0.43	0.51	0.47	0.40	0.52
200	0.25	0.39	0.35	0.41	0.27	0.46	0.40	0.47
300	0.32	0.35	0.38	0.43	0.35	0.41	0.43	0.51
LSD (P ≤ 0.05)	0.017	0.025	0.028	0.028	0.024	0.029	0.015	0.032
ns = not significant.								

3.5 Dry matter and moisture content

Dry matter was not significantly different between varieties in Trials I 2019 and II 2020 but was significant in Trial II 2019 (Monalisa = 4.03 vs. CU 999 = 3.91 g/100g; LSD = 0.030) and Trial I 2020 (CU 999 = 4.59 vs. Monalisa = 4.26; LSD = 0.270; Table 5). Spacing significantly influenced dry matter in all

trials; 75×75 cm generally produced higher dry matter content. NPK at 300 kg ha⁻¹ produced the highest dry matter in three of four trials (e.g., 5.27 g/100g in Trial I 2020 vs. 3.46 at control; LSD = 0.410), corroborating its role in promoting solids accumulation. Moisture content showed the complementary inverse pattern, with higher NPK and wider spacing associated with marginally lower moisture in some trials, consistent with the dry-matter enrichment effect.

Table 5
Effect of variety, spacing and NPK fertilizer rate on dry matter and moisture content (g/100g) of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 T I	2019 T II	2020 T I	2020 T II	2019 T I	2019 T II	2020 T I	2020 T II
	Dry Matter (g/100g)				Moisture (g/100g)			
Variety								
CU 999	2.62	3.91	4.59	4.55	94.27	92.97	95.41	95.45
Monalisa	2.61	4.03	4.26	4.33	94.27	92.85	95.74	95.67
LSD (P ≤ 0.05)	ns	0.030	0.270	ns	ns	0.030	0.270	ns
Spacing								
75 × 25 cm	2.61	3.62	4.18	4.36	94.20	93.26	95.82	95.64
75 × 50 cm	2.56	4.29	4.34	4.37	94.32	95.59	95.66	95.63
75 × 75 cm	2.68	4.00	4.76	4.60	94.20	92.87	95.24	95.40
LSD (P ≤ 0.05)	0.015	0.047	0.328	0.043	0.015	0.047	0.328	0.043
NPK rate (kg ha ⁻¹)								
0	2.40	3.88	3.46	4.02	87.60	86.12	96.54	95.98
100	2.51	4.21	4.28	4.62	92.49	90.79	95.72	95.38
200	2.56	4.10	4.69	4.22	94.95	93.40	95.31	95.78
300	2.98	3.69	5.27	4.91	102.30	101.31	94.73	95.09
LSD (P ≤ 0.05)	0.169	0.255	0.410	0.029	6.021	5.940	0.410	0.289
ns = not significant.								

3.6 Fat content

Fat content was uniformly low across all treatments (0.10–0.15 g/100g), consistent with the known low-lipid profile of cucumber fruits (Agatemor et al., 2018). No significant varietal difference was observed for fat content in any trial (Table 6). Spacing significantly influenced fat content in all trials; 75×75 cm plots generally produced fruits with higher fat content. NPK at 300 kg ha⁻¹ significantly increased fat content in Trial I of 2019 and both 2020 trials. Significant variety × spacing and spacing × fertilizer interactions were recorded in both 2019 and 2020 trials.

Table 6
Effect of variety, spacing and NPK fertilizer rate on fat content (g/100g) of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 Trial I	2019 Trial II	2020 Trial I	2020 Trial II
Variety				
CU 999	0.10	0.13	0.13	0.15
Monalisa	0.11	0.14	0.13	0.14
LSD ($P \leq 0.05$)	ns	ns	ns	ns
Spacing				
75 × 25 cm	0.11	0.12	0.11	0.14
75 × 50 cm	0.10	0.15	0.12	0.15
75 × 75 cm	0.12	0.13	0.15	0.14
LSD ($P \leq 0.05$)	0.002	0.002	0.012	0.002
NPK rate (kg ha⁻¹)				
0	0.10	0.14	0.12	0.14
100	0.10	0.14	0.13	0.14
200	0.10	0.14	0.13	0.14
300	0.14	0.12	0.14	0.15
LSD ($P \leq 0.05$)	0.007	0.009	0.010	0.010
ns = not significant.				

3.7 Vitamin A and B content

Monalisa produced fruits with slightly higher vitamin A than CU 999 in Trial II 2019 (32.97 vs. 32.53 µg/100g; LSD = 0.326) and Trial I 2020 (33.72 vs. 33.22; LSD = 0.027; Table 7; Fig. 3a). Spacing at 75×50 cm and 75×75 cm produced higher vitamin A than 75×25 cm in most trials. NPK at 300 kg ha⁻¹ significantly increased vitamin A across all four trials (e.g., 35.93 µg/100g in Trial II 2019 vs. 30.39 at control; LSD = 2.103; Fig. 3a). Vitamin B content was uniformly very low (0.03–0.04 mg/100g), with no

significant varietal differences in any trial (Fig. 3b). NPK at 300 kg ha⁻¹ significantly increased vitamin B only in the 2020 trials (LSD = 0.002).

Table 7

Effect of variety, spacing and NPK fertilizer rate on vitamin A (µg/100g) and vitamin B (mg/100g) content of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 T I	2019 T II	2020 T I	2020 T II	2019 T I	2019 T II	2020 T I	2020 T II
	Vitamin A (µg/100g)				Vitamin B (mg/100g)			
Variety								
CU 999	31.99	32.53	33.22	31.46	0.04	0.04	0.04	0.03
Monalisa	33.07	32.97	33.72	31.90	0.04	0.04	0.04	0.03
LSD (P ≤ 0.05)	1.084	0.326	0.027	0.146	ns	ns	ns	ns
Spacing								
75 × 25 cm	32.70	31.88	32.21	30.29	0.04	0.03	0.03	0.03
75 × 50 cm	32.58	33.15	34.25	32.82	0.04	0.04	0.04	0.04
75 × 75 cm	32.32	33.22	33.96	31.92	0.04	0.03	0.04	0.03
LSD (P ≤ 0.05)	0.029	0.084	0.037	0.113	ns	ns	0.003	0.0004
NPK rate (kg ha⁻¹)								
0	29.85	30.39	31.75	28.79	0.04	0.04	0.03	0.03
100	31.75	32.23	34.39	31.46	0.04	0.04	0.04	0.03
200	33.29	32.46	33.46	31.63	0.04	0.04	0.04	0.03
300	35.23	35.93	34.30	38.84	0.04	0.04	0.04	0.04
LSD (P ≤ 0.05)	2.066	2.103	0.428	2.013	ns	ns	0.002	0.002
ns = not significant.								

3.8 Vitamin C and K content

Monalisa had slightly higher vitamin C than CU 999 in Trial I 2019 (3.22 vs. 2.84 mg/100g; LSD = 0.265; Table 8). Spacing at 75×75 cm consistently produced the highest vitamin C across all trials (e.g., 3.59 vs. 3.26 mg/100g at 75×25 cm in Trial II 2019; LSD = 0.026). NPK at 300 kg ha⁻¹ significantly increased vitamin C in all four trials (e.g., 3.41 vs. 2.98 mg/100g in Trial II 2019; LSD = 0.205; Fig. 3c). Vitamin K

showed a consistent and highly significant response to both spacing and fertilizer across all trials. Wider spacing (75×75 cm) produced the highest vitamin K in all four trials (e.g., 17.55 vs. 16.50 µg/100g at 75×25 cm in Trial II 2019; Fig. 3d). NPK at 300 kg ha⁻¹ produced the highest vitamin K in all trials (e.g., 19.05 vs. 15.84 µg/100g at control in Trial I 2019; LSD = 1.098). CU 999 and Monalisa did not differ significantly in vitamin K in most trials.

Table 8

Effect of variety, spacing and NPK fertilizer rate on vitamin C (mg/100g) and vitamin K (µg/100g) content of cucumber fruits in both trials of 2019 and 2020.

Treatment	2019 T I	2019 T II	2020 T I	2020 T II	2019 T I	2019 T II	2020 T I	2020 T II
	Vitamin C (mg/100g)				Vitamin K (µg/100g)			
Variety								
CU 999	2.84	3.24	3.25	2.93	17.09	16.83	17.17	16.41
Monalisa	3.22	3.18	3.09	2.85	17.29	17.00	17.14	16.49
LSD (P ≤ 0.05)	0.265	ns	0.048	0.003	ns	0.118	ns	0.021
Spacing								
75 × 25 cm	3.06	3.26	3.07	3.01	17.17	16.50	16.42	15.74
75 × 50 cm	3.08	2.78	2.91	2.44	17.19	16.69	17.09	16.45
75 × 75 cm	2.95	3.59	3.53	3.19	17.22	17.55	17.95	17.18
LSD (P ≤ 0.05)	0.012	0.026	0.182	0.021	0.013	0.041	0.097	0.053
NPK rate (kg ha ⁻¹)								
0	2.64	2.98	2.96	2.65	15.84	15.84	16.75	15.17
100	3.23	3.17	3.18	2.84	16.12	16.47	17.11	16.07
200	3.18	3.29	3.30	2.94	17.77	17.00	17.32	16.71
300	3.07	3.41	3.24	3.11	19.05	18.35	17.42	17.87
LSD (P ≤ 0.05)	0.185	0.205	0.127	0.185	1.098	1.086	0.175	1.048
ns = not significant.								

3.9 Correlation matrix and PCA of quality traits

The Pearson correlation matrix (Fig. 4) revealed strong positive correlations among all vitamin parameters ($r = 0.70\text{--}0.91$), and between dry matter and vitamins A, C and K ($r = 0.65\text{--}0.84$). Firmness was positively correlated with dry matter ($r = 0.72$) and with vitamin K ($r = 0.68$). Green colour intensity (more negative a^*) was positively correlated with spacing width but showed modest negative correlations with firmness ($r = -0.41$), suggesting a mild trade-off between greenness and texture. Moisture content was negatively correlated with dry matter ($r = -0.93$) and with most vitamins, consistent with dilution effects.

PCA of the 13 quality variables (Fig. 5) showed that PC1 was primarily loaded by vitamin content (A, C, K), dry matter and firmness variables reflecting nutrient concentration and physical quality while PC2 was dominated by moisture and the proximate fractions (carbohydrate, crude protein, crude fibre). CU 999 treatments clustered in the upper-right quadrant of the biplot (higher firmness, higher dry matter), while Monalisa treatments occupied the positive PC2 region (higher moisture, slightly higher crude protein). Treatments at 300 kg ha^{-1} NPK consistently displaced toward higher PC1 scores, confirming the fertilizer-mediated enrichment of vitamin and dry matter content documented in the univariate analyses. Wider spacing treatments ($75\times 75\text{ cm}$) occupied a distinct region of positive PC2, reflecting their generally higher moisture-adjusted nutritional density.

Radar plots (Fig. 6a) further illustrate the normalised nutritional profiles of selected variety $\times$ spacing combinations, confirming that $75\times 75\text{ cm}$ spacing consistently elevated the multi-trait nutritional performance score relative to $75\times 25\text{ cm}$ within each variety. The dry matter response to NPK rate (Fig. 6b) shows a generally positive dose-response in the 2019 trials but a non-linear pattern in 2020, consistent with the rainfall-driven variation in soil nutrient availability between years.

4. Discussion

The consistently greater fruit firmness of CU 999 over Monalisa across most trials reflects genotypic differences in cell wall composition, turgor maintenance and pre harvest moisture relations (Bourne, 2002). Higher turgor pressure and greater cell wall polymer cross-linking in CU 999 are likely genetic attributes that translate into a firmer texture and longer potential shelf life commercially critical traits in Nigerian fresh markets where ambient storage is common. The superiority of CU 999 in firmness aligns with its higher dry matter content in Trial I of 2020, since greater dry matter is associated with stronger cell wall architecture and reduced susceptibility to postharvest softening (Barrett et al., 2010). Nandi et al., 2024 demonstrated that retention of green color is governed by a single recessive gene and is associated with extended shelf-life traits, including absence of shrinkage and retention of fruit firmness. They identified QTLs on chromosome 4 spanning 5.01 Mb associated with green color retention. This research reveals that cucumber fruit color is tightly controlled by specific transcriptional networks governing chloroplast development and pigment biosynthesis. The significant variety $\times$ spacing $\times$ fertilizer interaction for both firmness and colour across all four trials emphasises that no single variety unconditionally dominates all quality dimensions: growers targeting firmness should select CU 999, while those targeting skin colour for premium fresh markets may prefer Monalisa.

The consistent and dose-dependent increase in vitamin A, vitamin C and vitamin K with increasing NPK rate is physiologically coherent. Nitrogen promotes chloroplast biogenesis and photosynthetic electron transport, which supports carotenoid and ascorbate synthesis; phosphorus is essential for ATP-dependent vitamin biosynthetic reactions; and potassium regulates stomatal conductance and photosynthate flux toward fruit tissues, thereby supporting phytochemical accumulation (Lee et al., 2024). Lee et al. (2024), using mass-spectrometry metabolomics on cucumber fruit across low- and high-nutrient soils in Korea, found that NPK application altered amino acid and organic acid profiles substantially, with the nature and magnitude of changes dependent on initial soil fertility a finding consistent with the trial-to-trial variation in NPK effect sizes observed here between the low-organic-carbon 2019 and 2020 soils. Mi et al. (2022), in their physicochemical evaluation of cucumbers under five Chinese fertilizer regimes, found that combined organic and mineral NPK inputs produced the best colour and texture outcomes, suggesting that mineral NPK alone (as used here) is effective but could potentially be further enhanced by organic supplement an avenue for future research in SW Nigeria.

The promotion of vitamin K and vitamin C by wider spacing (75×75 cm) is explicable through canopy microclimate effects: reduced canopy density allows greater light interception per fruit, favouring menaquinone (vitamin K) synthesis in illuminated tissues and stimulating ascorbate accumulation via photoreduction (Gruda et al., 2017). The lower moisture content and higher dry matter observed at 75×75 cm are consistent with the notion that wider spacing reduces intra-plant competition for water, leading to more concentrated fruit solids a pattern reported for other cucurbits under contrasting plant populations (Nelson, 1998). The inverse relationship between higher moisture and lower vitamin concentrations documented in the correlation matrix (Fig. 4) is consistent with nutrient dilution theory: as individual fruit size increases under close spacing (75×25 cm), the absolute nutrient mass per fruit does not increase proportionately, leading to lower concentrations on a fresh-weight basis. This trade-off between per-hectare yield (maximised at 75×25 cm) and per-fruit nutritional concentration (maximised at 75×75 cm) is a fundamental management insight for cucumber producers who target both production volume and nutritional density markets simultaneously.

The low fat content (0.10–0.15 g/100g) recorded across all treatments is consistent with published values for cucumber (Agatemor et al., 2018), confirming its suitability for inclusion in low-fat dietary regimens. The response of crude protein to NPK at 100 kg ha⁻¹ rather than the expected monotonic increase to 300 kg ha⁻¹ is consistent with the well-documented phenomenon of luxury nitrogen consumption at high application rates, where excess nitrogen is not incorporated into protein but rather accumulated as soluble forms, diluting the protein concentration on a dry-weight basis (Gruda et al., 2017; Mi et al., 2022).

The significant three-way interactions for most quality traits across multiple trials confirm that no single factor independently determines fruit quality; rather, interactions among genotype, spatial arrangement and fertility management produce context-dependent outcomes. This integrated complexity is clearly visualised in the PCA biplot (Fig. 5), where treatment scores do not segregate cleanly by a single factor but by combinations thereof. The recommendation for quality-oriented production (both CU 999 and

Monalisa $\times 75 \times 75$ cm $\times 300$ kg ha⁻¹ NPK) is supported by the multivariate nutritional profile (Fig. 6a), which shows that this combination consistently achieves above-average scores across firmness, vitamins and dry matter simultaneously. This quality-optimising combination differs fundamentally from the yield-optimising recommendation (CU 999 $\times 75 \times 25$ cm $\times 300$ kg ha⁻¹), a finding with direct practical implications for market-targeted crop management in SW Nigeria: producers serving premium fresh-market or health-food channels should manage differently from those supplying commodity bulk markets.

5. Conclusions

This four-trial, two-year study is the most comprehensive simultaneous evaluation of postharvest quality and nutritional composition of cucumber under a replicated three-factor field design in tropical Nigeria. Variety CU 999 produced consistently firmer fruits while Monalisa maintained superior skin greenness. NPK at 300 kg ha⁻¹ significantly enhanced vitamin A (up to 35.93 μ g/100g), vitamin C and K, dry matter and carbohydrate content across trials. Wider spacing (75 $\times$ 75 cm) promoted greener colour, higher vitamin K and greater dry matter concentrations, revealing a trade-off between per-hectare yield (maximised at close spacing) and per-fruit nutritional density (maximised at wide spacing). Both varieties at 75 $\times$ 75 cm $\times 300$ kg ha⁻¹ are recommended for quality-oriented production, while CU 999 at 75 $\times$ 25 cm $\times 300$ kg ha⁻¹ targets maximum yield. Future research should explore organic–mineral fertilizer combinations, post-harvest handling protocols and consumer sensory evaluation to fully characterise the market value of quality-optimised cucumber production in SW Nigeria.

Declarations

Author contributions

O.O. Falaiye: Conceptualization, Methodology, Supervision, Writing – original draft, Project administration.

A.O. Kasali: Methodology, Investigation, Data curation, Project administration.

N.O. Adeyemi: Methodology, Data curation, Writing – review & editing.

O.E. Oni: Formal analysis, Data curation, Writing – review & editing.

R.A. Somoye: Validation, Investigation, Writing – review & editing.

O.M. Falaiye: Project administration, Resources, Writing – review & editing.

E.A. Adekunle: Validation, Supervision, Writing – review & editing.

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Declaration of competing interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest in this manuscript.

Data availability

Data available from the corresponding author upon reasonable request.

Data Ethics approval and consent to participate availability

The plant material used in this study was the Cucumber (*Cucumis sativus* L.) variety CU 999 and monalisa, a widely cultivated and commercially available variety. CU 999 and monalisa varieties are developed for improved adaptability, early maturity, and enhanced tolerance to common biotic and abiotic stresses. Specifically, the varieties is known for its high yield potential, good quality, and suitability for production, making it a commonly cultivated variety among farmers. The plant materials used were obtained from conventional agricultural sources, and their use complied with applicable institutional, local, and national guidelines governing plant research. Since the variety is widely cultivated and not subject to conservation restrictions or protected status, no special permissions or collection licenses were required or obtained for this study.

Clinical Trial Registration

This study does not involve clinical trials and therefore does not require registration.

Permissions to collect the plant/plant parts

Not applicable

Consent for publication

I inform you that the consent for publication was obtained from all authors who wrote the manuscript.

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Figures

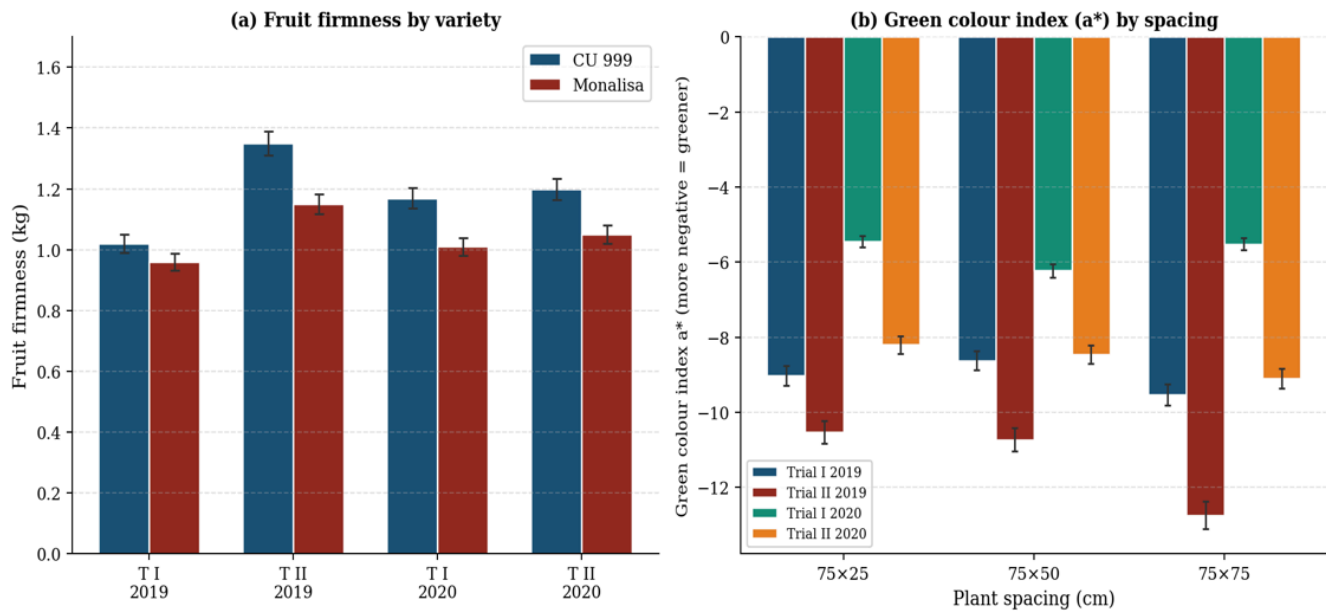


Figure 1

Postharvest quality of cucumber (*Cucumis sativus* L.) fruits: (a) fruit firmness (kg) by variety across four trials (2019–2020); (b) green colour index (CIE a*) by plant spacing across trials. More negative a* indicates greener fruit. Error bars = ± 1 SEM (n = 3).

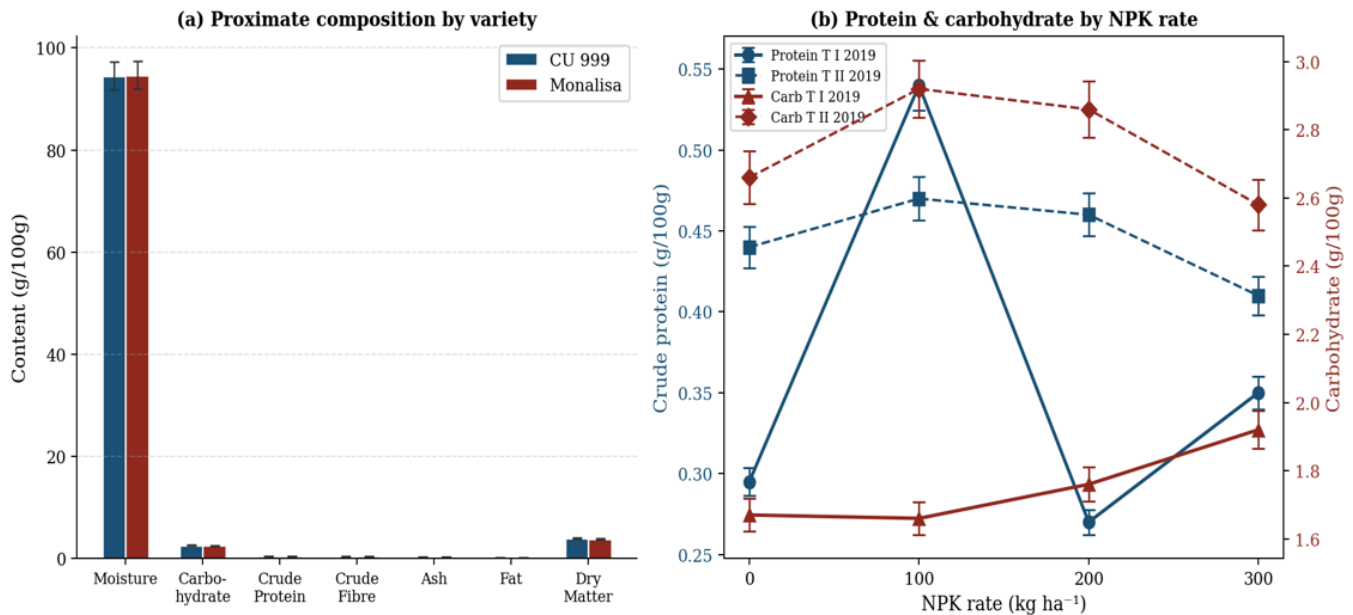


Figure 2

Proximate composition of cucumber (*Cucumis sativus* L.) fruits: (a) grand means of selected proximate fractions by variety across all trials; (b) crude protein (left axis) and carbohydrate (right axis) as influenced by NPK fertilizer rate in Trials I and II of 2019. Error bars = ± 1 SEM (n = 3).

Vitamin content of cucumber fruits as influenced by variety, spacing and NPK fertilizer rate

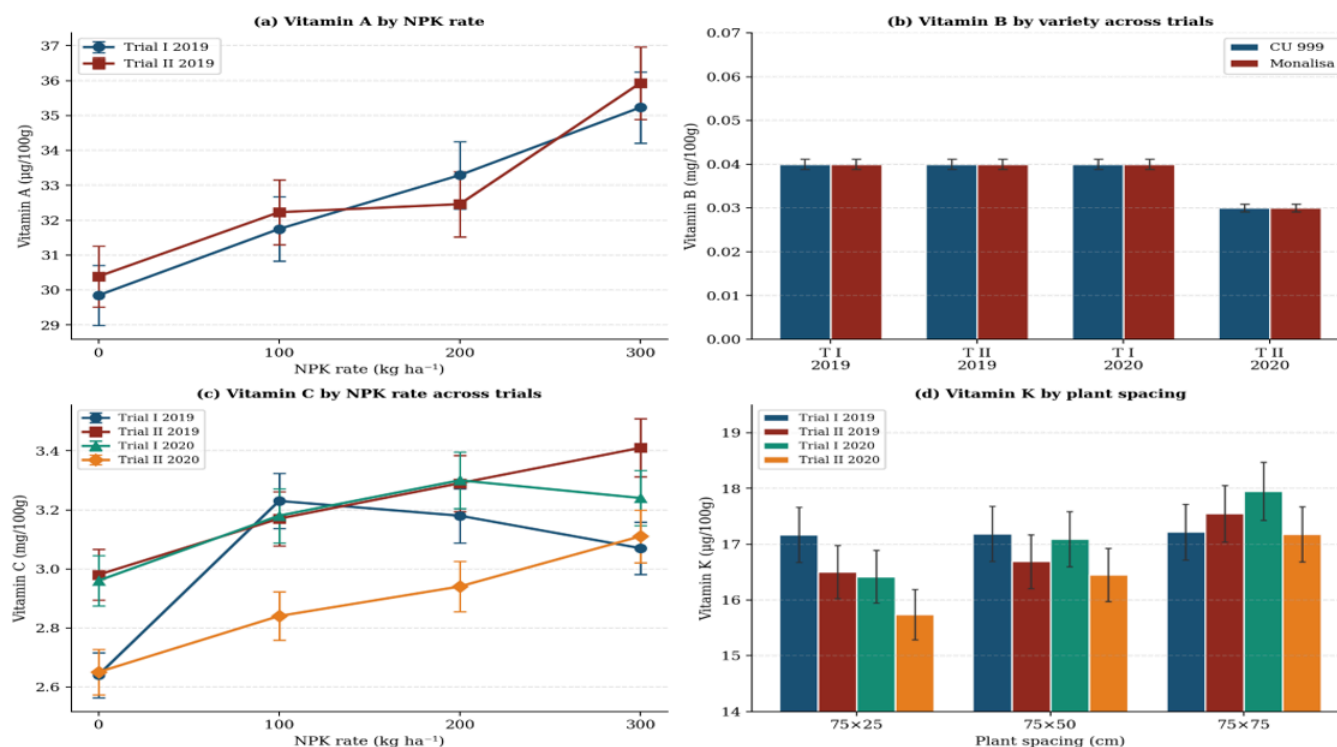


Figure 3

Vitamin content of cucumber (*Cucumis sativus* L.) fruits: (a) vitamin A (µg/100g) by NPK rate in Trials I and II 2019; (b) vitamin B (mg/100g) by variety across all trials; (c) vitamin C (mg/100g) by NPK rate across all four trials; (d) vitamin K (µg/100g) by plant spacing across all four trials. Error bars = ± 1 SEM (n = 3).



Figure 4

Pearson correlation matrix of 13 postharvest quality and nutritional variables measured on cucumber (*Cucumis sativus* L.) fruits across all treatments and trials (2019–2020). Colour scale: green = positive, red = negative correlation. Cell values are Pearson r coefficients.

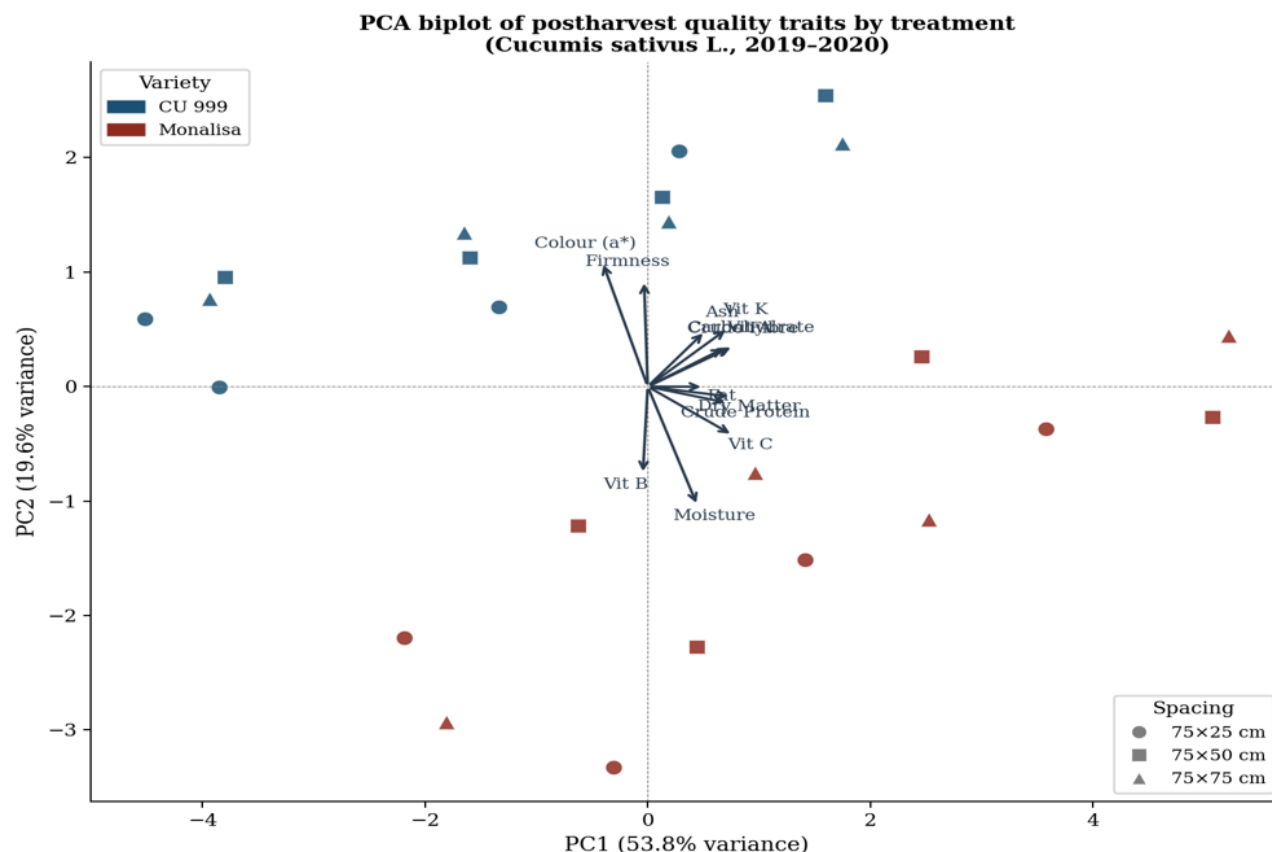


Figure 5

Principal component analysis (PCA) biplot of 13 postharvest quality and nutritional variables across 24 treatment combinations (*Cucumis sativus* L., 2019–2020). Loading arrows show variable contributions; symbols are treatment scores coded by variety (colour) and spacing (shape).

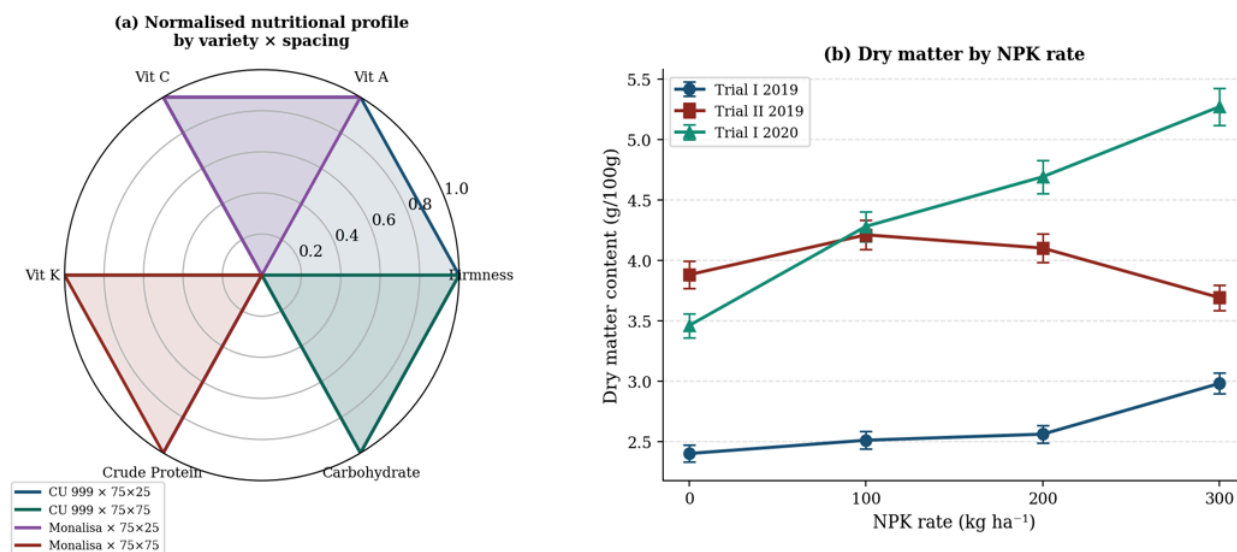


Figure 6

(a) Radar plot comparing normalised nutritional profiles (firmness, vitamin A, C, K, crude protein, carbohydrate) of four variety × spacing combinations across all trials; (b) dry matter content (g/100g) of cucumber fruits by NPK fertilizer rate across three trials. Error bars = ± 1 SEM (n = 3).