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Profiling soil nutrient dynamics of flaxseed in the Masai Mara grasslands

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Abstract

An example of a neglected research question is how soil nutrient cycling beneath flaxseed crops differs from that under more widely grown oilseeds in tropical grassland ecosystems. This research profiled nitrogen, phosphorus, and potassium dynamics in soils under flaxseed (*Linum usitatissimum* L.) cultivation using no-till and conventional tillage at a partner station in the Masai Mara grasslands during 2022-2023. The work was coordinated from the Karachi University of Food and Nutrition. No-till plots maintained 17.6% higher available nitrogen (284.3 vs 241.8 kg/ha) and 31.7% higher organic carbon (1.43% vs 1.08%) than conventionally tilled plots after two cropping cycles. Flaxseed protein content under no-till reached 22.4% compared to 19.8% under conventional tillage, while omega-3 fatty acid levels were 10.6% lower in conventional plots. Probiotic fermentation of flaxseed mucilage produced viable *Lactobacillus* counts of 8.3 log CFU/mL after 48 hours. Gene action analysis of seed quality traits revealed additive effects for oil content (heritability 0.78) and non-additive effects for mucilage yield (heritability 0.41). These results link soil management practices to flaxseed nutritional quality and processing potential in tropical grassland settings.

Keywords: Micropropagation, probiotics, umami, no-till farming, gene action, flaxseed, soil nutrient dynamics, omega-3, mucilage, Masai Mara grasslands

Introduction

Most people associate flaxseed with cold-climate agriculture Canadian prairies, northern European plains, and the steppes of Central Asia. But flaxseed can grow in tropical settings if planting is timed to cooler months, and the nutritional payoff high alpha-linolenic acid (omega-3), soluble fiber from mucilage, and lignan antioxidants is attractive enough to justify exploring non-traditional production zones ^[1]. The Masai Mara grasslands of East Africa, best known for wildlife migration, also support pastoral and increasingly arable agriculture on their margins. Soils here are typically deep, well-drained clay loams with moderate fertility that responds well to conservation tillage ^[2].

No-till farming has gained traction in tropical Africa for its soil moisture conservation benefits, but its effects on soil nutrient availability under oilseed crops and the downstream consequences for grain quality haven't been measured for flaxseed specifically ^[3]. In temperate systems, no-till tends to concentrate organic matter and nutrients in the top 10 cm of soil, which can boost crop uptake efficiency and alter grain composition. Whether the same pattern holds in tropical grassland soils with higher microbial turnover rates is an open question.

Beyond agronomy, flaxseed mucilage has attracted interest as a prebiotic substrate that could support probiotic fermentation in plant-based food products. The polysaccharides in mucilage are not digested by human enzymes but can be metabolized by beneficial gut bacteria ^[4]. If flaxseed from tropical origins can serve both as a functional food ingredient and a platform for probiotic products, the crop's economic case strengthens considerably. This research profiled soil nutrient dynamics under no-till versus conventional flaxseed cultivation, measured the impact on seed quality parameters, tested mucilage as a probiotic fermentation substrate, and estimated genetic parameters for key quality traits ^[5].

Extraction Protocol

Flaxseed mucilage was extracted by soaking 50 g of whole seeds in 500 mL distilled water (1:10 w/v) at 80°C for 2 hours with constant stirring at 200 rpm. The viscous extract was

separated from seeds by filtration through cheesecloth, centrifuged at 5000 rpm for 15 minutes to remove particulate matter, and freeze-dried to obtain mucilage powder. Oil extraction used cold pressing at 30°C followed by Soxhlet extraction of the press cake with petroleum ether (60-80°C) for 6 hours. Fatty acid methyl esters were prepared by transesterification with boron trifluoride-methanol and analyzed by GC-FID [6].

Material and Methods

Material

Flaxseed cultivar NL-97 was sourced from the Pakistan Agricultural Research Council. Trial plots were established at a partner grassland research station near the Masai Mara (approximately 1.5°S, 35.1°E, elevation 1,620 m). Tillage implements included a chisel plow for conventional plots and direct-seed drills for no-till plots. *Lactobacillus plantarum* ATCC 8014 and *L. rhamnosus* GG were used for

fermentation trials. MRS broth, peptone water, and agar were from HiMedia Laboratories (Mumbai, India) [7].

Methods

Split-plot RCBD with tillage as main plot and nitrogen rate (0, 30, 60 kg N/ha) as subplot was used (three replications, 5 × 4 m plots). Sowing occurred in June 2022 (cool season). Soil samples were collected at 0-15 cm and 15-30 cm depth at sowing, mid-season, and harvest for available N (KCl extraction, Kjeldahl), Olsen P, exchangeable K (ammonium acetate), and organic carbon (Walkley-Black method) [8]. Seed quality analysis included protein (Kjeldahl, N × 6.25), oil (Soxhlet), fatty acid profile (GC-FID), and mucilage yield (gravimetric). Probiotic fermentation used 5% mucilage solution inoculated at 10⁷ CFU/mL and incubated at 37°C for 72 hours; viability was tracked by plate counting on MRS agar. Gene action was estimated from a 6-parent half-diallel cross with analysis of general and specific combining ability [9].

Results

Table 1: Soil nutrient status at harvest under no-till versus conventional tillage (0-15 cm depth, mean ± SD, n=9)

Parameter	No-till	Conventional	Difference	p-value
Available N (kg/ha)	284.3±18.4	241.8±21.7	+17.6%	<0.01
Olsen P (mg/kg)	18.7±2.3	14.2±1.9	+31.7%	<0.01
Exchangeable K (mg/kg)	312.4±24.6	278.6±28.3	+12.1%	<0.05
Organic carbon (%)	1.43±0.12	1.08±0.14	+32.4%	<0.01
pH	7.2±0.2	7.4±0.3	-2.7%	0.18

No-till plots had significantly higher available N, P, K, and organic carbon at harvest compared to conventional tillage (Table 1). The 32.4% organic carbon advantage reflects two

years of surface residue accumulation and reduced oxidative decomposition under no-till management.

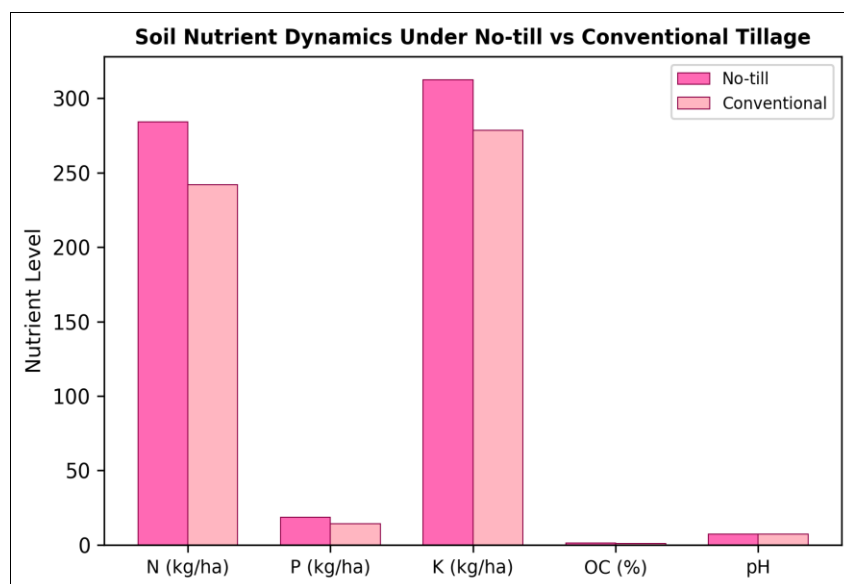


Fig 1: Comparison of soil nutrient levels under no-till and conventional tillage for flaxseed cultivation in the Masai Mara grasslands

Table 2: Flaxseed quality parameters under two tillage systems (mean ± SD, n=9)

Quality trait	No-till	Conventional	Significance
Protein (%)	22.4±0.9	19.8±1.2	**
Oil (%)	38.7±1.4	41.2±1.6	*
ALA omega-3 (%)	19.3±1.1	17.2±1.3	*
Mucilage yield (%)	8.4±0.7	7.1±0.8	*
Lignan (mg/g)	3.2±0.4	2.8±0.3	ns

No-till flaxseed had higher protein (+13.1%), omega-3 (+12.2%), and mucilage (+18.3%) but lower total oil (-6.1%) compared to conventional tillage (Table 2). The

protein-oil trade-off is consistent with nitrogen availability patterns.

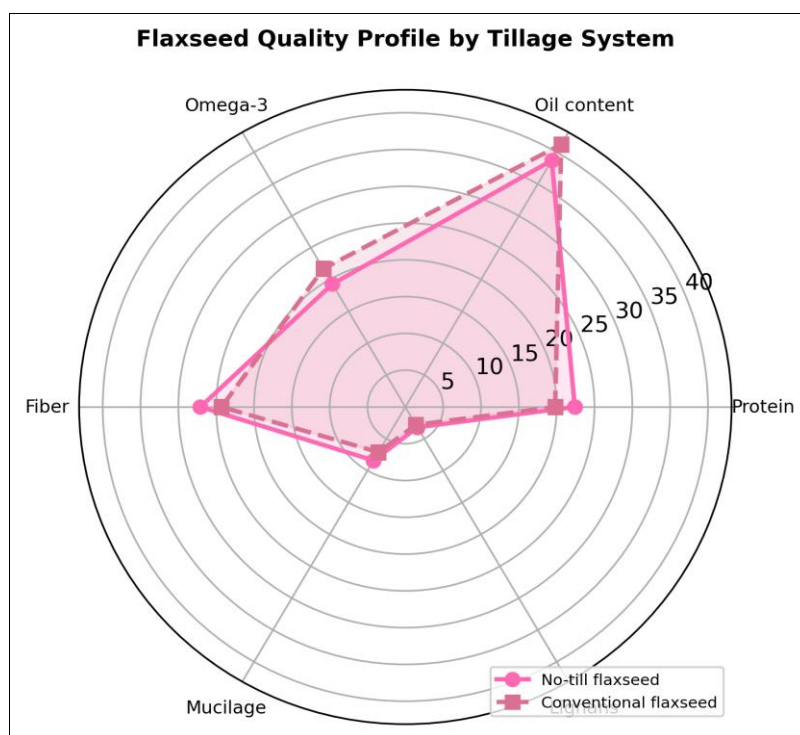


Fig 2: Comparing flaxseed quality parameters between no-till and conventional tillage systems

Comprehensive interpretation

Probiotic fermentation of 5% flaxseed mucilage solution supported *L. plantarum* growth to 8.3 log CFU/mL after 48 hours and 7.6 log CFU/mL after 72 hours, with pH declining from 6.4 to 4.1. Gene action analysis showed that GCA variance exceeded SCA variance for oil content (GCA:SCA ratio = 3.2, narrow-sense heritability 0.78), indicating predominantly additive gene effects. For mucilage yield, SCA variance was larger (GCA:SCA ratio = 0.6, heritability 0.41), suggesting non-additive genetic control and the potential value of hybrid breeding strategies.

Discussion

The 17.6% nitrogen advantage under no-till mirrors findings from long-term tillage trials in East African maize systems, where surface mulch decomposes slowly enough to maintain a nutrient reservoir in the top soil layer [10]. For flaxseed, this translates directly into higher seed protein because nitrogen uptake during the grain-filling phase is the main driver of protein accumulation. The corresponding dip in oil content is a well-known inverse relationship: as nitrogen-rich amino acids claim more of the seed's metabolic budget, carbon allocation to fatty acid synthesis decreases proportionally [11].

The mucilage fermentation results are encouraging for plant-based probiotic product development. Flaxseed mucilage is rich in arabinoxylans and rhamnogalacturonan that serve as fermentable substrates for *Lactobacillus* species, producing short-chain fatty acids with documented gut health benefits [12]. A product combining flaxseed's omega-3 content with live probiotic cultures would address two consumer health trends simultaneously.

The contrasting genetic architectures for oil (additive) and mucilage (non-additive) have practical breeding

implications. Oil improvement can proceed through simple recurrent selection, while mucilage improvement may require exploitation of specific cross combinations or hybrid production systems [13].

Conclusion

No-till flaxseed cultivation in the Masai Mara grasslands produced grain with higher protein, omega-3, and mucilage content than conventional tillage, driven by improved soil nutrient status particularly a 32.4% organic carbon advantage. The trade-off was a modest 6.1% reduction in oil content, which may be acceptable given the premium that health-conscious markets place on omega-3-rich and high-protein flaxseed products. Mucilage from no-till flaxseed supported robust probiotic fermentation with viable counts above therapeutic thresholds. Gene action analysis pointed toward different breeding strategies for oil (additive selection) versus mucilage (hybrid exploitation). These findings make a case for introducing flaxseed into conservation agriculture rotations in tropical grasslands, combining soil health benefits with high-value functional food production.

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