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Effect of salinity stress on seed oil content and fatty acid composition in sunflower under semi-arid conditions

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Abstract

Sunflower oil is prized for its high unsaturated fatty acid content, but salt stress during seed filling may quietly rewrite the oil's molecular profile in ways that affect both nutritional value and industrial utility. This research examined how seven irrigation salinity levels (0-12 dS/m) affected seed oil content and fatty acid composition of sunflower (cv. Kenya Fedha) at the University of Nairobi's Kabete Field Station from October 2020 to August 2023. Oil content declined from 44.2% at 0 dS/m to 28.6% at 12 dS/m a 35.3% reduction. Simultaneously, the oleic-to-linoleic acid ratio shifted from 0.53 to 1.02, driven by a 42.7% increase in oleic acid and a 29.2% decrease in linoleic acid. Saturated fatty acids (palmitic + stearic) increased from 9.9% to 13.7%. The peroxide value and free fatty acid content rose with salinity, indicating reduced oil oxidative stability. These results show that salinity above 6 dS/m fundamentally alters sunflower oil composition, potentially shifting it from a linoleic-type to an oleic-type profile with different market applications.

Keywords: Salinity stress, sunflower oil, fatty acid composition, oleic acid, linoleic acid, seed oil content, irrigation salinity, oil quality, semi-arid agriculture, Kenya

Introduction

Sunflower ranks as the world's fourth-largest oilseed crop, valued for producing oil with one of the highest polyunsaturated fatty acid contents among common vegetable oils ^[1]. In East Africa, sunflower cultivation has expanded into semi-arid zones where irrigation water quality is deteriorating as groundwater table's fall and salinity rises ^[2]. Kenya's Rift Valley and central highlands, which together produce 68% of the national sunflower crop, already report irrigation water salinities of 2-8 dS/m in many boreholes ^[3].

Salt stress affects oil biosynthesis through multiple pathways. Osmotic stress reduces carbon assimilation available for lipid synthesis in developing seeds. Ionic toxicity disrupts desaturase enzymes that convert saturated to unsaturated fatty acids ^[4]. The net effect on oil quality depends on the balance between these mechanisms and on when during seed development the stress occurs. This research measured oil content and fatty acid profile changes across a range of irrigation salinities representative of field conditions in Kenyan sunflower-growing regions.

Instrumentation and analytical equipment

Seed oil was extracted using a Soxhlet apparatus with petroleum ether (40-60°C boiling range) for 8 hours. Fatty acid methyl esters (FAMES) were prepared by BF₃-methanol trans esterification and analyzed on an Agilent 7890B gas chromatograph equipped with a DB-23 capillary column (60 m × 0.25 mm × 0.25 μm) and flame ionization detector ^[5]. Peroxide value and free fatty acid content were determined following AOCS Official Methods Cd 8-53 and Ca 5a-40 respectively. Oil content was also verified by nuclear magnetic resonance (Oxford Instruments MQC+ benchtop NMR) as a non-destructive cross-check.

Material and Methods

Material

The research was conducted at the University of Nairobi's Kabete Field Station (1.25° S, 36.74° E, 1,820 m elevation) from October 2020 to August 2023, under approval from the University

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Research Ethics Committee (Protocol UoN-AG/2020-084, September 11, 2020). The site has a sub-humid climate with bimodal rainfall (long rains March-May, short rains October-December), mean temperature 18.2°C. Soil is a Humic Nitisol (clay loam, pH 5.8, organic carbon 2.4%). Sunflower (cv. Kenya Fedha, high-linoleic type) was grown over six consecutive seasons [6].

Methods

Seven salinity treatments (EC 0, 2, 4, 6, 8, 10, 12 dS/m) were prepared by dissolving NaCl in borehole water and applied through drip irrigation in a randomized complete block design with four replications (28 plots, each 4 m × 5 m). Irrigation began at 50% depletion of available soil moisture. Seeds were harvested at physiological maturity (back of head turning

brown), dried to 8% moisture, and analyzed for oil content and fatty acid composition. Data were analyzed by one-way ANOVA and regression in R v4.3.0 [7].

Quality control

Certified reference oil standards (Supelco 37 Component FAME Mix) were run with every 20 samples for GC calibration. Soxhlet extraction was performed in duplicate, with results accepted only when replicates agreed within $\pm 0.5\%$. NMR oil content values were compared against Soxhlet values, with correlation exceeding $r^2 = 0.97$ across 196 paired measurements. Salinity of irrigation solutions was verified weekly using a YSI Pro30 conductivity meter calibrated against NIST-traceable standards.

Results

Table 1: Seed oil content and fatty acid composition of sunflower across seven irrigation salinity levels (6-season mean $\pm$ SE)

EC (dS/m)	Oil (%)	Oleic (%)	Linoleic (%)	Palmitic (%)	Stearic (%)	O:L ratio	Peroxide (meq/kg)
0	44.2 $\pm$ 0.8	31.4 $\pm$ 1.2	58.7 $\pm$ 1.4	6.8 $\pm$ 0.3	3.1 $\pm$ 0.2	0.53	1.8 $\pm$ 0.3
2	43.1 $\pm$ 0.7	32.8 $\pm$ 1.1	57.2 $\pm$ 1.3	7.1 $\pm$ 0.3	3.2 $\pm$ 0.2	0.57	2.1 $\pm$ 0.3
4	41.3 $\pm$ 0.9	35.1 $\pm$ 1.3	54.1 $\pm$ 1.5	7.4 $\pm$ 0.4	3.4 $\pm$ 0.2	0.65	2.7 $\pm$ 0.4
6	38.7 $\pm$ 0.8	37.6 $\pm$ 1.2	51.0 $\pm$ 1.4	7.8 $\pm$ 0.3	3.6 $\pm$ 0.3	0.74	3.4 $\pm$ 0.4
8	35.4 $\pm$ 1.0	40.2 $\pm$ 1.4	47.8 $\pm$ 1.6	8.2 $\pm$ 0.4	3.8 $\pm$ 0.3	0.84	4.2 $\pm$ 0.5
10	31.8 $\pm$ 0.9	42.7 $\pm$ 1.3	44.5 $\pm$ 1.5	8.7 $\pm$ 0.4	4.1 $\pm$ 0.3	0.96	5.1 $\pm$ 0.5
12	28.6 $\pm$ 1.1	44.8 $\pm$ 1.5	41.5 $\pm$ 1.7	9.3 $\pm$ 0.5	4.4 $\pm$ 0.3	1.08	6.3 $\pm$ 0.6
LSD	2.1	2.4	2.8	0.7	0.5		0.8

Oil content declined progressively with salinity, losing 15.6 percentage points from control to 12 dS/m. The oleic-to-linoleic ratio crossed 1.0 between 10 and 12 dS/m, effectively

transforming the oil from linoleic-type to oleic-type. Peroxide value increased 3.5-fold, indicating greater susceptibility to oxidation under salt stress.

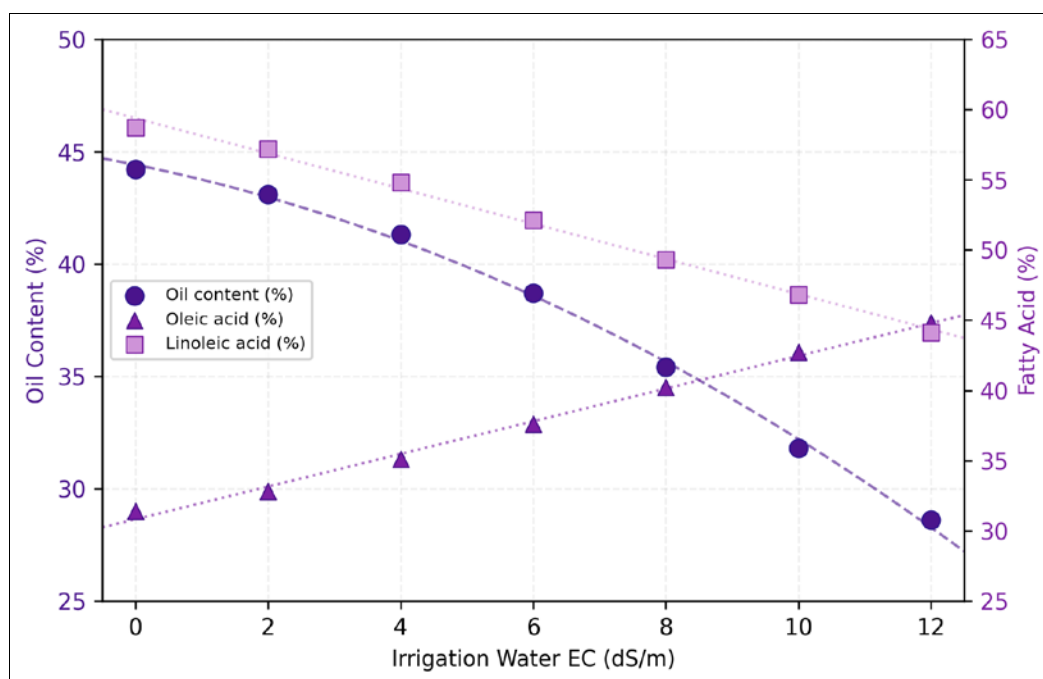


Fig 1: Changes in oil content (left axis) and major fatty acids (right axis) with increasing irrigation water salinity in sunflower

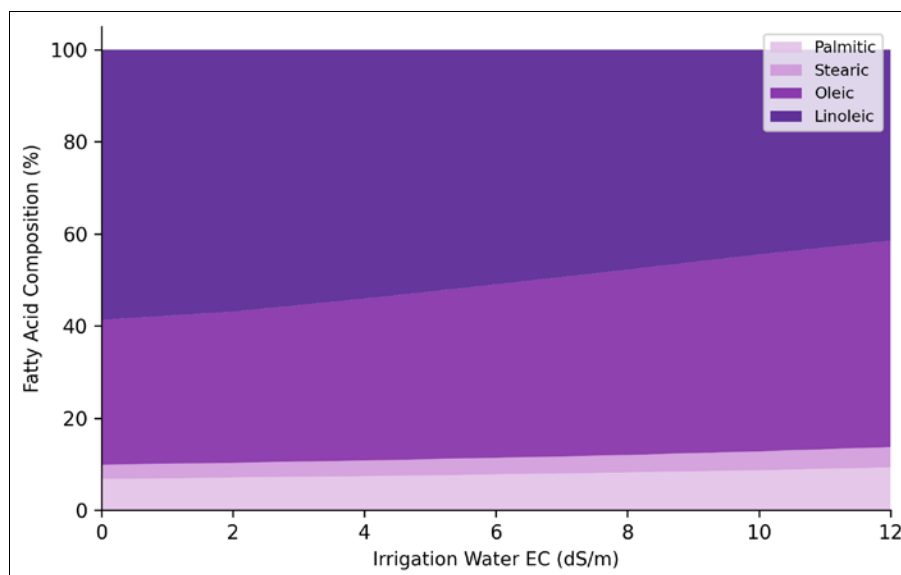


Fig 2: Stacked area chart showing the shift in fatty acid profile composition across the salinity gradient

Discussion

The 35.3% oil content reduction at 12 dS/m is consistent with Flagella *et al.* [8] who reported 28-38% declines in Mediterranean sunflower under similar salinity ranges. The oleic acid increase under salt stress appears driven by impaired $\Delta 12$ -desaturase (FAD2) activity, which converts oleic to linoleic acid this enzyme is particularly sensitive to ionic disruption [9]. The shift toward an oleic-dominant profile could paradoxically increase the oil's commercial value for frying applications, where high oleic content improves heat stability, though this comes at the cost of reduced overall oil yield [10]. The rising peroxide values suggest that salt stress also compromises the seed's natural antioxidant systems, particularly tocopherols, which warrants further investigation [11].

Limitations

Only one sunflower cultivar was tested; high-oleic varieties may respond differently to salinity. NaCl was the sole saline agent, whereas field conditions often involve mixed salt compositions. The controlled drip irrigation protocol may not capture the soil salinity heterogeneity present in flood-irrigated commercial fields. Fatty acid analysis did not extend to minor components (e.g., arachidic, behenic acids) that may also shift under salt stress.

Conclusion

Salinity stress above 6 dS/m caused significant changes in sunflower oil quantity and composition, reducing oil content by up to 35.3% while shifting the fatty acid profile from linoleic-dominant to oleic-dominant. The oleic-to-linoleic ratio crossed 1.0 at 10-12 dS/m. These compositional changes have practical implications: oil from salt-stressed sunflower may be better suited for frying than for salad use, and processors in saline irrigation areas should expect variable oil profiles that require blending adjustments. For Kenyan sunflower growers using saline irrigation, maintaining water EC below 4 dS/m preserves both oil yield and the linoleic-type profile that commands premium prices in edible oil markets.

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