PLANT SCIENCE TODAY
Vol x(x): xx–xx
https://doi.org/10.14719/pst.9886

eISSN 2348-1900

RESEARCH ARTICLE

Combining ability, FTIR spectroscopy and fatty acid profiling of sunflower (*Helianthus annuus* L.) hybrids

Venkata Mohan Reddy G[1], Jayashree Kar[1*], Digbijaya Swain[1], KC Samal[2], Rajkumari Bhol[3], Hima Bindu Bhadragiri[1], Kalyan Kumar Mohanty[4] & Pratikshya Mishra[1]

[1]Department of Plant Breeding and Genetics, Odisha University of Agriculture & Technology, Bhubaneswar 751 003, Odisha, India
[2]Department of Agricultural Biotechnology, Odisha University of Agriculture &Technology, Bhubaneswar 751 003, Odisha, India
[3]Department of Plant Physiology, Odisha University of Agriculture &Technology, Bhubaneswar 751 003, Odisha, India
[4]Department of Vegetable Science, Odisha University of Agriculture &Technology, Bhubaneswar 751 003, Odisha, India

*Correspondence email - jayashreekarbbsr@gmail.com

Received: 07 June 2025; Accepted: 07 July 2025; Available online: Version 1.0: 01 August 2025

Cite this article: Venkata MRG, Jayashree K, Digbijaya S, Samal KC, Rajkumari B, Hima BB, Kalyan KM, Pratikshya M. Combining ability, FTIR spectroscopy and fatty acid profiling of sunflower (*Helianthus annuus* L.) hybrids. Plant Science Today (Early Access). https:/doi.org/10.14719/pst.9886

Abstract

Ten CMS lines and three R lines were crossed using a line × tester mating design to assess the combining ability for yield and component characters in sunflower (*Helianthus annuus* L.). Fourier Transform Infrared Spectroscopy (FTIR), fatty acid profiling and protein content analysis of thirty developed hybrids and their parents were conducted to identify and estimate the relative amounts of various bioactive compounds in sunflower. The analysis of variance showed significant variation among lines as well as testers for all the traits under study indicating presence of substantial genetic variation. The line CMS-519 was observed as good general combiner for plant height, head diameter, stem diameter, number of leaves/plants, seed yield/plant, biological yield/plant, where as CMS-240 was good general combiner for oil content and volume weight. Among the testers GP4-1424 was identified as a good general combiner for most traits. Among the hybrids, CMS-519 × GP4-1424 exhibited the highest specific combining ability (SCA) for plant height, head diameter, stem diameter, biological yield per plant and seed filling percentage. The cross CMS-207 × RHA-1-1 and CMS-243 × GP4-1424 showed highest SCA for seed yield and oil content respectively. Fatty acid composition analysis revealed that the hybrids were rich in unsaturated fatty acids, particularly oleic and linoleic acids. FTIR analysis confirmed the presence of functional groups such as =C-H, -C-H (CH_3), -C-H (CH_2), -C=O (ester), -C-O, -$(CH_2)_n$-. Crosses such as CMS-240 × IR-6, CMS-243 × GP4-1424, HA-89 × IR-6 and CMS-519 × GP4-1424 were superior in terms of both oil yield and protein content.

Keywords: combining ability; fatty acid profiling; Fourier Transform Infrared Spectroscopy (FTIR); general combining ability; oil content; specific combining ability; sunflower

Introduction

Sunflower is one of the most important oilseed crops grown throughout the world as a source of premium oil and dietary fibre that significantly contributes to human health (1). Due to the ever-increasing human population, the demand for sunflower oil and by-products has also increased and to meet the demand, there is a need to intensify efforts to expand sunflower output (2). Common sunflower (*Helianthus annuus* L.) cultivars exhibit limited genetic variation. This is largely due to hybrid breeding programs relying on a relatively narrow genetic base. Modern sunflower breeding programs are directed towards improving high yield traits combined with resistance to abiotic and biotic stress. Hybridization and introgression breeding have been of paramount significance in the exploration and utilization of wild germplasm for the genetic enhancement of sunflower (3).

The high percentage of C:18 fatty acids, specifically linoleic (18:2) and oleic acid (18:1), which together account for approximately 90 % of the total fatty acid content, is the reason for the nutritional quality of sunflower oil. The remaining fatty acids are palmitic (C16:0) and stearic acid (C18:0). The interest in polyunsaturated fatty acids of plant origin increased following the publication of the WHO guidelines (2023) (4) on the potential adverse effects of certain fats and oils on human health. Many studies have been conducted to ascertain the impact of the various fatty acids on the diet on human health. Fatty acids have historically been linked to cardiovascular disease, but it is now known that they also affect several other illnesses, including cancer, inflammatory conditions and metabolic disorders like type 2 diabetes (5).

Sunflower oil is mostly composed of oleic acid, a mono-saturated fat and linoleic acid, a polyunsaturated fat. Sunflower oil contains approximately 5 % palmitic acid, 6 % stearic acid, 30 % oleic acid (monounsaturated omega-9) and 59 % linoleic acid (polyunsaturated omega-6) (6).

The main concern of the oil processing industry and consumers is the adulteration of edible oils. This involves substitution with cheaper oils such as palm oil and addition of non-edible oils such as mineral oil. Fourier Transform Infrared Spectroscopy (FTIR), one of the well-known vibrational spectroscopies, has emerged as a viable method for detecting edible oil adulteration in recent years. For both qualitative and quantitative research on edible oil adulteration, it is an extremely sensitive and dependable analytical technique. It offers a quick, safe and non-destructive alternative with minimal sample preparation and no use of hazardous reagents (7).

This study aims to identify heterotic hybrids based on their combining ability studies and to carryout FTIR spectra analysis, fatty acid profiling and protein content estimation of heterotic hybrids.

Materials and Methods

The experimental material comprised 30 hybrids developed using line × tester mating design, along with their parents (10 CMS lines and 3 restorer lines) and 3 check varieties. All 46 genotypes were grown in randomized block design (RBD) with three replications at the (EB II) research plot of the Department of Plant Breeding and Genetics, Odisha University of Agriculture & Technology, Bhubaneswar during the rabi 2023 season. The crop was raised under protective irrigation with recommended agronomic practices such as thinning at 15 days after sowing, weeding, top dressing and earthing up and plant protection measures includes spraying of imidacloprid.

Data on 12 quantitative characters were recorded from five competitive plants per replication. These included: days to 50 % flowering, days to maturity, plant height (cm), head diameter (cm), stem diameter (mm), number of leaves per plant, seed yield per plant (g), biological yield per plant (g), seed filling percentage, hulling percentage, volume weight (g), 100- achene weight (g). Plot yield was recorded from all the plants in the plot. Harvest index was calculated using the formula (Yield of harvested product / Total above-ground biomass). Oil content and fatty acid profiling were carried out at Indian institute of Oilseeds Research (IIOR) using nuclear magnetic resonance spectroscopy (8). The protein content was determined using Kjeldahl method in the laboratory of Department of Soil Science and Agricultural Chemistry. FTIR analysis was carried out at the Central Laboratory of OUAT.

Statistical analysis

The means of the data recorded from five plants were subjected to statistical analyses. Line × Tester analysis was carried out (9) to study the nature of gene action and combining ability of the parents and crosses. Statistical analysis of line × tester was analysed using R-software with significant levels of $^{*}p \leq 0.05$, $^{**}p \leq 0.01$. FTIR graphs were made using the Origin software.

Results and Discussion

Per se performance

The *per se* performance is the primary criteria in selecting superior hybrids. The average performance of crosses and parents (lines and testers) is shown in Table 1. Most traits exhibited considerable variation in mean performance between parents and their hybrids. Of all the lines PET-2-7 had shown superior performance for days to 50 % flowering (55 days) and days to maturity (83 days), CMS-519 had performed better for plant height (149.53 cm) and biological yield per plant (119.53 g). CMS-852A had shown superior performance for the traits like head diameter (22.87 cm) and stem diameter (16.82 mm). The line CMS-207 has shown superior performance for number of leaves per plant (23.20), seed filling percentage (94.67 %) and 100- achene weight (6.85 g), whereas the line CMS-240 has shown superior performance for volume weight (42.71 g) and oil content (40.78 %). The line HA-89 and CMS-243 were found superior for hulling percentage (25.84 %) and for harvest index (44.08) respectively. The line CMS-2A had shown superior performance with respect to seed yield (45.87 g), oil yield (943.42 q/ha) and plot yield (25.48 q/ha). Among testers, GP4-1424 was found superior for almost all the traits including oil yield (693.71 q/ha). RHA-1-1 has shown superior performance for days to 50 % flowering (59.33 days) and days to maturity (87.33 days). IR-6 has shown superior performance for harvest index (42.43) and volume weight (47.93 g). Among crosses CMS-519 × GP4-1424 had shown superior performance for most of traits i.e. plant height (188.93 cm), head diameter (29.20 cm), stem diameter (21.55 mm), number of leaves/ plant (28.00), seed yield/plant (63.63 g), biological yield/plant (191.80 g) and plot yield (35.35 q/ha). CMS-2A × GP4-1424 had shown superior performance regarding days to 50 % flowering (55.67 days) and days to maturity (80.00days), whereas CMS-852A × IR-6 had performed better for seed filling percentage (96.67 %). Cross between COSF-7A × GP4-1424 had performed better for hulling percentage (32.26 %), cross CMS-240 × IR-6 had shown superior performance for volume weight (48.84 g) and oil yield (1320.68 q/ha). Cross CMS-243 × GP4-1424 had performed better with respect to 100- achene weight (9.00 g). Cross CMS-240 × GP4-1424 had shown superior performance regarding oil content (44.31 %).

Analysis of variance for combining ability

The analyses of variances (Table 2) revealed significant difference among parents for all the traits, whereas significant differences were observed among crosses for all the traits except for hulling percentage. Among lines differences were observed for traits like days to 50 % flowering, days to maturity, stem diameter, hulling %, volume weight and oil content. The significant differences were observed for traits like days to 50 % flowering, days to maturity, stem diameter, hulling %, volume weight, 100- achene weight and oil content among the testers. Mean sum of squares for line × testers were significant for all the traits except for hulling %. The above results suggested that ample variation was present. Also, the significance with respect to effects of parents' vs. crosses indicated the presence of heterosis among cross combination. Several workers have reported significant differences among lines, testers as well as line × tester interactions for yield and contributing traits and these traits can be subjected to heterosis breeding (10, 11).

Combining ability and gene action

The general combining ability of parents is presented in Table 3. Line CMS-519 recorded good general combining ability for plant height (12.962), head diameter (2.512), stem diameter (2.977), number of leaves per plant (2.218), seed yield per

Table 1. Mean performance of crosses and parents

CROSSES	DFF	DM	PH (cm)	HD (cm)	SD (mm)	NLP	SYP (g)	HI	BYP (g)	SF %	H %	VW (100 ml)	100- AW (g)	OC (%)	PY (q/ha)	OY (q/ha)
CMS852 × RHA-1-1	60.33	88.33	170.60	23.20	14.45	26.60	49.34	36.35	135.69	89.33	40.14	39.05	6.68	35.86	27.41	983.26
CMS852 × IR-6	64.33	89.33	150.87	24.93	16.11	25.47	53.31	43.54	122.93	96.67	39.58	44.14	6.60	36.75	29.61	1089.03
CMS852 × GP4-1424	60.67	88.67	145.93	22.13	17.15	24.00	52.81	41.94	126.20	90.67	39.86	40.06	7.21	39.19	29.34	1149.61
CMS240 × RHA-1-1	61.67	88.00	154.80	21.07	14.71	23.60	51.54	45.98	112.09	94.33	33.00	45.01	6.73	40.75	28.63	1166.87
CMS240 × IR-6	64.67	90.67	184.33	23.13	17.20	25.53	54.91	33.30	165.15	94.67	32.85	48.84	6.52	43.28	30.51	1320.68
CMS240 × GP4-1424	62.33	90.67	161.13	20.00	14.64	20.27	33.62	35.81	92.90	78.00	32.49	48.25	5.67	44.31	18.68	825.12
CMS519 × RHA-1-1	62.33	90.00	158.67	20.82	16.01	22.60	45.72	38.41	119.07	89.67	41.46	37.04	7.54	33.17	25.40	840.67
CMS519 × IR-6	66.67	93.00	161.13	24.07	16.66	25.67	58.00	46.98	123.77	89.00	39.70	40.41	5.83	36.81	32.22	1186.43
CMS519 × GP4-1424	67.67	93.00	188.93	29.20	21.55	28.00	63.63	33.04	191.80	95.00	38.53	35.17	6.90	36.06	35.35	1278.20
COSF7A × RHA-1-1	58.33	87.00	152.53	21.07	13.27	21.80	57.33	41.15	138.53	87.00	33.67	41.96	7.28	38.70	31.85	1232.40
COSF7A × IR-6	62.00	89.33	153.33	20.60	14.11	22.47	42.64	41.11	103.63	92.00	32.57	46.24	6.82	42.09	23.69	996.69
COSF7A × GP4-1424	57.33	85.00	155.33	20.27	14.06	22.00	30.78	30.21	101.69	78.00	32.26	47.50	6.51	44.23	17.10	756.57
CMS2A × RHA-1-1	62.67	90.00	147.60	22.00	15.19	22.67	44.97	47.39	94.57	91.67	33.65	41.26	6.60	38.43	24.98	959.65
CMS2A × IR-6	58.67	88.00	149.33	20.93	12.97	21.67	46.80	38.63	120.38	90.67	36.39	42.54	6.47	38.94	26.00	1010.49
CMS2A × GP4-1424	55.67	80.00	151.87	23.73	15.48	23.33	41.17	37.88	108.68	92.67	34.70	41.46	7.39	41.43	22.87	949.16
CMS207 × RHA-1-1	58.67	88.00	145.73	24.93	14.69	21.80	59.02	41.71	141.61	91.67	36.87	40.49	8.56	37.13	32.79	1216.89
CMS207 × IR-6	63.00	87.67	151.47	22.20	15.53	23.60	40.42	36.31	111.02	89.00	38.06	45.23	6.14	38.34	22.45	860.93
CMS207 × GP4-1424	58.00	85.67	152.00	21.80	16.01	23.27	34.80	37.16	93.20	89.00	35.46	43.11	6.70	41.52	19.33	805.80
CMS243 × RHA-1-1	58.00	85.00	143.73	21.53	13.29	20.60	42.29	38.30	110.34	94.67	38.64	41.64	8.57	34.25	23.49	805.57
CMS243 × IR-6	59.67	87.33	149.47	22.13	15.16	21.73	55.12	52.25	105.05	90.67	34.11	43.33	6.59	40.79	30.62	1247.39
CMS243 × GP4-1424	57.67	84.33	164.13	21.87	16.28	20.00	54.90	45.23	121.40	94.00	33.43	47.45	9.00	43.16	30.50	1318.40
COSF6A × RHA-1-1	60.00	87.67	137.53	20.13	13.56	21.13	31.60	34.41	92.49	89.00	36.68	42.03	7.17	37.72	17.56	662.79
COSF6A × IR-6	58.67	87.67	153.40	21.47	14.73	21.80	48.47	40.31	120.20	86.67	34.02	44.45	6.77	40.05	26.93	1076.56
COSF6A × GP4-1424	58.00	85.67	148.87	21.73	14.10	22.13	50.47	46.33	108.80	87.33	34.04	44.67	6.89	41.91	28.04	1176.22
PET-2-7 × RHA-1-1	57.33	84.33	146.20	21.93	13.24	27.07	49.73	56.83	87.20	95.33	35.60	40.68	7.67	37.32	27.63	1034.68
PET-2-7 × IR-6	58.67	86.33	156.27	21.80	15.00	23.20	45.90	37.12	123.80	89.00	34.55	41.82	6.84	40.68	25.50	1036.94
PET-2-7 × GP4-1424	56.00	82.67	159.60	21.40	14.23	24.60	46.93	43.03	109.00	84.00	33.71	45.04	7.42	42.62	26.07	1112.32
HA89 × RHA-1-1	58.00	86.33	150.33	22.80	14.26	18.73	50.79	49.38	102.84	95.00	37.92	38.19	7.80	37.21	28.22	1049.69
HA89 × IR-6	59.67	87.00	177.60	20.93	14.67	25.20	55.29	44.83	123.42	94.67	33.66	46.34	6.84	41.63	30.72	1280.68
HA89 × GP4-1424	56.67	85.00	175.73	21.67	14.63	25.60	35.17	32.91	106.48	85.33	32.50	44.52	6.47	42.91	19.54	836.81
Mean of crosses	**60.11**	**87.39**	**156.62**	**22.18**	**15.10**	**23.20**	**47.58**	**40.93**	**117.13**	**90.16**	**35.67**	**42.93**	**7.01**	**39.58**	**26.43**	**1042.22**
PARENTS	**DFF**	**DM**	**PH (cm)**	**HD (cm)**	**SD (mm)**	**NLP**	**SYP (g)**	**HI**	**BYP (g)**	**SF%**	**H%**	**VW (100 ml)**	**100- AW (g)**	**OC (%)**	**PY (q/ha)**	**OY (q/ha)**
CMS852A	68.00	93.67	122.87	22.87	16.82	22.60	40.20	35.91	112.00	86.33	42.96	29.18	5.14	31.26	22.33	698.15
CMS240	65.67	85.00	147.47	16.87	13.25	22.93	34.20	40.17	85.40	93.67	33.39	42.71	4.44	40.78	19.00	774.79
CMS519	60.00	87.67	149.53	19.07	14.92	22.20	40.69	33.93	119.53	92.33	41.35	38.96	6.40	31.50	22.60	711.37
COSF7A	57.00	84.33	118.60	20.47	14.67	18.20	14.27	26.95	52.40	91.67	33.44	38.91	6.37	32.71	7.93	259.12
CMS2A	59.00	87.33	139.33	21.67	13.88	18.93	45.87	43.95	104.13	90.00	38.44	39.59	6.82	37.02	25.48	943.42
CMS207	58.33	86.33	145.07	22.20	14.18	23.20	37.15	40.56	91.90	94.67	33.89	39.81	6.85	36.38	20.64	750.75
CMS243	56.00	83.33	115.73	20.13	11.68	21.00	35.60	44.08	80.51	93.00	34.54	42.57	5.43	40.11	19.78	793.86
COSF6A	57.00	83.67	110.13	20.20	14.67	18.82	30.45	38.24	79.65	91.33	39.03	40.28	6.20	34.96	16.92	591.43
PET-2-7	55.00	83.33	108.93	20.32	15.17	20.07	3.97	7.52	52.88	75.67	29.72	35.90	6.39	36.45	2.20	80.21
HA89	79.00	105.00	99.47	7.20	8.62	23.00	6.75	25.33	27.02	80.67	25.84	41.19	2.87	33.01	3.75	123.69
RHA-1-1	59.33	87.33	95.93	14.27	11.42	17.33	12.02	17.47	68.57	75.33	38.21	37.20	5.25	31.21	6.68	206.50
IR-6	64.67	98.33	112.87	11.80	10.03	17.93	15.80	42.43	37.15	78.00	35.57	47.93	3.37	39.23	8.78	343.16
GP4-1424	64.00	90.33	118.93	16.80	14.06	21.67	29.66	36.08	82.50	82.00	31.12	43.52	6.48	42.22	16.48	693.71
Mean of parents	**61.77**	**88.90**	**121.91**	**17.99**	**13.34**	**20.61**	**26.66**	**33.28**	**76.43**	**86.51**	**35.19**	**39.83**	**5.54**	**35.91**	**14.81**	**536.17**
Standard error	0.95	0.48	3.67	0.58	0.56	0.67	3.62	2.63	3.55	1.34	1.51	1.04	0.33	0.73	2.01	75.50
CD at 5 %	2.67	1.35	10.30	1.64	1.57	1.89	10.17	7.40	9.97	3.77	4.24	2.92	0.92	2.06	5.65	212.34
CD at 1 %	3.54	1.79	13.64	2.18	2.07	2.51	13.48	9.80	13.21	4.99	5.62	3.88	1.22	2.73	7.49	281.43

(DFF- Days to 50 % flowering, DM- Days to maturity, PH- Plant height, HD- Head diameter, SD- Stem diameter, NLP- Number of leaves per plant, SYP-Seed yield per plant, HI- Harvest index, BYP- Biological yield per plant, SF %- Seed filling percentage, H %- Hulling percentage, VW- Volume Weight, 100- AW- Hundred Achene weight, OC- Oil content, PY- Plot yield, OY- Oil yield, CD- Critical difference)

Table 2. Analysis of variance of parents and F_1 crosses in sunflower for yield and its component characters

Sources	d.f.	Mean Sum of Squares (MSS)														
		DFF	DM	PH (cm)	HD (cm)	SD (mm)	NLP	SYP (g)	HI	BYP (g)	SF %	H %	VW (100 ml)	100- AW (g)	OC (%)	PY (q/ha)
Replications	2	9.08*	7.50**	17.32	1.88	4.39**	0.87	14.30	4.46	123.53*	12.79	16.51	13.96*	0.63	0.12	4.41
Treatments	42	57.98**	54.48**	1359.40**	36.12**	12.21**	18.55**	608.11**	2.21**	2743.93**	97.45**	35.58**	45.74**	4.01**	39.46**	187.69**
Parents	12	129.35**	127.85**	970.55**	62.12**	15.66**	13.90**	604.13**	3.67**	2363.06**	156.31**	68.82**	58.63**	5.03**	44.18**	186.46**
Parents vs crosses	1	74.8**	61.92**	32767.61**	478.61**	84.54**	183.65**	11907.11**	1.59**	45066.12**	361.05**	6.21**	262.02**	58.59**	365.35**	3675.03**
Crosses	29	27.86**	23.86**	437.26**	10.11**	8.29**	14.78**	220.14**	1.13**	1442.14**	64.01**	22.83	32.94**	1.71**	26.27**	67.94**
Lines	9	58.19**	44.79**	627.91*	13.08	13.93**	22.56	147.75	70.72	1299.94	46.96	56.34**	61.10**	1.84	39.75**	45.60
Testers	2	53.91**	49.54**	787.96	1.42	18.22**	7.40	249.64	167.01	569.02	172.47	32.31**	111.23**	6.33**	167.26**	77.05
Lines × Testers	18	9.81**	10.54**	302.96**	9.59**	4.36**	11.70**	253.05**	129.38**	1610.26**	60.49**	5.03	10.17**	1.13**	3.87**	78.10**
Error	84	2.75	0.71	41.91	1.05	0.83	1.23	33.62	1.88	36.01	5.30	6.59	3.16	0.29	1.70	10.37

(*: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, d.f. Degree of freedom, DFF- Days to 50 % flowering, DM- Days to maturity, PH- Plant height, HD- Head diameter, SD- Stem diameter, NLP- Number of leaves per plant, SYP– Seed yield per plant, HI- Harvest index, BYP- Biological yield per plant, SF %- Seed filling percentage, H %- Hulling percentage, VW- Volume Weight, 100- AW- Hundred Achene Weight, OC- Oil content, PY - Plot yield)

Table 3. General combining ability (GCA) effects of the 10 lines and 3 testers for quantitative characters

Parents	DFF	DM	PH (cm)	HD (cm)	SD (mm)	NLP	SYP (g)	HI	BYP (g)	SF %	H %	VW (100 ml)	100- AW (g)	OC (%)	PY (q/ha)
Lines (females)															
CMS-852A	1.667**	1.389**	-0.816	1.239**	0.806**	2.151**	4.238*	-0.317	11.143**	2.067**	4.19**	-1.848**	-0.174	-2.307**	2.354*
CMS-240	2.778**	2.389**	10.14**	-0.783*	0.417	-0.071	-0.894	-2.564	6.248**	-1.156*	-2.889**	4.436**	-0.701**	3.205**	-0.497
CMS-519	5.444**	4.611**	12.962**	2.512**	2.977**	2.218**	8.204**	-1.452	27.75**	1.067	4.224**	-5.391**	-0.249	-4.228**	4.558**
COSF-7A	-0.889	-0.278	-2.882	-1.538**	-1.287**	-1.116**	-3.998*	-3.436*	-2.512	-4.489**	-2.839**	2.301**	-0.136	2.097**	-2.221*
CMS-2A	-1.111*	-1.389**	-7.016**	0.039	-0.551	-0.649	-3.271	0.372*	-9.253**	1.511	-0.756	-1.179*	-0.186	0.026	-1.817
CMS-207	-0.222	-0.278	-6.882**	0.795*	0.314	-0.316	-2.835	-2.535	-1.857	-0.267	1.127	0.015	0.128	-0.58	-1.575
CMS-243	-1.667**	-1.833**	-4.171	-0.338	-0.189	-2.427**	3.186	4.332**	-4.868*	2.956**	-0.277	1.21*	1.049**	-0.172	1.77
COSF-6A	-1.222*	-0.389	-10.016**	-1.072**	-0.969**	-1.516**	-4.071*	-0.577	-9.968**	-2.489**	-0.753	0.786	-0.061	0.317	-2.262*
PET-2-7	-2.778**	-2.944**	-2.593	-0.472	-0.94**	1.751**	-0.06	4.731**	-10.465**	-0.711	-1.051	-0.418	0.301	0.633	-0.033
HA-89	-2**	-1.278**	11.273**	-0.383	-0.578	-0.027	-0.499	1.446	-6.219**	1.511	-0.977	0.087	0.029	1.009*	-0.277
S.E. (g_i) female	0.55	0.28	2.16	0.34	0.3	0.37	1.93	1.45	2	0.77	0.86	0.59	0.18	0.43	1.07
Testers (males)															
RHA-1-1	-0.378	0.078	-5.842**	-0.234	-0.831**	-0.544**	0.651	2.062*	-3.689**	1.611**	1.093*	-2.195**	0.455**	-2.521**	0.362
IR-6	1.489**	1.244**	2.104	0.037	0.116	0.429*	2.503*	0.511	4.804**	1.144**	-0.121	1.404**	-0.464**	0.361	1.391*
GP4-1424	-1.111**	-1.322**	3.738**	0.197	0.715**	0.116	-3.155**	-2.573**	-1.116	-2.756**	-0.972	0.791*	0.009	2.16**	-1.753**
S.E. (g_i) male	0.3	0.15	1.18	0.18	0.167	0.202	1.05	0.79	1.09	0.42	0.47	0.33	0.1	0.24	0.59

(*: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, DFF- Days to 50% flowering, DM- Days to maturity, PH- Plant height, HD- Head diameter, SD- Stem diameter, NLP- Number of leaves per plant, SYP– Seed yield per plant, HI- Harvest index, BYP- Biological yield per plant, SF %- Seed filling percentage, H %- Hulling percentage, VW- Volume Weight, 100- AW- Hundred Achene Weight, OC- Oil content, PY- Plot yield, SE- Standard error) plant (8.204) and biological yield per plant (27.75). Line PET-2-7 recorded good combining ability for days to 50 % flowering (-2.778), maturity (-2.944) and harvest index (4.731). Line CMS-240 recorded good combining ability for hulling percentage (-2.889), volume weight (4.436) and oil content (3.205). Lines CMS-852A and CMS-243 recorded good combining ability for seed filling percentage (2.956) and 100- achene weight (1.049). Regarding testers, GP4-1424 exhibited good general combining ability (GCA) for days to 50 % flowering (-1.111), maturity (-1.322), plant height (3.738), head diameter (0.197), stem diameter (0.715), hulling percentage (-0.972) and oil content (2.16). In addition, IR-6 recorded good general combining ability for number of leaves per plant (0.429), seed yield per plant (2.503), biological yield per plant (4.804), volume weight (1.404) and plot yield (1.391). Tester RHA-1-1 recorded good combining ability for seed filling percentage (1.611), harvest index (2.062) and 100- achene weight (0.455). Thus, lines CMS-519, PET-2-7, CMS-240 and testers GP4-1424 and IR-6 were deemed superior for seed yield and component traits while considering the effects of general combining ability. In some traits, the GCA of parents did not align with their per se performance, indicating that selection should rely primarily on GCA rather than observed values alone.

The hybrids' specific combining ability (SCA) is shown in Table 4. Of all the hybrids, two hybrids (CMS-519 × RHA-1-1 and CMS-2A × GP4-1424) recorded negative and significant SCA values for days to 50 % flowering and 3 hybrids (CMS-240 × RHA -1-1, CMS-519 × RHA-1-1 and CMS-2A × GP4-1424) for days to maturity as negative values indicated less days for maturity which is desirable. Among the 30 hybrids evaluated, four showed significant SCA for plant height, six for head diameter, three for stem diameter, six for number of leaves per plant, five for seed yield per plant, plot yield and harvest index, nine for biological yield per plant, eight for seed filling percentage, only one (CMS-243 × GP4-1424) for volume weight and oil content, three for 100- achene weight. No hybrid exhibited significant SCA effects for hulling percentage. CMS-519 × IR-6 reported non -significant SCA among the hybrids produced utilizing good general combiners for seed yield, suggesting that the gene action engaged in this cross may be attributable to an additive kind of gene action, while CMS-519 × GP4-1424 recorded positive and significant SCA indicating the presence of non-additive type of gene action. Regarding oil content the hybrids generated using the good general combiners, CMS-240 × GP4-1424 recorded non-significant SCA indicating the presence of additive type of gene action. The GCA variance and SCA variance was found to be equal for days to 50 % flowering indicating that equal contribution of both additive and dominance variances (Table 5). This indicates that both selection (for additive effects) and hybridization (for non-additive effects) are viable breeding strategies. Regarding all other traits except volume weight and oil content the ratio of GCA variance to SCA variance was found to be less than unity indicating the pre ponderance of non-additive gene action. For volume weight and oil content, the GCA variance and SCA variance ratio were found to be greater than unity indicating the presence of additive type of gene action. These results are consistent with earlier reports (10-15).

FTIR spectral studies

Fourier transform infrared (FTIR) is one of the important analytical techniques for researchers. This type of analysis can be used for characterizing samples in the forms of liquids, solutions, pastes, powders, films, fibres and gases. This analysis is also possible for analysing material on the surfaces of substrate (16). Compared to other types of characterization analysis, FTIR is quite popular. It is quite rapid, good in accuracy and relatively sensitive (17).

In the FTIR analysis, samples were subjected to contact with infrared (IR) radiation. The particular absorption and/or transmission of energy is the outcome of the IR radiations' effects on a molecule's atomic vibrations in the sample. Because of this, the FTIR can be used to identify certain chemical vibrations in the material (18).

FTIR spectra of all the 46 samples (30 hybrids, 13 parents and 3 checks) recorded (Fig. 1a-1e) in the wave number range of 4000 cm^{-1} - 500 cm^{-1} revealed highly similar pattern of peaks with minor differences. Their characteristics bands are presented in Table 6. Similar results have been reported (19-23).

Fatty acid profiling

As essential fatty acids are not produced by the body and directly affect human health, vegetable oils with a high proportion of unsaturated fatty acids can be categorized as such (24). About 85 % of the fatty acids in regular sunflower oil are unsaturated and 15 % are saturated. About 44-75 % of unsaturated fatty acids are linoleic acid and about 14-43 % are oleic acid (25). The fatty acid profiling along with protein content of all the parents, checks and nine promising hybrids (high oil yielders) which includes HA-89 × IR-6, CMS-240 × IR-6, COSF-7A × RHA-1-1, CMS-207 × RHA-1-1, CMS-243 × GP4-1424, CMS-243 × IR-6, COSF-6A × GP4-1424, CMS-519 × GP4-1424 and CMS-519 × IR-6 is presented in Table 7.

Palmitic acid (%)

The overall range of palmitic acid was 4.85 % to 9.88 % among all the genotypes. Low levels of palmitic acid (16:0) are considered favorable for health, as a reduced saturated fatty acid content in oil is desirable. Among the parents, the palmitic acid ranged from 5.44 % to 9.88 %. The lowest palmitic acid percentage was observed in IR-6 (5.44 %) and the highest was observed in CMS2A (9.88 %). Among the three checks, KBSH-78 has shown the lowest palmitic acid percentage with the value of 4.85 % and the highest was shown by KBSH-44 with the value of 7.6 %. Among the selected hybrids, the palmitic acid ranged from 6.64 % to 9.65 %. Lowest palmitic acid was observed in HA-89 × IR-6 (6.64 %) and the highest was observed in CMS-243 × IR-6 with the value of 9.65 %.

Stearic acid (%)

Stearic acid (%) is also type saturated fatty acid. A lower level of saturated fatty acids in sunflower oil is preferred; therefore, a low percentage of stearic acid is desirable. The overall range of stearic acid was 1.72 % to 4.03 %. Among the parents, the stearic acid ranged from 1.72 % to 4.03 %. The lowest stearic acid percentage was observed in PET-2-7 (1.72 %) and the highest was observed in HA 89 (4.03 %). Among three checks,

Table 4. Specific combining ability (SCA) effects of F1 crosses for quantitative characters in Sunflower

S.No.	Crosses	DFF	DM	PH (cm)	HD (cm)	SD (mm)	NLP	SYP (g)	HI	BYP (g)	SF %	H %	VW (100 ml)	100- AW (g)	OC (%)	PY (q/ha)
1	CMS852A × RHA-1-1	-1.067	-0.522	20.642**	0.012	-0.62	1.789**	-3.131	-6.321*	11.104**	-4.5**	-0.812	0.159	-0.607	1.113	-1.74
2	× IR-6	1.067	-0.689	-7.038	1.474*	0.089	-0.318	-1.017	2.419	-10.146**	3.3*	-0.156	1.656	0.235	-0.878	-0.565
3	× GP4-1424	0	1.211*	-13.604**	-1.486*	0.531	-1.471*	4.148	3.902	-0.959	1.2	0.968	-1.815	0.372	-0.235	2.304
4	CMS240 × RHA-1-1	-0.844	-1.856**	-6.113	-0.099	0.023	1.011	4.198	5.552*	-7.603*	3.722**	-0.872	-0.158	-0.027	0.491	2.332
5	× IR-6	0.289	-0.356	15.473**	1.696**	1.572**	1.971**	5.719	-5.573*	36.967**	4.522**	0.187	0.07	0.675*	0.139	3.177
6	× GP4-1424	0.556	2.211**	-9.36*	-1.597**	-1.595**	-2.982**	-9.916**	0.021	-29.363**	-8.244**	0.684	0.089	-0.648*	-0.63	-5.509**
7	CMS519 × RHA-1-1	-2.844**	-2.078**	-5.069	-3.643**	-1.236*	-2.278**	-10.714**	-3.132	-22.12**	-3.167*	0.474	1.695	0.327	0.347	-5.952**
8	× IR-6	-0.378	-0.244	-10.549**	-0.665	-1.526**	-0.184	-0.289	6.999**	-25.913**	-3.367*	-0.078	1.466	-0.461	1.103	-0.16
9	× GP4-1424	3.222**	2.322**	15.618**	4.308**	2.762**	2.462**	11.002**	-3.867	48.033**	6.533**	-0.396	-3.161**	0.133	-1.45	6.112**
10	COSF7A × RHA-1-1	-0.511	-0.189	4.642	0.657	0.29	0.256	13.098**	1.595	27.603**	-0.278	-0.257	-1.08	-0.042	-0.455	7.276**
11	× IR-6	1.289	0.978*	-2.504	-0.082	0.179	-0.051	-3.444	3.111	-15.79**	5.189**	-0.144	-0.399	0.414	0.057	-1.914
12	× GP4-1424	-0.778	-0.789	-2.138	-0.575	-0.469	-0.204	-9.653**	-4.706	-11.813**	-4.911**	0.401	1.48	-0.372	0.398	-5.363**
13	CMS2A × RHA-1-1	4.044**	3.922**	3.842	0.012	1.471**	0.656	0.004	4.028	-9.616**	-1.611	-2.357	1.703	-0.675*	1.353	0.002
14	× IR-6	-1.822	0.756	-2.371	-1.326*	-1.691**	-1.318*	-0.014	-3.183	7.694*	-2.144	1.595	-0.616	0.117	-1.025	-0.008
15	× GP4-1424	-2.222*	-4.678**	-1.471	1.314*	0.219	0.662	0.01	-0.845	1.921	3.756**	0.762	-1.087	0.558	-0.328	0.006
16	CMS207 × RHA-1-1	-0.844	0.811	1.842	2.19**	0.113	-0.544	13.625**	1.252	30.021**	0.167	-1.021	-0.257	0.971**	0.652	7.57**
17	× IR-6	1.622	-0.689	-0.371	-0.815	0.003	0.282	-6.833*	-2.593	-9.062*	-2.033	1.387	0.881	-0.527	-1.016	-3.796*
18	× GP4-1424	-0.778	-0.122	-1.471	-1.375*	-0.116	0.262	-6.792*	1.341	-20.959**	1.867	-0.365	-0.624	-0.443	0.364	-3.773*
19	CMS243 × RHA-1-1	-0.067	-0.633	-2.869	-0.077	-0.791	0.367	-9.132**	-9.024**	1.762	-0.056	2.149	-0.303	0.063	-2.629**	-5.074**
20	× IR-6	-0.267	0.533	-5.082	0.252	0.133	0.527	1.846	6.476*	-12.014**	-3.589**	-1.159	-2.215*	-1.002**	1.029	1.025
21	× GP4-1424	0.333	0.1	7.951*	-0.175	0.657	-0.893	7.287*	2.548	10.252**	3.644**	-0.99	2.517*	0.939**	1.6*	4.048*
22	COSF6A × RHA-1-1	1.489	0.589	-3.224	-0.743	0.264	-0.011	-12.562**	-8.006**	-10.988**	-0.278	0.673	0.512	-0.23	0.345	-6.979**
23	× IR-6	-1.711	-0.578	4.696	0.318	0.485	-0.318	2.452	-0.55	8.236*	-2.144	-0.772	-0.67	0.292	-0.206	1.362
24	× GP4-1424	0.222	-0.011	-1.471	0.425	-0.748	0.329	10.11**	8.555**	2.752	2.422	0.099	0.159	-0.061	-0.139	5.617**
25	PET-2-7 × RHA-1-1	0.378	-0.189	-1.98	0.457	-0.086	2.656**	1.56	9.112**	-15.778**	4.278**	-0.11	0.362	-0.093	-0.367	0.867
26	× IR-6	-0.156	0.644	0.14	0.052	0.726	-2.184**	-4.126	-9.052**	12.329**	-1.589	0.051	-2.094*	-0.007	0.112	-2.292
27	× GP4-1424	-0.222	-0.456	1.84	-0.508	-0.64	-0.471	2.566	-0.06	3.449	-2.689**	0.059	1.732	0.1	0.255	1.425
28	HA89 × RHA-1-1	0.267	0.144	-11.713**	1.234*	0.572	-3.9**	3.055	4.943	-4.387	1.722	2.133	-2.633*	0.313	-0.85	1.697
29	× IR-6	0.067	-0.356	7.607	-0.904	0.029	1.593*	5.707	1.946	7.7*	1.856	-0.911	1.922	0.265	0.685	3.17
30	× GP4-1424	-0.333	0.211	4.107	-0.331	-0.601	2.307**	-8.762*	-6.889**	-3.313	-3.578**	-1.222	0.711	-0.578	0.165	-4.868*
	S.E. (gij)	0.957	0.486	3.738	0.593	0.527	0.64	3.347	2.509	3.464	1.329	1.482	1.027	0.315	0.753	1.859

(*: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, DFF- Days to 50 % flowering, DM- Days to maturity, PH- Plant height, HD- Head diameter, SD- Stem diameter, NLP- Number of leaves per plant, SYP– Seed yield per plant, HI- Harvest index, BYP- Biological yield per plant, SF %- Seed filling percentage, H %- Hulling percentage, VW- Volume Weight, 100- AW- Hundred Achene Weight, OC- Oil content, PY- Plot yield, SE- Standard error)

Table 5. Components of variance for quantitative characters in F_1 crosses of Line × Tester design in Sunflower

SOURCES	DFF	DM	PH (cm)	HD (cm)	SD (mm)	NLP	SYP (g)	HI	BYP (g)	SF %	H %	VW (100 ml)	100- AW (g)	OC (%)	PY (q/ha)
σ^2gca	2.36	1.88	20.70	-0.11	0.60	0.16	-2.78	-0.55	-34.66	2.59	2.01	3.89	0.15	5.10	-0.86
σ^2sca	2.35	3.27	258.05	2.84	1.17	3.49	73.14	36.83	524.66	18.39	-0.52	2.33	0.27	0.72	22.57
σ^2gca / σ^2sca	1.00	0.57	0.08	-0.04	0.51	0.05	-0.04	-0.01	-0.07	0.14	-3.87	1.67	0.56	7.08	-0.04

(*: significant at $p \leq 0.05$, **: significant at $p \leq 0.01$, DFF- Days to 50 % flowering, DM- Days to maturity, PH- Plant height, HD- Head diameter, SD- Stem diameter, NLP- Number of leaves per plant, SYP-Seed yield per plant, HI- Harvest index, BYP- Biological yield per plant, SF %- Seed filling percentage, H %- Hulling percentage, VW- Volume Weight, 100- AW- Hundred Achene Weight, OC- Oil content, PY- Plot yield)

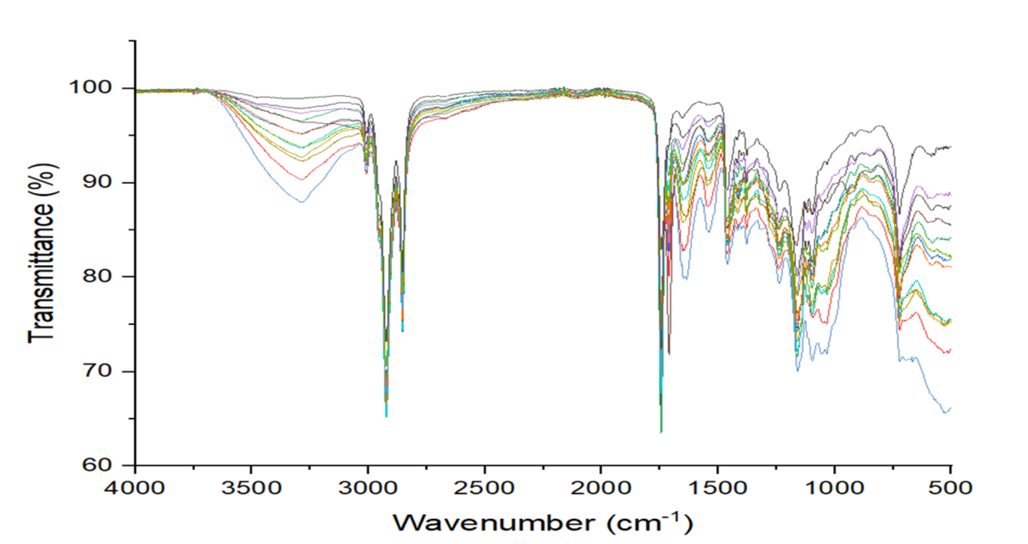

Fig. 1a. FTIR overlay spectra of 13 parents used in the study. Parents: COSF-6A, CMS-2A, CMS-519, CMS-243, CMS-207, GP4-1424, CMS-240, PET -2-7, COSF-7A, CMS-852A, RHA-1-1, HA-89 and IR-6.

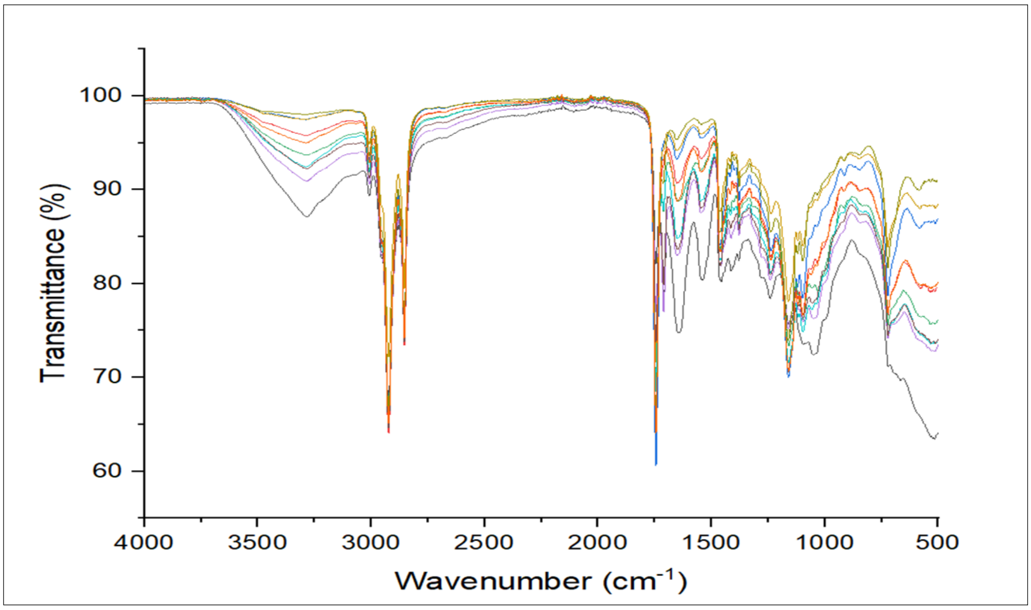

Fig. 1b. FTIR overlay spectra of crosses (Cross 1-10) used in the study. Crosses: CMS-2A × GP4-1424, CMS-207 × IR-6, HA-89 × RHA-1-1, CMS-852A × GP4-1424, CMS-240 × GP4-1424, PET-2-7 × IR-6, CMS-243 × RHA-1-1, PET-2-7 × GP4-1424, COSF-6A × IR-6 and HA-89 × IR-6.

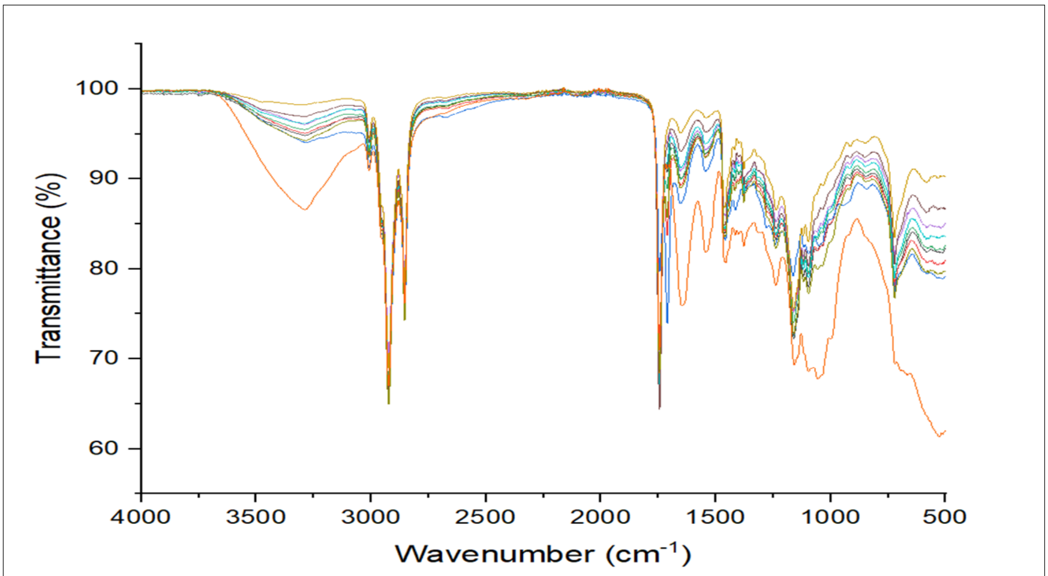

Fig. 1c. FTIR overlay spectra of crosses (Cross 11-20) used in the study. Crosses: CMS-852A × RHA-1-1, CMS-240 × IR-6, CMS-207 × GP4-1424, COSF-7A × RHA-1-1, CMS-2A × IR-6, CMS-207 × RHA-1-1, CMS-243 × GP4-1424, COSF-7A × IR-6, CMS-243 × IR-6 and COSF-6A × GP4-1424.

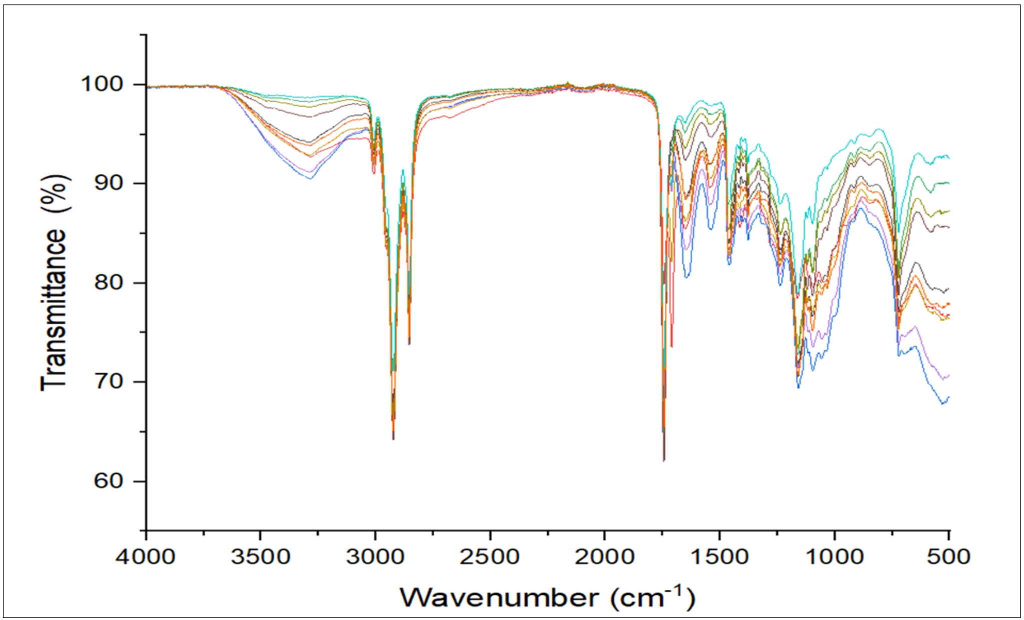

Fig. 1d. FTIR overlay spectra of crosses (Cross 21-30) used in the study. Crosses: COSF-6A × RHA-1-1, COSF-7A × GP4-1424, CMS-852A × IR-6, CMS-240 × RHA-1-1, CMS-519 × GP4-1424, HA-89 × GP4-1424, CMS-519 × RHA-1-1, CMS-519 × IR-6, PET-2-7 × RHA-1-1 and CMS-2A × RHA-1-1.

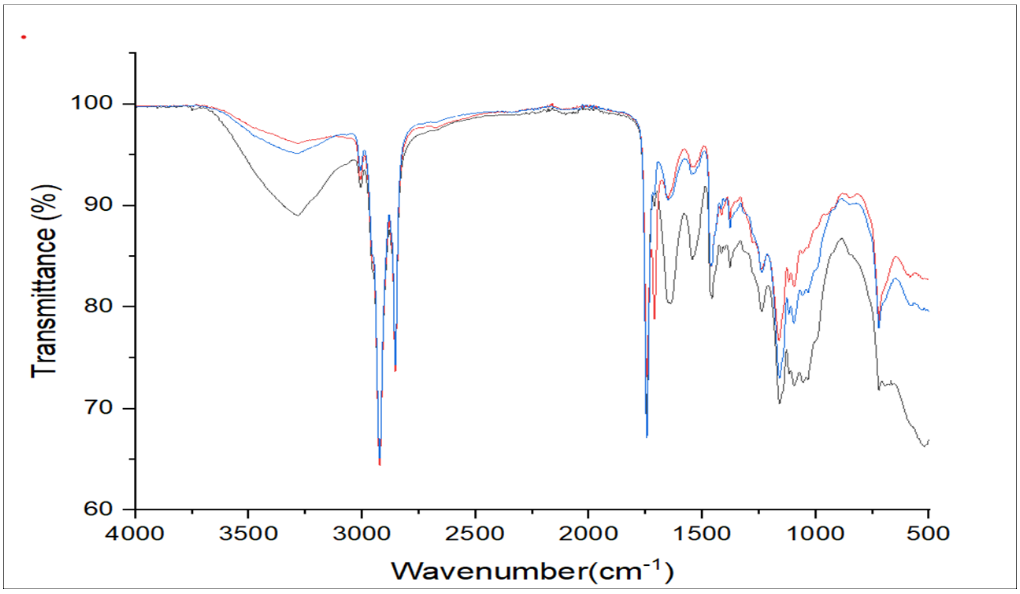

Fig. 1e. FTIR overlay spectra of checks. Checks: KBSH-78, DRS1 and KBSH-44.

Table 6. Characteristic bands of FTIR spectroscopy

S. No.	Wavenumber (cm^{-1})	Type of Vibration	Functional group
1	3008	Asymmetric stretching vibration	=C-H
2	2923.50	Symmetric stretching vibration	-C-H (CH_3)
3	2854	Asymmetric stretching vibration	-C-H (CH_2
4	1744	Stretching vibration	-C=O (ester)
5	1461	Scissoring bending vibration	-C-H (CH_2)
6	1378	Symmetric bending vibration	-C-H (CH_3)
7	1240, 1160 and 1092	Stretching vibration	-C-O
8	721	Rocking vibration	-$(CH_2)_n$-

Table 7. Fatty acid profiling and protein content of parents, checks and promising hybrids

S.No.	Genotype	Saturated fatty acids		Unsaturated fatty acids				Crude protein (%)
		Palmitic acid (C16:0)	Stearic acid (C18:0)	Oleic acid (C18:1)	Linoleic acid (C18:2)	S/US ratio	O/L ratio	
1	CMS-852	5.88	1.84	46.68	45.61	0.08	1.02	25.48
2	CMS-240	7.89	2.32	52.85	36.94	0.11	1.43	21.67
3	CMS-519	8.03	2.59	46.91	42.47	0.12	1.10	27.88
4	COSF-7A	6.73	3.08	48.21	41.98	0.11	1.15	28.96
5	CMS-2A	9.88	3.15	42.49	44.49	0.15	0.96	26.27
6	CMS-207	8.28	3.07	47.74	40.91	0.13	1.17	23.77
7	CMS-243	9.62	3	50.58	36.81	0.14	1.37	23.07
8	COSF-6A	6.17	2.33	45.99	45.5	0.09	1.01	28.16
9	PET-2-7	6.76	1.72	57.81	33.72	0.09	1.71	28.71
10	HA-89	8.6	4.03	44.41	42.96	0.14	1.03	30.01
11	RHA-1-1	7.3	3.28	40.9	48.52	0.12	0.84	29.73
12	IR-6	5.54	2.09	43.21	49.15	0.08	0.88	18.44
13	GP4-1424	8.03	2.5	44.06	45.42	0.12	0.97	16.79
14	HA-89 × IR-6	6.64	2.55	50.32	40.49	0.10	1.24	22.83
15	CMS-240 × IR-6	7.03	2.55	52.2	38.21	0.11	1.37	21.3
16	COSF-7A × RHA-1-1	8.87	3.39	50.16	37.59	0.14	1.33	18.79
17	CMS-207 × RHA-1-1	6.72	2.46	46.45	44.37	0.10	1.05	21.55
18	CMS-243 × GP4-1424	9.33	3.28	48.96	38.43	0.14	1.27	19.06
19	CMS-243 × IR-6	9.65	3.12	51.42	35.81	0.15	1.44	18.81
20	COSF-6A × GP4-1424	7.01	2.83	48.31	41.85	0.11	1.15	22.68
21	CMS-519 × GP4-1424	7.12	2.58	54.97	35.32	0.11	1.56	24.3
22	CMS-519 × IR-6	8.34	2.6	49.51	39.55	0.12	1.25	19.89
23	KBSH-78	4.85	2.28	71.58	21.29	0.08	3.36	24.91
24	DRS I	7.01	2.55	52.76	37.68	0.11	1.40	25.21
25	KBSH-44	7.6	3.82	51.89	36.69	0.13	1.41	25.19
	Maximum	9.88	4.03	71.58	49.15	0.15	3.36	30.01
	Minimum	4.85	1.72	40.09	21.29	0.08	0.84	16.79

(S/US- Saturated/Unsaturated, O/L- Oleic/Linoleic)

KBSH-78 has shown the lowest stearic acid percentage with the value of 2.28 % and the highest was shown by KBSH-44 with the value of 3. 82 %. Among the selected hybrids, the stearic acid ranged from 2.46 % to 3.39 %. the lowest stearic acid was observed in CMS-207 × RHA-1-1 (2.46 %) and the highest was observed in COSF-7A × RHA-1-1 with the value of 3.39 %.

Oleic acid (%)

Oleic acid (18:1) is one of the mono unsaturated fatty acids having nutritionally prime importance. Higher proportion of oleic acid is desired in sunflower oil not only for health benefits like heart health and reducing inflammation but also in the quality of biodiesel production (26). The overall range of oleic acid was 40.09 % to 71.58 %. Among the parents, the oleic acid ranged from 40.9 % to 57.81 %. The lowest oleic acid percentage was observed in RHA-1-1 (40.9 %) and the highest was observed in PET-2-7 (57.81 %). Among three checks, KBSH-78 has shown the highest oleic acid percentage with the value of 71.58 % and the lowest was shown by KBSH-44 with the value of 51.89 %. Among the selected hybrids, the oleic acid ranged from 46.45 % to 54.97 %. Oleic acid content was least in CMS-207 × RHA-1-1 (46.45 %) and the highest was observed in CMS-519 × GP4-1424 with the value of 54.97 %.

Linoleic acid (%)

Linoleic acid (18:2) is one of the essential fatty acids having polyunsaturated bonds. Keeping quality of oil linked to linoleic acid i.e. oil with lower linoleic acid have higher self-life. The overall range of linoleic acid was 21.29 % to 49.05 %. Among the parents, the linoleic acid ranged from 33.72 % to 49.15 %. The lowest linoleic acid percentage was observed in PET-2-7 (33.72 %) and the highest was observed in IR-6 (49.15 %). Among three checks, KBSH-78 has shown the lowest linoleic acid percentage with the value of 21.29 % and the highest was shown by DRSH 1 with the value of 37.68 %. Among the selected hybrids, the linoleic acid ranged from 35.32 % to 44.37 %. The lowest linoleic acid was observed in CMS-519 × GP4-1424 (35.32 %) and the highest was observed in CMS-207 × RHA-1-1 with the value of 44.37 %. Similar results of fatty acid profiling have been reported by (27-30).

Ratio of saturated to unsaturated fatty acid

A lower ratio of saturated to unsaturated fatty acids is nutritionally desirable. The overall ratio ranged from 0.08 to 0.15 (Table 7) among all the genotypes. Among the parents the saturated to unsaturated fatty acid ratio ranged from 0.08 (CMS852 and IR-6) to 0.15 (CMS2A). Among promising hybrids, the ratio ranged from 0.10 (HA-89 × IR-6 and CMS-207 × RHA-1 -1) to 0.15 (CMS-243 × IR-6). Similar results have been reported previously (31).

Ratio of oleic acid to linoleic acids

The ratio of oleic acid to linoleic acid is most important parameter for keeping quality of oil (32). Higher the ratio, longer is the shelf-life of the oil because Oleic acid is monounsaturated acid which contain only single double bond due to which oxidation of oil is lesser which in turn increases the shelf-life. The ratio varied from 0.84 to 3.36 across all samples (Table 7). Among the parents the ratio ranged from 0.84 (RHA-1-1) to 1.43 (CMS-240). Among the selected hybrids, the ratio ranged from 1.05 (CMS-207 × RHA-1 -1) to 1.44 (CMS-243 × IR-6).

Protein content

Sunflower seed cake has long been utilized as animal feed, organic fertilizer and soil compost; but, in recent years, numerous studies have been carried out to examine its nutritional value for human consumption, given that it still contains a variety of components. One of the nutritional benefits is the presence of high protein content in its seed cake. Protein analysis of nine promising hybrids, 13 parents and 3 checks has been done and the results are presented in the Table 7. The overall range of protein content was observed to be 16.79 % to 30.01 %. Among the parents HA-89 has shown highest protein content with the value of 30.01 %, whereas GP4-1424 has shown the lowest protein content with the value of 16.79 %. Among the crosses the highest protein content was shown by CMS-519 × GP4-1424 with the value of 24.30 % followed by HA-89 × IR-6 with the value of 22.83 %. Similar results have been reported earlier (28, 33). Comparative performance of Oil Yield (OY), Crude protein (CP), Oleic acid (OLA) and linoleic acid (LINLA) of promising hybrids is shown in the Fig. 2.

Conclusion

A prevalence of non-additive gene action across all the traits stress upon the potential of breeding to exploit hybrid vigor in sunflower. Higher proportion of unsaturated fatty acids such as oleic and linoleic acids in the present study would certainly offer health benefits. FTIR analysis revealed variations in absorption spectra corresponding to functional groups such as =C-H, -C-H (CH_3), -C-H (CH_2), -C=O (ester), -C-O, -$(CH_2)_{-n}$. Crosses like CMS-240 × IR-6, CMS-243 × GP4-1424, HA-89 × IR-6 and CMS-519 × GP4-1424 proved to be better regarding both oil yield and protein content. Given the predominance of non-additive gene action across traits, future breeding programs should emphasize hybrid development using heterotic grouping and line × tester analysis to maximize hybrid vigor in sunflower. The identification of genotypes rich in unsaturated fatty acids like oleic and linoleic acids highlights the need for targeted breeding for oil quality improvement to meet growing consumer demand for heart-healthy oils.

Acknowledgements

The authors are thankful to the Department of Plant Breeding and Genetics, College of Agriculture, OUAT, Bhubaneswar for providing the scope and opportunity for conducting the research. The facilities and support provided by OUAT, Bhubaneswar and IIOR, Hyderabad are gratefully acknowledged.

Authors' contributions

Conceptualization and material preparation was done by JK. Conduct of experiment, data collection and analysis were performed by VMRG, HBB, KKM and PM. The first draft of the manuscript was written by VMRG and checked by JK and RB. Statistical analysis was done by VMRG, HBB and KKM. The manuscript was reviewed, read and edited with significant contributions by DS, KCS and RB. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors do not have any conflicts of interest to declare.

Ethical issues: None

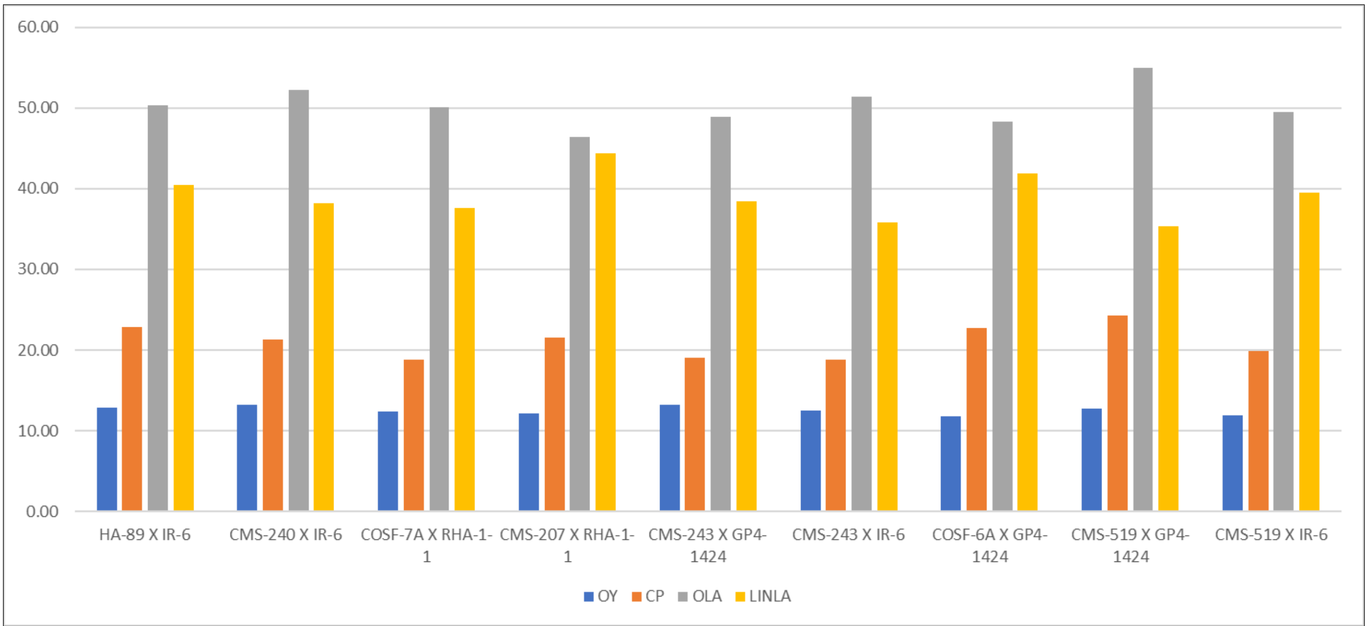

Fig. 2. Comparative performance of OY (oil yield), CP (crude protein), OLA (oleic acid), LINLA (linoleic acid) of promising hybrids.

References

1. Khan S, Choudhary S, Pandey A, Khan MK, Thomas G. Sunflower oil: Efficient oil source for human consumption. Emerg Life Sci Res. 2015;1:1-3.
2. Taher M, Javani M, Beyaz R, Yildiz M. A new environmental friendly production method in sunflower for high seed and crude oil yields. Fresen Environ Bull. 2017;26(6):4004-10.
3. Kaya VI, Vassilevska-Ivanova I. Uses and importance of wide hybridization in sunflower (*Helianthus annuus* L.) improvement. In Proceedings IV. Balkan Agricultural Congress. 2022; 1:950-961.
4. Switzerland. World Health Organization. WHO updates guidelines on fats and carbohydrates [Internet]. Geneva: 2023. Available from: https://www.who.int/news/item/17-07-2023-who-updates-guidelines-on-fats-and-carbohydrates
5. Calder PC. Functional roles of fatty acids and their effects on human health. J Parent Eternal Nutri. 2015;39:18S-32S. https://doi.org/10.1177/0148607115595980
6. Adeleke BS, Babalola OO. Oilseed crop sunflower (*Helianthus annuus*) as a source of food: Nutritional and health benefits. Food Sci Nutri. 2020;8(9):4666-84. https://doi.org/10.1002/fsn3.1783
7. Jamwal R, Kumari S, Sharma S, Kelly S, Cannavan A, Singh DK. Recent trends in the use of FTIR spectroscopy integrated with chemometrics for the detection of edible oil adulteration. Vibrat Spectr. 2021;113:103222. https://doi.org/10.1016/j.vibspec.2021.103222
8. Madsen E. Nuclear magnetic resonance spectrometry as a quick method of determination of oil content in rapeseed. J Am Oil Chem Soc. 1976;53(7):467-69.
9. Kempthorne O. An introduction of genetic statistics, John Willey & Sons Inc. New York, USA. 1957:468-73.
10. Kaila V. Combining ability analysis and estimation of heterosis for agronomic and oil parameters in sunflower. Electron J Plant Breed. 2024;15(2):428-34. https://doi.org/10.37992/2024.1502.040
11. Ghayas M, Cheema AF, Asadullah, Rauf S, Ashfaq A. Combining ability and heterosis analysis for quality and yield traits in sunflower. Agrobiol Rec. 2023;14:22-29. https://doi.org/10.47278/journal.abr/2023.034
12. Arshad A, Iqbal MA, Farooq S, Abbas A. Genetic evaluation for seed yield and its component traits in sunflower (*Helianthus annuus* L.) using line× tester approach. Bull Biol All Sci Res. 2024;(1):63-63. https://doi.org/10.54112/bbasr.v2024i1.63
13. Dhanalakshmi R, Manivannan N, Viswanathan PL, Sasikala R, Rajendran L, Senthivelu M. Combining ability analysis in sunflower (*Helianthus annuus* L.). Electron J Plant Breed. 2022;13(3):1036-41. https://doi.org/10.37992/2022.1303.137
14. Ahmed M, Noaman HM, Zahran H. Combining ability estimation for yield and its components of sunflower inbred lines. Egypt J Chem. 2022;65(3):19-28. https://doi.org/10.21608/ejchem.2021.102004.4736
15. Doke SR N, Ghodke MK. Study of combining ability analysis and gene action in sunflower (*Helianthus annuus* L.). Int J Res Agron. 2024;7(4):506-10. https://doi.org/10.33545/2618060X.2024.v7.i4g.598
16. Fan CH, Ma HR, Hua L, Wang JH, Wang HJ. FTIR and XPS analysis of characteristics of synthesized zeolite and removal mechanisms for Cr (III). Spectrosc Spect Anal. 2012;32(2):324-29. https://doi.org/10.3964/j.issn.1000-0593(2012)02-0324-06
17. Jaggi N, Vij DR. Fourier transform infrared spectroscopy. In Handbook of Applied Solid State Spectroscopy. 2006; p. 411-50. https://doi.org/10.1007/0-387-37590-2_9
18. Kirk RE, Othmer DF. Encyclopedia of Chemical Technology: John Wiley, Interscience. 1947;(1):918.
19. Moharam MA, Abbas LM. A study on the effect of microwave heating on the properties of edible oils using FTIR spectroscopy. Afr J Microbiol Res. 2010;4:1921-27.
20. Rexhepia F, Surlevab A, Hysenia A, Bruçia M, Kodraliua B. Comprehensive investigation of thermal degradation characteristics and properties changes of plant edible oils by FTIR spectroscopy. Acta Chem. IASI. 2019;27(2):263-86. https://doi.org/10.2478/achi-2019-0017
21. Alshuiael SM, Al-Ghouti MA. Multivariate analysis for FTIR in understanding treatment of used cooking oil using activated carbon prepared from olive stone. PLos One. 2020;15(5):e0232997. https://doi.org/10.1371/journal. pone.0232997
22. Bathini V, Kalakandan SK, Pakkirisamy M, Ravichandran K. Structural elucidation of peanut, sunflower and gingelly oils by using FTIR and ^{1}H NMR spectroscopy. Pharmacog J. 2018;10(4):753-57. https://doi.org/10.5530/pj.2018.4.126
23. Yi Y, Yao J, Xu W, Wang LM, Wang HX. Investigation on the quality diversity and quality-FTIR characteristic relationship of sunflower seed oils. RSC Adv. 2019;9(47):27347-60. https://doi.org/10.1039/c9ra04848k
24. Kapoor B, Kapoor D, Gautam S, Singh R, Bhardwaj S. Dietary polyunsaturated fatty acids (PUFAs): Uses and potential health benefits. Curr Nutri Rep. 2021;10:232-42. https://doi.org/10.1007/s13668-021-00363-3
25. Akkaya MR. Fatty acid compositions of sunflowers (Helianthus annuus L.) grown in east Mediterranean region. Rivista Italiana Delle Sostanze Grasse. 2018;95(4):239-47.
26. Ramos MJ, Fernández CM, Casas A, Rodríguez L, Pérez Á. Influence of fatty acid composition of raw materials on biodiesel properties. Bioresour Technol. 2009;100(1):261-68. https://doi.org/10.1016/j.biortech.2008.06.039
27. Hosni T, Abbes Z, Abaza L, Medimagh S, Ben Salah H, Kharrat M. Biochemical characterization of seed oil of Tunisian sunflower (*Helianthus annuus* L.) accessions with special reference to its fatty acid composition and oil content. J Food Qual. 2022;(1):2875072. https://doi.org/10.1155/2022/2875072
28. Gagour J, Ahmed MN, Bouzid HA, Oubannin S, Bijla L, Ibourki M, et al. Proximate composition, physicochemical and lipids profiling and elemental profiling of rapeseed (*Brassica napus* L.) and sunflower (*Helianthus annuus* L.) grown in Morocco. Evidence-Based Complementary and Alternative Medicine. 2022;(1):3505943. https://doi.org/10.1155/2022/3505943
29. Lužaić T, Kravić S, Stojanović Z, Grahovac N, Jocić S, Cvejić S, et al. Investigation of oxidative characteristics, fatty acid composition and bioactive compounds content in cold pressed oils of sunflower grown in Serbia and Argentina. Heliyon. 2023;9(7). https://doi.org/10.1016/j.heliyon.2023.e18201
30. Cojocaru F, Joiţa-Păcureanu M, Negoiţă M, Mihai L, Popescu G, Ciornei L, et al. The impact of climatic conditions on oil content and quality, in sunflower. Rom Agric. Res. 2023;62:19-27. https://doi.org/10.59665/rar4024
31. Garapova A, Kirchev H. Oil content of saturated and unsaturated fatty acids in tribenuron-methyl resistant sunflower hybrids, depending on the amount of macronutrients in the soil. Sci Papers Ser Agron. 2023;66(2):214-20.
32. Chamberlin KD, Melouk HA, Madden R, Dillwith JW, Bannore Y, El Rassi Z, Payton M. Determining the oleic/linoleic acid ratio in a single peanut seed: A comparison of two methods. Peanut Sci. 2011;38(2):78-84. https://doi.org/10.3146/PS11-3.1
33. Li Z, Xiang F, Huang X, Liang M, Ma S, Gafurov K, et al. Properties and characterization of sunflower seeds from different varieties of edible and oil sunflower seeds. Foods. 2024;13(8):1188. https://doi.org/10.3390/foods13081188

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.