**Fatty Acid Dynamics Across Reproductive Stages in Sunflower (*Helianthus anuus* L.) to Optimize Oil Quality**

**ABSTRACT:** The biochemical composition of sunflower seeds, particularly the fatty acid profile, significantly influences the quality and nutritional value of sunflower oil. This study examined the dynamics of oil content and fatty acid accumulation in high, mid and low oleic sunflower hybrids. Field experiments conducted in three replications using RCBD to observe morphological parameters, seed characteristics and fatty acid composition from anthesis to maturity. Results revealed that oleic and linoleic acid levels varied among hybrids due to genetic differences and temperature fluctuations during seed development. Despite differences in total oil content, all hybrids showed a steady increase in oil accumulation across growth stages, reflecting continuous biosynthesis. Notably, hybrids with high oleic acid content demonstrated a more consistent accumulation pattern, while mid and low oleic hybrids exhibited greater variability influenced by environmental conditions. The observed variations in oil content and oleic acid accumulation are attributed to the hybrids' unique genetic makeup and metabolic pathways. These findings highlight the critical post-anthesis stage as a sensitive period influencing fatty acid composition. Consequently, sunflower breeding and cultivation practices can be optimized to enhance oil content and nutritional quality by targeting this crucial growth phase. Understanding these dynamics is essential for developing sunflower hybrids with superior oil quality, catering to both nutritional and commercial demands.

***Keywords:*** *Oil content, post anthesis stage, saturated fatty acids, sunflower, unsaturated fatty acids.*

**INTRODUCTION**

Sunflower oil is renowned for its rich composition of fatty acids, with linoleic acid (omega-6) comprising 65-70%, oleic acid (omega-9) 20-30%, along with smaller percentages of palmitic and stearic acids (Adeleke and Babalola, 2020). The balance between monounsaturated and polyunsaturated fats, as well as the levels of saturated fats, determines its quality (Baydar and Erbas, 2005).

The biochemical composition of sunflower seeds is substantially influenced by genotype and environmental factors such as light and temperature (Schulte *et al*., 2013). High day and night temperatures during seed filling increase oleic acid content and decrease linoleic acid content (Izquierdo *et al*., 2002). Even though sunflower is a temperate crop, it adapts well to various climates and soils. However, temperature variations from anthesis to maturity alter the oleic to linoleic acid ratio in sunflower oil. Continuous high temperatures during grain development can reduce linoleic acid percentage, potentially due to the impact on the enzyme oleate desaturase (Flagella *et al.,* 2002, Grompone 2005).

A study by Demurin *et al*. (2000), elucidated that unsaturated fatty acid profile is strongly influenced by genetics and climate, with a 1°C rise in temperature during seed development leads to approximately 2% increase in oleic acid content. Therefore, oil and fatty acid composition are the key targets of sunflower breeding program under changing climate.

Understanding the accumulation of oil and fatty acids during various reproductive growth stages is crucial. While previous experiments have examined oil and fatty acid accumulation in different whorls of the sunflower head (Baydar and Erbas, 2005, Munshi *et al*., 2003, Rehmatalla, 2001), there's an urgent need to delve into the accumulation process across different reproductive growth stages, spanning from anthesis to physiological maturity. This study was aimed at finding specific growth stages where environmental factors like temperature or light exert significant influence on the accumulation patterns. Towards this, an experiment was conducted in three distinct sunflower hybrids with varying levels of oleic acid content (high, moderate and low oleic acid content) to further understand the accumulation patterns from anthesis to harvest, shedding light on the dynamics of oil content and fatty acid accumulation throughout the reproductive growth stages of sunflower.

**MATERIAL AND METHODS**

**Plant material and growth conditions:** Sunflower being a photo-period insensitive crop it can be grown in all seasons (*Kharif*, *rabi* and summer) under a wide range of agro-climatic condition in India (Vikram *et al.,* 2019). Here, a field experiment was conducted during *Kharif* 2020 at the University of Agricultural Sciences, Bangalore to assess differential oleic acid accumulation during seed filling stage of sunflower. Three hybrids, PAC-3794 [high oleic acid (82-84%) hybrid released by Advanta India Limited in 2013], KBSH-44 [medium oleic acid (66-68%) hybrid released by University of Agricultural Sciences, Bangalore in 2002] and RSFH-130 [low oleic acid (32-34%) containing hybrid released by University of Agricultural Sciences, Raichur in 2008] were grown in three replications in a Randomized Complete Block Design (RCBD) (Banuvalli *et al*., 2021). Plants were grown under open field conditions with red laterite soil and supplied with farm yard manure @ 10 tonnes per hectare and recommended dose of fertilizers. All prophylactic measures were taken to have healthy plants until the harvest.

**Morphological parameters:** The morphological parameters were recorded at 60 days after sowing (DAS) at five days interval till physiological maturity. Five uniform and randomly selected plants per hybrid were tagged at 30 DAS and used for recording observations. Plant height was recorded from base of the stem to the base of the capitulum at flowering and expressed in cm. Total leaf area, an indicator of total photosynthesizing area of the plant, was measured following a non-destructive method (factorial method) as described by Nanja Reddy *et al*. (1995). Briefly, the total number of leaves were counted and multiplied with a constant value of 0.369 to arrive at the position of the leaf from the top to be considered for length (cm) and width (cm) measurements. When the value is a fraction it was rounded off to the nearest whole number. The values of length and width were again multiplied with another constant value of 0.69 to determine the total leaf area, which was expressed in cm2 plant-1.

Total leaf area (cm2 plant-1) = Length x width of index leaf x 0.69 x Total number of leaves

**Yield parameters:** The plants were harvested at physiological maturity and sun dried. The seeds were threshed manually, cleaned, dried and weight was taken to determine yield and expressed as gram per plant. Test weight was determined by weighing 100 randomly selected seeds from each hybrid and expressed in grams. The kernel to husk ratio was calculated by separating kernels from husk in 100 seeds and taking their weight. To determine the seed weight on volume basis (cc per 100 ml), volumetric flask was used to measure 100 ml seeds and their weight was recorded. Total dry matter (g plant-1) was measured by taking the weight of **c**ompletely dried leaves, stem and thalamus of individual plants. Further, the harvest index was calculated as per Donald (1962) using the following formula and expressed in per cent.

Harvest Index (%) = (Total Biological Yield/Economic Yield​) × 100

**Estimation of oil and quality parameters:** To estimate oil content and fatty acid profiles, sampling was done in 3 flower heads from each replication per hybrid at two days interval after 50 % flowering (60 DAS). Seeds from four border whorls of the head were collected for estimation of oil content and fatty acid profiles.

Fatty acid composition was determined by gas chromatography (Agilent technologies 7890A) from three replicates per hybrid. The oleic acid, linoleic acid, palmitic acid and stearic acid content were estimated expressed as percentage of the total fatty acids in the oil. The fatty acid estimation protocol includes two steps viz., oil extraction and esterification. In oil extraction, three grams of dry seed was ground to fine powder and extracted with Chloroform: Methanol (3:1) and filtered using Whatman filter paper. A pinch of anhydrous sodium sulphate was added to the filtrate to remove moisture. Again, filtered using Whatman filter paper and the filtrate was evaporated to get only oil. During esterification, 2 ml of BF3 Methanol (Boron tri-fluoride methanol complex) was added to the extracted oil and kept on water bath at 47oC for 2 minutes with intermittent mixing. To the mixture 2 ml of heptane was added and again kept on water bath at 47oC for 2 minutes with intermittent shaking. Further, the sample was taken out from water bath and 1 ml of heptane was added and cooled to room temperature. To the cool mixture 2 ml of saturated NaCl was added. Total oil contentwasestimated using Multistat Soxhlet. The oil content was calculated as given below and expressed in per cent.

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Oil (%) = (Final weight of jar (g) − Initial weight of jar (g) / Weight of sample (g) ) × 100

The results were analyzed by using RCBD with factorial concept and suitable ANOVA. The critical difference between the treatments was calculated at five per cent significance (Snedecor and Cochran, 1967).

The data were statistically analyzed using analysis of variance (ANOVA) following the procedure described by Gomez and Gomez (1984) for a randomized complete block design (RCBD).

**RESULTS AND DISCUSSION**

At harvest, highest plant height was observed in KBSH-44 (201.8 cm) among three hybrids followed by RSFH-130 (199.0 cm) and PAC-3794 (140.6 cm) (Table 1). These differences in plant height is attributed to the genetic characteristics of the hybrids as documented by Sarwar (2013). The leaf area (cm² plant-1) in all three hybrids showed a significant increase up to 60 days after sowing (DAS), reaching peak during the vegetative stage and subsequently decreased with the onset of the reproductive stage. At 70 DAS, RSFH-130 showed the highest leaf area of 18854 cm² plant-1, followed by KBSH-44 with 15780 cm² plant-1, and PAC-3794 with 10224 cm² plant-1. Though RSFH-130 was little smaller than KBSH-44 in terms of height it showed nearly 20 % more leaf area compared to KBSH-44 at 70 DAS. In addition, the leaf senescence was faster in KBSH-44 compared to other two hybrids. Similar results were also observed by Banuvalli *et al*. (2021) suggesting the maintenance of more photosynthetic area in the PAC3794 and RSFH-130 towards maturation.

**Table 1. Growth parameters recorded at different stages from anthesis to harvesting in sunflower hybrids**

|  |  |  |
| --- | --- | --- |
| **Time of observation** | **Plant height (cm)** | **Total leaf area (cm2)** |
| **KBSH-44** | **PAC 3794** | **RSFH-130** | **KBSH-44** | **PAC 3794** | **RSFH-130** |
| 60 DAS | 196.0 | 134.4 | 191.2 | 15916 | 8090 | 17591 |
| 65 DAS | 200.6 | 139.6 | 196.2 | 15333 | 9409 | 18680 |
| 70 DAS | 201.6 | 140.6 | 197.8 | 15780 | 10224 | 18854 |
| 75 DAS | 201.8 | 140.6 | 198.2 | 14182 | 9878 | 17987 |
| 80 DAS | 201.8 | 140.6 | 199.0 | 12924 | 9166 | 17544 |
| **CV %** | **0.45** | **0.27** | **0.28** |  **9.59** |  **3.13** |  **2.46** |
| **SEm±** | **0.40** | **0.17** | **0.25** | **635.85** | **130.00** | **199.44** |
| **CD at 5%** | **1.21** | **0.50** | **0.75** | **1906.29** | **392.21** | **597.93** |

No significant difference among the hybrids was noticed for head diameter, test weight and total dry matter (Table 2). Seed volume by weight basis was lower in PAC-3794, while KBSH-44 and RSFH-130 showed similar values. This lower seed volume by weight in PAC-3794 could be because of the lower density of seeds. Kernel-to-husk ratio was higher in RSFH-130 compared to the other two hybrids suggesting potential higher density of the seed and thinnes husk. The yield was higher in KBSH-44 at 41.4 g with better harvest index, test weight and total dry matter. Biomass has been shown to be positively correlated with yield in many crops (Iqbal *et al*., 2017). The hybrid KBSH-44 which had higher dry matter also showed higher yield, bolder seeds and higher harvest index. This is the kind of hybrid required in the climate change scenario where higher yield under control may translate into higher yield under stress and also enhancing biomass would also enhance yield and harvest index (Dobre, 2021).

**Table 2. Yield parameters in different sunflower hybrids**

|  |  |  |  |
| --- | --- | --- | --- |
| **Hybrids/yield parameters** | **KBSH-44** | **PAC-3794** | **RSFH-130** |
| Head diameter (cm) | 23.86 | 23.73 | 22.44 |
| Test weight (g) | 5.58 | 5.09 | 5.38 |
| Seed volume by weight basis (cc) | 30.64 | 27.60 | 30.40 |
| Kernel to husk ratio | 1.35 | 1.41 | 2.21 |
| Seed yield (g plant-1) | 41.47 | 35.61 | 36.23 |
| Harvest index | 24.72 | 21.96 | 23.17 |
| Total dry matter (g plant-1) | 168.75 | 162.50 | 156.55 |

Oil content was measured from 56 DAS and there was a consistent increase in oil content in all hybrids until harvest suggesting gradual accumulation of oil in the developing seeds until harvest. Though there were some differences in the middle stages, both KBSH-44 and RSFH-130 showed similar oil content at first measurement and the final measurement suggesting possibility of differential rate of accumulation of oil in different hybrids (Table 3). While all hybrids showed an increase in oil content leading up to harvest, KBSH-44 and RSFH-130 showed similar oil content at harvest, both reaching 40 %, while PAC-3794 had a relatively lower oil content at harvest at 37.2 %. Though the oil content is highly controlled by the genetics of the hybrid several environmental factors such as high temperature (Harris *et al*., 1978), light intensity during anthesis (Dosio *et al*. 2000 and Aguirrezábal *et al*., 2003), agronomic practices (Skarpa *et al*., 2013 and Ahmad *et al*., 2011) and soil moisture levels (Ling Wang *et al*., 2022 and Chirkova, 2002) have been shown to influence oil content. To understand the influence of these environmental factors these hybrids have to be grown under different conditions and oil content has to be measured. Additionally, these environmental factors which increase oil content can be identified towards enhancing oil production in the county.

**Table 3. Oil content (%) at various crop growth stages for different sunflower hybrids**

|  |  |
| --- | --- |
| **DAS** | **Oil Content (%)** |
| **KBSH-44** | **PAC 3794** | **RSFH-130** |
| **56** | 1.90 | 1.35 | 1.91 |
| **58** | 2.04 | 1.60 | 1.97 |
| **60** | 2.27 | 2.24 | 2.57 |
| **62** | 3.45 | 3.35 | 3.45 |
| **64** | 4.34 | 4.29 | 5.57 |
| **66** | 4.59 | 8.33 | 7.70 |
| **68** | 8.66 | 12.63 | 11.56 |
| **70** | 12.23 | 17.56 | 14.91 |
| **72** | 16.29 | 21.60 | 19.43 |
| **74** | 20.68 | 25.82 | 22.48 |
| **76** | 24.24 | 28.38 | 25.27 |
| **78** | 27.38 | 30.31 | 28.29 |
| **80** | 31.04 | 34.71 | 31.06 |
| **82** | 33.51 | 33.68 | 34.14 |
| **84** | 36.51 | 37.18 | 37.82 |
| **86** | 40.45 | - | 40.21 |
| **CV %** | 4.29 | 5.99 | 3.96 |
| **SEm±** | 0.42 | 0.61 | 0.41 |
| **CD at 5%** | 1.21 | 1.76 | 1.19 |

Results of oleic acid measurement from anthesis to maturity showed highest oleic acid content in PAC-3794 (33%) followed by KBSH-44 (29.3 %) and RSFH-130 (17.7%) (Table 4). From 64-70 DAS, oleic acid content declined inKBSH-44 and RSFH-130 and increased later. However, in PAC-3794 it reduced from 62-64 DAS and then increased. These variations might be attributed to environment and also stage dependent genetic regulation by each hybrid (Schulte *et al*., 2013). At the end of harvest PAC-3794 (81.5%) maintained higher oleic acid content followed by KBSH-44 (63%). Least oleic acid content was found in RSFH-130 with only 36%.

Similarly, the linoleic acid content also varied among the hybrids and it was lesser than the oleic acid in all hybrids. RSFH-130 showed highest linoleic acid content at 47 % and PAC-3794 was the lowest at 8.67 % during harvest. Several studies have demonstrated an inverse relationship between oleic and linoleic content in sunflower (Grunvald *et al*., 2013; Van Der Merwe *et al*., 2013; and Piao *et al*., 2014). Temperature has been shown to highly impact oleic to linoleic acid ratio in sunflower oil due altered synthesis or activity of the oleate desaturase . **Low temperatures have been shown to stimulate its activity, leading to a lower oleic acid content, whereas high temperature suppress it, resulting in higher oleic acid content**, as observed in studies by Sarmiento *et al*., (1998) and Flagella *et al*., (2002). Therefore, the ratio of oleic to linoleic acid can be manipulated by growing sunflower under varying temperature conditions.

In general, oil content in sunflower hybrids increased progressively through growth stages, with differences in fatty acid composition reflecting their genetic traits. Hybrids with higher oil content, like PAC-3794, exhibit greater oleic acid accumulation and lower linoleic acid levels, indicating an inverse relationship between these two fatty acids. Conversely, hybrids with lower oleic acid content, such as RSFH-130, tend to have higher linoleic acid levels. This consistent inverse correlation suggests that as oil content increases, the balance between oleic and linoleic acids shifts depending on the hybrid’s genetic predisposition.

**Table 4. Unsaturated fatty acid content in sunflower hybrids from anthesis to physiological maturity**

|  |  |  |  |
| --- | --- | --- | --- |
| **DAS** | **Oleic acid (%)** | **DAS** | **Linoleic acid (%)** |
| **KBSH-44** | **PAC-3794** | **RSFH-130** |  | **KBSH-44** | **PAC-3794** | **RSFH-130** |
| **56** | 29.34 | 33.00 | 17.69 | **56** | 18.78 | 25.25 | 20.45 |
| **58** | 33.06 | 38.11 | 31.06 | **58** | 28.52 | 26.32 | 26.26 |
| **60** | 36.50 | 40.59 | 31.30 | **60** | 28.12 | 24.82 | 28.82 |
| **62** | 40.52 | 30.75 | 37.20 | **62** | 29.49 | 23.53 | 25.26 |
| **64** | 37.98 | 32.19 | 32.00 | **64** | 26.60 | 19.86 | 27.55 |
| **66** | 29.62 | 41.38 | 44.35 | **66** | 26.07 | 23.57 | 24.65 |
| **68** | 34.50 | 44.44 | 31.90 | **68** | 26.80 | 24.74 | 36.93 |
| **70** | 40.35 | 60.95 | 32.27 | **70** | 21.51 | 15.65 | 37.15 |
| **72** | 46.52 | 68.26 | 47.71 | **72** | 11.52 | 14.21 | 34.16 |
| **74** | 47.92 | 76.79 | 42.72 | **74** | 36.06 | 10.10 | 38.26 |
| **76** | 60.38 | 71.48 | 43.66 | **76** | 23.17 | 17.73 | 42.66 |
| **78** | 54.74 | 65.78 | 40.42 | **78** | 29.53 | 23.58 | 44.58 |
| **80** | 52.54 | 70.59 | 34.06 | **80** | 34.11 | 18.21 | 43.87 |
| **82** | 54.67 | 79.29 | 37.13 | **82** | 33.64 | 8.76 | 42.35 |
| **84** | 57.42 | 81.55 | 36.68 | **84** | 26.96 | 8.67 | 46.09 |
| **86** | 63.01 |  - | 36.15 | **86** | 24.55 |  - | 46.99 |
| **CV %** | 9.39 | 8.19 | 8.09 | **CV %** | 15.63 | 19.63 | 8.09 |
| **SEm±** | 2.44 | 2.63 | 1.71 | **SEm±** | 2.40 | 2.15 | 1.62 |
| **CD at 5%** | 7.04 | 7.63 | 4.94 | **CD at 5%** | 6.93 | 6.24 | 4.68 |

The results of saturated fatty acid measurements (Table 5) indicate higher palmitic acid content in KBSH-44 from 56 DAS to 72 DAS and it declined till harvest. Similar trend was observed in PAC-3794 though it was lowest (5.24%) at the time of harvest. Low oleic acid containing RSFH-130 accumulated more of palmitic acid at the initial stages after anthesis and it was maintained till harvest except at 76 and 78 DAS. KBSH-44 recorded higher stearic acid (4.65%) at harvest, followed by PAC-3794 (3.34%) and it was lowest in RSFH-130 (2.17%).

**Table 5. Saturated fatty acid content in sunflower hybrids from anthesis to physiological maturity**

|  |  |  |  |
| --- | --- | --- | --- |
| **DAS** | **Palmitic acid (%)** | **DAS** | **Stearic acid (%)** |
| **KBSH-44** | **PAC 3794** | **RSFH-130** | **KBSH-44** | **PAC 3794** | **RSFH-130** |
| **56** | 24.64 | 16.33 | 31.39 | **56** | 6.55 | 10.30 | 6.32 |
| **58** | 23.99 | 18.71 | 25.53 | **58** | 7.20 | 13.89 | 9.67 |
| **60** | 24.23 | 20.43 | 25.38 | **60** | 11.15 | 14.16 | 10.60 |
| **62** | 19.77 | 23.92 | 19.56 | **62** | 10.22 | 14.60 | 10.80 |
| **64** | 21.30 | 27.16 | 25.90 | **64** | 14.25 | 15.52 | 6.52 |
| **66** | 23.29 | 23.36 | 24.02 | **66** | 13.47 | 9.53 | 5.56 |
| **68** | 22.78 | 21.26 | 24.37 | **68** | 12.59 | 7.76 | 4.20 |
| **70** | 20.79 | 14.06 | 24.73 | **70** | 15.13 | 7.27 | 4.82 |
| **72** | 23.13 | 4.80 | 13.57 | **72** | 11.63 | 12.22 | 3.25 |
| **74** | 9.22 | 7.10 | 14.29 | **74** | 6.81 | 6.01 | 3.44 |
| **76** | 7.36 | 6.83 | 7.10 | **76** | 8.64 | 3.97 | 5.75 |
| **78** | 9.28 | 6.43 | 8.30 | **78** | 5.35 | 2.90 | 5.56 |
| **80** | 7.73 | 7.13 | 13.75 | **80** | 5.05 | 3.90 | 3.29 |
| **82** | 7.17 | 6.13 | 14.51 | **82** | 4.45 | 3.18 | 2.68 |
| **84** | 6.38 | 5.24 | 12.92 | **84** | 5.24 | 3.34 | 2.04 |
| **86** | 7.31 |  Trace | 10.96 | **86** | 4.65 |  Trace | 2.17 |
| **CV %** | 27.27 | 23.52 | 14.65 | **CV %** | 24.07 | 28.19 | 30.25 |
| **SEm±** | 2.54 | 1.89 | 1.37 | **SEm±** | 1.24 | 1.39 | 0.92 |
| **CD at 5%** | 7.34 | 5.48 | 3.96 | **CD at 5%** | 3.57 | 4.04 | 2.67 |

During the initial sampling at anthesis (56 days after sowing), it was observed that seeds contained nearly 70 % of major fatty acids. Therefore, further efforts were made to estimate 20-30 % of remaining fatty acids (Table 6). The results showed that PAC-3794 accumulated all 21 minor fatty acids estimated in the study. Interestingly, two fatty acids, methyl heneicosanoate and methyl tricosanoate, were absent in KBSH-44. Similarly, RSFH-130 lacked methyl undecanoate and methyl tridecanoate. Towards maturity the major fatty acids content increased suggesting potential reduction in minor fatty acids. However, these variations and mechanisms of these changes needs to be empirically evaluated by the time course analysis of the activity of enzymes involved in fatty acid biosynthesis. Further, it would be interesting to study the influence of environmental factors on the total oil content and also variations in major and minor fatty acids.

**Table 6. Minor fatty acids (%) estimated at first stage of the anthesis (56 DAS)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sl. No** | **Minor fatty acids** | **KBSH-44** | **PAC-3794** | **RSFH-130** |
|  | Methyl undecanoate | 1.72 | 0.59 | - |
|  | Methyl laurate | 1.06 | 1.04 | 2.38 |
|  | Methyl tridecanoate | 0.84 | 0.46 | - |
|  | Methyl myristate | 0.57 | 0.71 | 0.40 |
|  | Myristoleate methyl ester | 0.47 | 0.45 | 0.63 |
|  | Elaidic acid Methyl ester | 3.47 | 2.66 | 2.46 |
|  | Lenolelaidic acid methyl ester | 1.01 | 3.08 | 4.46 |
|  | Methyl linoleate | 3.00 | 2.71 | 2.77 |
|  | Methyl arachidate | 2.19 | 2.44 | 1.74 |
|  | Gamma linoleic acid methyl ester | 1.56 | 1.60 | 2.21 |
|  | Methyl eicosanoate | 0.72 | 0.98 | 1.20 |
|  | Methyl heneicosanoate | - | 1.86 | 0.35 |
|  | Methyl eicosadienoate | 1.33 | 0.97 | 1.36 |
|  | Methyl behanate | 1.39 | 3.66 | 7.36 |
|  | Cis- 11,14,17-eicotrienoic acid methyl ester | 1.61 | 3.03 | 2.45 |
|  | Methyl Cis- 5,8,11,14,17 eicosapentaenoate | 1.59 | 1.75 | 3.55 |
|  | Methyl tricosanoate  | - | 1.33 | 0.29 |
|  | Cis 13,16- docosadienoic acid methyl ester | 0.63 | 1.92 | 0.14 |
|  | Methyl lignocerate  | 2.58 | 4.11 | 10.96 |
|  | Methyl Cis- 5,8,11,14,17 eicosapentaenoate | 0.97 | 1.16 | 0.26 |
|  | Methyl nervonate | 0.73 | 0.55 | 0.25 |

**CONCLUSION**

At harvest, both KBSH-44 and RSFH-130 showed a maximum oil content of 40 % with PAC-3794 37% oil content. Interestingly, PAC-3794 with lower total oil content showed significantly higher oleic acid (81 %), compared to KBSH-44 (63 %) and RSFH-130 (36%). From the human health perspective, unsaturated fatty acids are good therefore total oil yield could be further enhanced in PAC-3794 which has higher unsaturated fatty acids. These differences in oil content and oleic acid accumulation among the sunflower hybrids likely stem from their unique genetic makeup and metabolic pathways. PAC-3794 may possess genetic traits that enhance the synthesis and accumulation of oleic acid, possibly through upregulated expression of enzymes involved in oleic acid biosynthesis or regulatory mechanisms favoring oleic acid production. Environmental factors such as temperature and soil moisture could also influence fatty acid metabolism, further impacting oil composition. Further research into the molecular and physiological mechanisms governing fatty acid biosynthesis in these hybrids is necessary for a comprehensive understanding.

**Disclaimer (Artificial intelligence)**

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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