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Original article

Achene yield and oil quality of diverse sunflower (*Helianthus annuus* L.) hybrids are affected by different irrigation sources

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ABSTRACT

Objectives: Sunflower (*Helianthus annuus* L.) is a major oilseed crop grown for its edible oil across the globe, including Pakistan. The production of edible oil in Pakistan is less than the required quantity. The scarcity of water resources is one of the major challenges all over the world in sunflower production. The water availability in arid and semi-arid is becoming a limiting factor to meet the food demands of increasing global population. Therefore, this study was aimed at enhancing the production of hybrid sunflower utilizing different water resources i.e., irrigation with canal, tube well and sewage sludge.
Methods: A field experiment (2-years) was conducted to evaluate the impact of different irrigation sources on achene yield, oil contents and fatty acid composition of diverse sunflower hybrids *viz.*, 'ESFH-3391', 'ESIH-35', 'SHF-80', 'AQSHF-3', 'FMC-1', 'PARSON' and 'SINJI'.
Results: The result indicated that sunflower hybrids exhibited varied response for plant height, stem diameter, head diameter, 1000-achene weight and achene yield. Among the irrigation sources, canal irrigation proved superior to other water sources in improving 1000-achene weight of hybrid 'ESFH-3391' (89.7 g), achene yield of the hybrid 'AQSHF-3' (2649 kg ha^{-1}), oil contents and fatty acid profiles.
Conclusions: It is concluded that sunflower hybrid 'AQSHF-3' produced the highest achene yield with canal water irrigation water and it is recommended to grow in the semi-arid climate of Punjab, Pakistan.

1. Introduction

Increasing population in arid and semi-arid areas is the main factor for the rising water demand. Recycling of wastewater has become a key challenge for water source management and the plans are made throughout the world (Surucu et al., 2020). Pakistan ranks third among the countries that are facing water scarcity issues (Salehi, 2022). Pakistan Academy of Technology and Council of Studies in Water Resources (PCRWR) predicted that Pakistan will be facing severe water shortage in 2025 (Rasheed et al., 2021). Currently, the restricted and sustainable water delivery in the country is the main threat due to climate exchange and growing pollutants levels. Except urgent steps are taken, water security will result in extra adversities and inequality for vulnerable organizations in society (Salehi, 2022).

Sunflower (*Helianthus annuus* L.) is an important oilseed crop. Its oil contents vary from 34.26 to 39.13% (Hussain et al., 2018). The oil of sunflower is comprised of soluble vitamins A, D, E and K. Sunflower cake and margarine are used as feedstuff for livestock (Soare and Chiurciu, 2018). Its seeds can be roasted and are consumed by humans (Al-Qubaie, 2012). In Pakistan, sunflower is grown on an area of 151 thousand acres, with seed production of 87 thousand tons and oil production of 33 thousand tons (GOP, 2021). The major oilseed crops in the country include sunflower, canola, cotton, and rapeseed/mustard (Ijaz et al., 2021). During

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2020–21, the total demand for edible oil was 3.291 million tonnes; of which 0.374 million tonnes was met through local production and the contribution of import was 2.917 million tonnes (worth U$$ 3.419 billion). Sunflower gives 33 thousand tons of oil. In the economy of Pakistan, oilseed crops play a major share and contribute more than 17% to meet the domestic edible oil requirement. Sunflower contributes about 11% to domestic edible oil production (GOP, 2021)). However, a wide gap exists in this sector which can be improved for enhancing local production. Thus, there is a dire need to improve oilseed production in the country to meet the requirements of the country.

Low yield and production of sunflower hybrids are due to unavailability of better cultivars/hybrids, high prices of imported seed and the losses of the crop at maturity birds (Hussain et al., 2018). Other reasons for low yield are inefficient and false marketing systems, non-availability and expensive inputs used for crop cultivation (Farooq et al., 2017; Hussain et al., 2016a, 2016b), dependence on old methods for sowing (Farooq et al., 2015), and harvesting, post-harvest losses and lack of knowledge among farmers regarding the latest techniques of sunflower production technology (Malik et al., 2004).

In arid and semi-arid areas, the yield and productivity of sunflowers are reduced by drought stress (Hussain et al., 2018). It is reported that the distribution and quality of water have a major impact on the oil and seed yield of sunflower (García-López et al., 2016). Yield and yield attributes were significantly affected by the irrigation treatments applied for sunflower hybrid under arid and semi-arid environments (Abdou et al., 2011; García-López et al., 2016; Surucu et al., 2020). Sunflower also contains some genetic potential to survive in moderately salt-affected regions having a threshold level of ECe 2.5 dS m^{-1} (Douaoui et al., 2006). Cost of production increases due to high seed prices of the import hybrids in addition to other expensive inputs. Most growers cannot afford to purchase hybrid seeds because the hybrid seed can't be used in the next generation and also have issues of adaptations in local climates. Hence there is a extensive demand for time to develop the local hybrids with high yield potential (Hussain et al., 2012).

For many decades, water has been a major international agenda for its issues regarding its availability because water is the main source of life on earth. Hence, many areas of Pakistan are facing water scarcity issues (Rasheed et al., 2021). The life of Pakistan's agriculture is considered its irrigation water, but water shortage issues are faced by the country as challenging circumstances as an intention to conserve all available water resources (Hussain et al., 2008a, 2008b). Thus, production through agriculture is being decreased due to a severe shortage of water in the country. In the future socio-economic conditions for the rural population will be harder due to continuous water shortage in the country.

Treated wastewater is one of the promising water resources in sustainable agricultural development (Surucu et al., 2020). When the wastewater is free from toxic compounds, the nutrients are converted to valuable biomass, which contains more protein and less fiber than emergent plants (de Freitas et al., 2012). However, treated wastewaters can still be used for irrigation under controlled conditions which minimize hazards from pathogenic and toxic contaminants to agricultural products, soils, surface, and groundwater (Baawain et al., 2019; Kiziloglu et al., 2007).

From the above discussion, it is obvious that irrigation with sewage sludge water can negatively impact plant health and environment quality. Thus, it is needed to devise agronomic, breeding and other crop management strategies to reduce the negative impacts of sewage sludge water irrigation on crop growth. In this scenario, the use of sewage sludge water if treated might be a viable option. To the best of our knowledge, no work has been carried out to check the influence of canal and sewage water irrigation on the productivity of sunflowers.

Our study aimed at evaluating the performance of sunflower hybrids based on productivity and quality under various irrigation sources (canal, tube well and sewage sludge) in Thal region of Punjab, Pakistan.

2. Materials and methods

2.1. Site and soil

Two-year (2017 and 2018) field experiment was carried out at the Research Area of Bahadur sub-Campus, Bahauddin Zakariya University (BZU), Layyah-Pakistan. The soil of the experimental area was sandy-loam having EC 126 dSm^{-1}, pH 8.2, soil organic matter 0.69%, available phosphorus 3–4 ppm, and potash 153 ppm. The daily maximum and minimum temperature (°C) and rainfall (mm) was recorded during the growth period of both years are given in Table 1.

For the analysis of water of different irrigation water sources (canal, tube well and sewage sludge), the water samples were taken from the irrigation canal (Layyah minor), the outlet of tube well and sewage sludge (BZU, Bahadur Campus Layyah). A water sample taken from the site was immediately transferred to the soil and water testing laboratory, Layyah for the analysis of electric conductivity, calcium, magnesium, sodium, carbonate, bicarbonate, chloride, sodium absorption ratio and residual sodium carbonate as given in Table 2.

2.2. Experimental design and treatments

The field trial consisted of seven sunflower hybrids *viz.,* 'ESFH-3391', 'ESIH-35', 'SHF-80', 'AQSHF-3', 'FMC-1', 'PARSON' and 'SINJI', and three different irrigation sources (canal, tube well and sewage sludge). The experiment was laid out in randomized complete block design (RCBD) with split plot arrangements with three replications. The net plot size was 3 m × 5 m keeping irrigation sources in the main plot and hybrids were sown in subplots.

Table 1
Weather data recorded during the experimentation period.

	Maximum temperature (°C)		Minimum temperature (°C)		Average Rainfall (mm)	
	2017	2018	2017	2018	2017	2018
February	24.03	28.3	11.22	13.8	14.66	14.00
March	26.20	29.3	14.66	18.7	119.9	121.7
April	33.9	35.4	19.4	20.5	16	18
May	40.7	41.5	25.3	27.7	1	1
June	41.6	43.7	28.8	29.8	36	38
July	37.0	39.5	27.0	29.0	85	88

Table 2
Analysis of various irrigation water sources.

Irrigation water source	EC (dS cm 1)	Ca + Mg	Na	CO_3	HCO_3	Cl	SAR	RSC
Tube well	778	6.41	1.37	Nil	5.40	–	Nil	0.76
Canal water	472	4.56	0.16	Nil	4.23	–	Nil	0.10
Sewage sludge	262	5.46	0.23	Nil	4.67	–	Nil	0.15

EC, electrical conductivity; Ca **+** Mg, calcium, and magnesium; Na, sodium; CO_3, carbonates; HCO_3, bicarbonates; Cl, chloride; SAR, sodium absorption ratio and RSC, residual sodium carbonates.

2.3. Experimental details

Seeds of sunflower hybrids were obtained from National Agriculture Research Centre (NARC), Islamabad-Pakistan. The seedbed was prepared by cultivating the soil twice at depth of 0.30 m followed by planking. After preparation of the seedbed, the ridges were made by a tractor ridger with 75 cm distance among the ridges. The seeds were sown manually on the ridges and the seed rate used for sowing was 7 kg ha^{-1}.

2.4. Observations

At random, ten plants from each plot were selected to record the plant height, number of leaves per plant, stem diameter and head diameter which was averaged later for each replication. The chlorophyll index was measured with SPAD meter (SPAD-502 Chlorophyll Index, SCI). Three samples of 1000-achenes from each plot were counted and 1000-achene weight was measured on an electric balance. The whole plot was harvested, and the plants were sundried. Then the total biomass (stem yield + achene yield) was taken with a spring balance and was then converted to kg ha^{-1}. The heads were removed from the plants and the grains were threshed manually. The weight of all the grains from every plot was measured on an electric balance and was later expressed in kg ha^{-1}.

The seed protein and oil contents were recorded using the Near-infrared Reflectance Spectroscopy system (NIRS) as detailed in (Chen et al., 2008). The profiling of fatty acids *viz.*, stearic acid, palmitic acid, linolenic acid and oleic acid was done by using the NIRS as detailed in (Chen et al., 2008).

The oil content in intact seeds was estimated by nuclear magnetic resonance (MQC23, Oxford Instruments, UK), which is non-destructive, quick, easy to perform and simple to calibrate. A standard sample containing 5 g seeds of all hybrids of sunflower with known oil content was set to calibrate the instrument. The fatty acid composition was determined by gas chromatography of fatty acid methyl esters. These were prepared as per the procedure developed by Appelqvist13 and analyzed on a gas Chromatograph (model 7820A series, Agilent Technologies, Palo Alto, CA, USA) equipped with a flame ionization detector with CP-Sil 88 (25 m × 0.25 mm × 0.20 mm) FAME column. Temperatures of the oven, detector and injector were maintained at 210, 240 and 230 °C, respectively. Two microlitres of the sample were injected at a split rate of 10:1. Individual fatty acids were expressed as percentages of the total fatty acids. Total linoleic acid was measured by the sodium tetrachloropalladate (Na_2PdC_{l4}) method14 and expressed as μmol g^{-1} defatted meal.

2.5. Statistical analysis

The data recorded on morphological and yield traits were analyzed using Fisher's analysis of variance (ANOVA) technique and the least significant difference (LSD), a *post hoc* test, at 5% probability level was used to estimate the differences between the treatment means (Steel et al., 1997). For treatment comparison, replicated data was arranged in Microsoft Excel 2016.

3. Results

3.1. Morphological traits

The morphological traits (*viz.,* plant height, number of leaves, stem diameter and head diameter) indicates that the sunflower hybrids were significantly different during both years of experimentation (Table 3).

The individual effects of sunflower hybrids and irrigation sources on plant height were found non-significant. The interactive effect of sunflower hybrids and irrigation water sources was significantly different for plant height. The highest plant height was recorded in sunflower hybrid 'SHF-80' with canal water irrigation during both years. Similarly, the individual effect of sunflower hybrids and irrigation sources on the number of leaves was found non-significant. Likewise, the interaction of sunflower hybrids with irrigation water sources was also significant for the number of leaves during 2018 (Table 3). Maximum numbers of leaves were recorded in sunflower hybrid 'PARSON' which was statistically similar to 'SHF-80' with canal water irrigation. The individual effect of sunflower hybrids and irrigation sources against stem diameter was found non-significant. The interaction of sunflower hybrids with irrigation water sources was also significant for stem diameter. Maximum stem diameter was recorded in sunflower hybrid 'FMC-1' which was statistically at par with sunflower hybrid 'ESIH-35' with canal water irrigation. The interaction of sunflower hybrids with irrigation water sources was also significant for head diameter in 2018. Among the irrigation water sources, the highest plant height was recorded with canal water irrigation in sunflower hybrid 'ESIH-35' which was statistically at par with sunflower hybrid 'PARSON' (Table 3).

3.2. Yield variables

The field experiment indicated that the sunflower hybrids were significantly different for yield parameters (*viz.,* 1000-seed weight, biological yield, and achene yield) during both 2017 and 2018 (Table 4).

The interaction of sunflower hybrids with irrigation water sources was significant for 1000-seed weight. The highest 1000-seed weight was recorded in sunflower hybrid 'ESFH-3391' with canal water irrigation. The result indicated that biological yield was significantly different among various irrigation water sources. Likewise, different sunflower hybrids also differed for biological yield. The maximum biological yield was recorded in sunflower hybrid 'AQSHF-3' with canal water irrigation and the lowest biological yield was recorded with tube well irrigation. The achene yield was significantly different among various irrigation water sources and sunflower hybrids in 2017. The highest achene yield was recorded in sunflower hybrid 'AQSHF-3' which was statistically at par with sunflower hybrid 'SHF-80' with canal water irrigation (Table 4).

Table 3
Influence of various irrigation water sources on plant height, number of leaves, stem/head diameter of different sunflower hybrids under the arid climate of Layyah during 2017 and 2018.

Genotypes/Irrigation resources	Plant height (cm)						Number of leaves (per plant)					
	2017			2018			2017			2018		
	Tube well	Canal	Sewage	Tube well	Canal	Sewage	Tube well	Canal	Sewage	Tube well	Canal	Sewage
ESFH-3391	146 i	185 ab	116 n	141.6 gh	142.0 gh	179.9 a	18.2	21.6	13.2	15.0 cd	16.6 bc	11.3 h
ESIH-35	138 k	181 c	119 m	142.0 gh	134.2 j	176.3b	17.3	22.3	14.5	13.6 ef	17.6 ab	12.0 f-h
SHF-80	148 h	187 a	115 n	140.7 h	181.3a	142.6 g	16.4	22.2	14.6	13.0 e-h	18.6 a	12.3 f-h
AQSHF- 3	158 g	185 b	109 o	143.2 g	153.3f	179.8 a	15.4	23.1	16.7	12.0 f-h	18.0 ab	12.3 f-h
FMC 1	164 f	177 d	106 p	143.8 a	159.4 e	173.6c	16.2	22.8	14.2	12.0 f-h	18.0 ab	11.6 gh
PARSON	145 j	167 e	106 p	143.2b	139.7 hi	162.3 d	15.8	24.0	17.2	13.3 d-g	19.3 a	14.3 de
SINJI	143 j	163 f	132 l	142.2 g	138.7 i	158.8 e	18.0	21.2	14.3	12.3 f-h	16.6 bc	11.3 h
LSD (p ≤ 0.05)	**1.47**			**1.74**			**NS**			**1.69**		
	Stem diameter (cm)						**Head diameter (cm)**					
ESFH-3391	1.37 i	1.86 c	1.13 j	1.17 g	1.31 def	1.03 h	13.5	14.1	12.3	11.6 fg	12.2 d-g	10.9 g
ESIH-35	1.47 gh	2.20 a	0.91 kl	1.16 gh	1.87 a	0.89 i	15.8	18.3	13.3	13.4 c-e	16.6 a	11.9 e-g
SHF-80	1.57 e-g	1.69 de	0.93 k	1.34 cde	1.46 bc	0.88 i	15.2	17.2	13.2	13.0 c-f	15.6 a	11.6 fg
AQSHF- 3	1.49 f-h	1.79 cd	0.94 k	1.25 efg	1.49 b	0.88 i	18.2	15.7	12.5	16.0 a	14.1 bc	11.4 g
FMC 1	1.60 e	2.09 b	0.88 kl	1.38 bcd	1.95 a	0.85 ij	13.1	17.6	13.5	11.9 fg	15.6 a	11.8 fg
PARSON	1.43 hi	1.80 c	0.92 k	1.21 fg	1.50 b	0.85 ij	17.3	15.7	13.8	15.1 ab	13.5 cd	12.0 d-g
SINJI	1.43 hi	1.60 ef	0.81 l	1.19 fg	1.46 bc	0.77 j	13.8	18.3	13.1	11.7 fg	16.2 a	11.3 g
LSD (p ≤ 0.05)	**0.10**			**0.10**			**NS**			**1.43**		

Means of main effects and interaction sharing the same case letter do not differ significantly at p ≤ 0.05; NS = non-significant.

Table 4
Influence of various irrigation water sources on 1000 seed weight, achene yield, biological yield and chlorophyll contents of different sunflower hybrids under the arid climate of Layyah during 2017 and 2018.

Genotypes/ Irrigation resources	1000 seed weight (g)						Achene yield Kg ha^{-1}					
	2017			2018			2017			2018		
	Tube well	Canal	Sewage	Tube well	Canal	Sewage	Tube well	Canal	Sewage	Tube well	Canal	Sewage
ESFH-3391	79.0 de	89.7 a	60.8 j	74.0 cd	85.0 a	56.0 h	2331.7c	2482.3b	1952.0 ij	2122.3	2125.3	2147.3
ESIH-35	65.5 i	70.0 h	51.3 m	60.8 g	65.4 f	49.2 j	2256.7 ce	2345.7 c	2140.0 eg	2125.3	2147.3	2156.0
SHF-80	77.1 fg	87.0 b	54.1 l	72.3 de	82.0 b	50.2 j	2167.3 dg	2530.7 ab	2285.7 cd	2147.3	2156.0	2162.3
AQSHF- 3	79.3 de	81.2c	58.1 k	74.2 cd	76.6 c	53.3 hi	2284.7 cd	2649.0 a	2232.7 c-f	2156.0	2162.3	2174.3
FMC 1	70.0 h	66.6 i	49.4 n	66.9f	61.2 g	46.4 k	2325.3c	2558.0 ab	1558.0 k	2162.3	2174.3	2180.0
PARSON	65.9 i	77.6 ef	53.8 l	60.1 g	73.7 de	51.3 ij	2083.3 g-i	2094.3 f-h	1682.3 k	2174.3	2180.0	2184.7
SINJI	75.7 g	79.6 cd	65.6 i	70.6 e	74.7 cd	61.7 g	1637.7 k	1842.3 j	2003.3 hi	2180.0	2184.7	2200.3
LSD (p ≤ 0.05)	**1.68**			**2.75**			**124.4**			**NS**		
	Biological Yield (Kg ha^{-1})						**Chlorophyll Contents (SPAD value)**					
ESFH-3391	28,217 ef	35,991 b	25,231 i	26249 fg	34,682 b	24186 h	20.4 ab	23.5 a	20.8 ab	18.7 ab	18.5 ab	21.3 a
ESIH-35	27,668 e-g	27,855 e-g	26924 fg	25932 fg	26328 fg	25,359 gh	19.7 ab	22.8 ab	22.8 ab	17.5 ab	20.7 a	20.6 a
SHF-80	30,311 d	35,115b	32,557c	28,458 e	33,051 c	30,785 d	21.9 ab	21.1 ab	22.4 ab	20.0 ab	20.4 ab	19.3 ab
AQSHF-3	27,731 e-g	39,512 a	25,461 hi	26386 fg	38,750 a	24042 h	20.6 ab	22.8 ab	21.9 ab	18.5 ab	19.8 ab	20.3 ab
FMC 1	28,519 e	26,731 gh	26937 fg	26,936f	25,264 gh	25,147 gh	18.8 b	21.8 ab	22.8 ab	16.4b	20.6 a	19.4 ab
PARSON	22,547 j	28,325 e	22,068 j	21,553 i	27,037 f	21,001 I	22.1 ab	22.0 ab	21.0 ab	19.8 ab	18.6 ab	19.9 ab
SINJI	22,445 j	22,372 j	22,661 j	21,145 i	21,214 i	21,267 I	21.2 ab	21.6 ab	20.4 ab	19.6 ab	18.2 ab	19.8 ab
LSD (p ≤ 0.05)	**1279.3**			**1421.0**			**3.95**			**3.86**		

Means of main effects and interaction sharing the same case letter do not differ significantly at p ≤ 0.05; NS = non-significant.

3.3. Chlorophyll content (SPAD value)

The individual effect of sunflower hybrids and irrigation sources against chlorophyll content was found non-significant. The interaction of sunflower hybrids with irrigation water sources was significant for chlorophyll content. Maximum chlorophyll content was recorded in sunflower hybrid 'ESFH-3391' in 2017 and 'ESIH-35' in 2018 with canal water irrigation (Table 4).

3.4. Seed oil quality traits

The individual effect of sunflower hybrids and irrigation sources against oil and protein content was found non-significant. The interaction of sunflower hybrids × irrigation water sources was significant for oil and protein content. Among the irrigation water sources, the highest oil/protein content was recorded with canal water irrigation while the lowest was recorded with tube well irrigation. Among the sunflower hybrids, the highest oil/protein content was recorded in the sunflower hybrid 'FMC-1'. The lowest oil/protein content was recorded in the sunflower hybrid 'SINJI' (Fig. 1).

3.5. Fatty acid profile

The fatty acid profile (stearic acid, palmitic acid, oleic acid and linoleic acid) was found non-significant among various irrigation

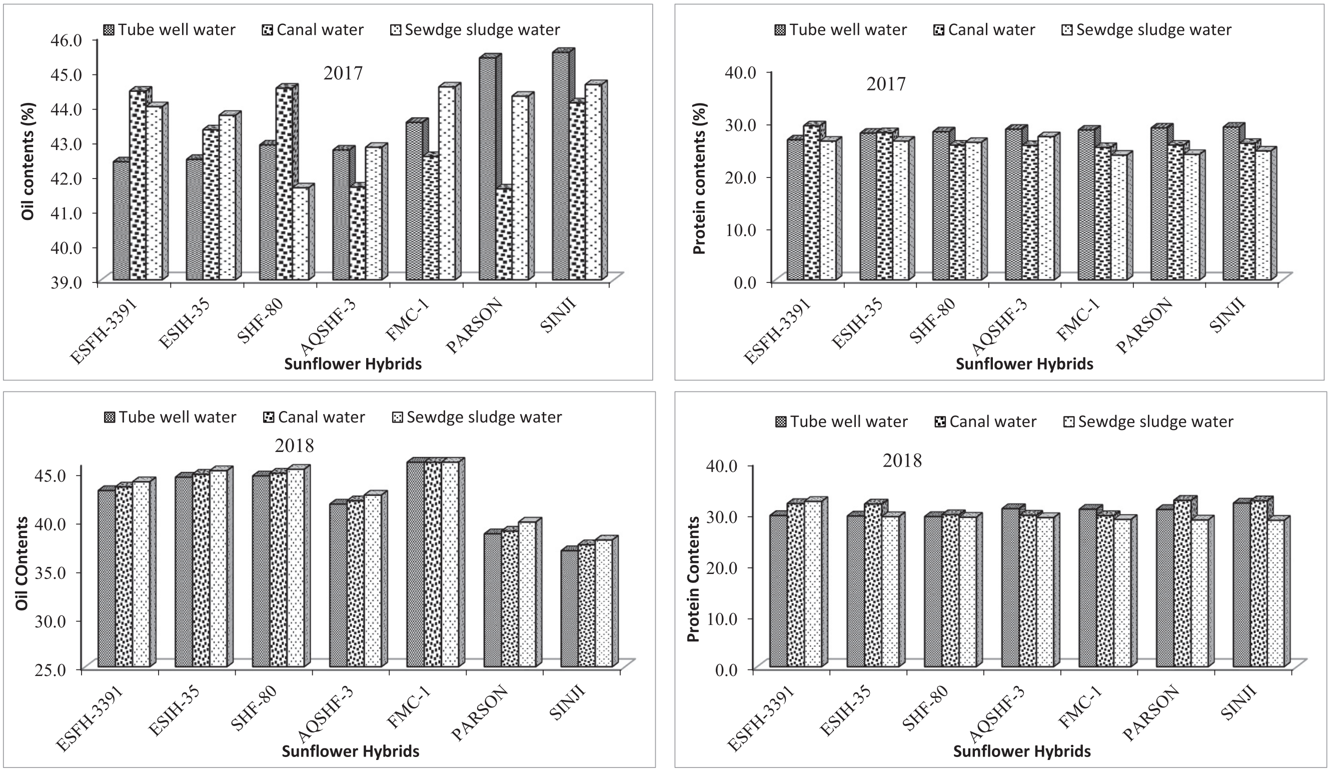

Fig. 1. Effect of various irrigation sources on oil contents and protein contents of different sunflower hybrids.

water sources and sunflower hybrids. But the interaction of sunflower hybrids with irrigation water sources was significant for the fatty acid profile. Among the irrigation water sources, the highest stearic/palmitic/oleic and linoleic acid was recorded with canal water irrigation. Among the sunflower hybrids, the highest above-mentioned traits were recorded in sunflower hybrid 'ESIH-35' while the lowest was recorded in sunflower hybrid 'PARSON' (Figs. 2 and 3).

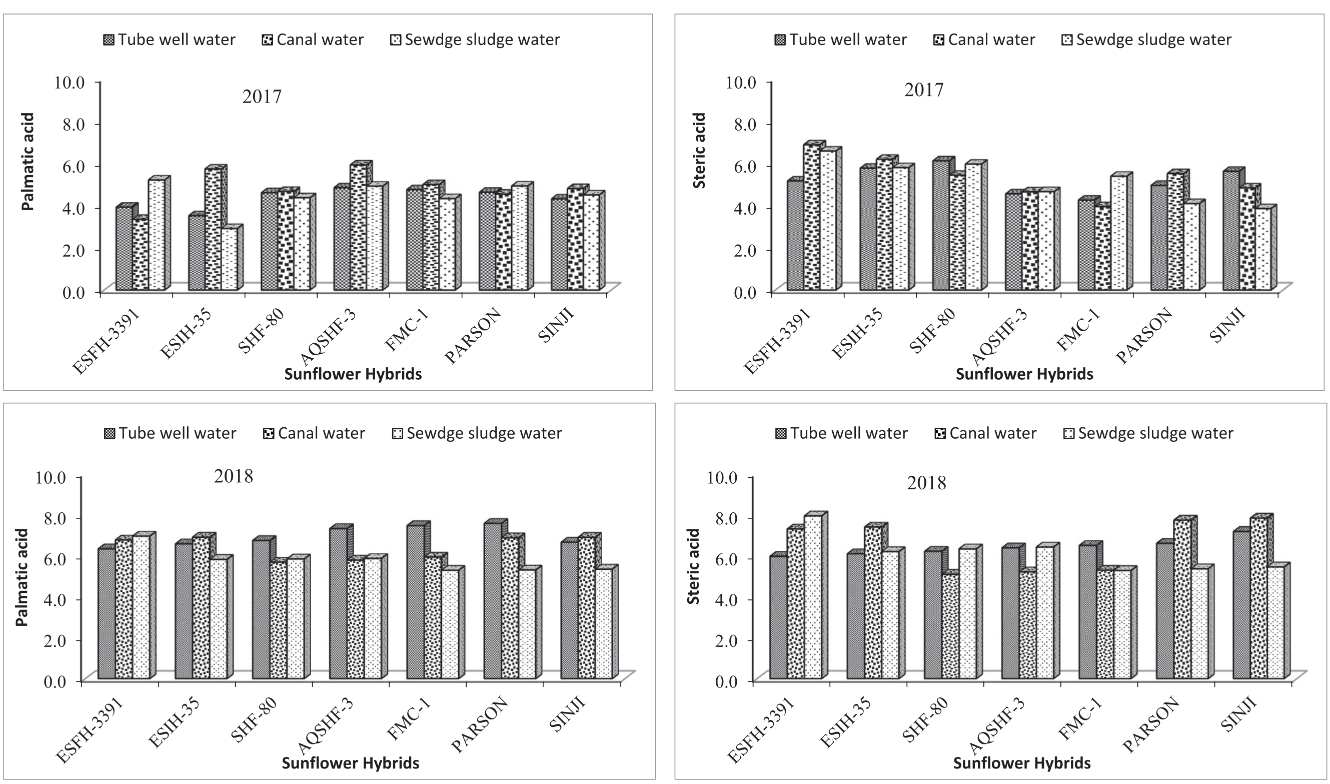

Fig. 2. Effect of various irrigation sources on palmitic acid and steric acid of different sunflower hybrids.

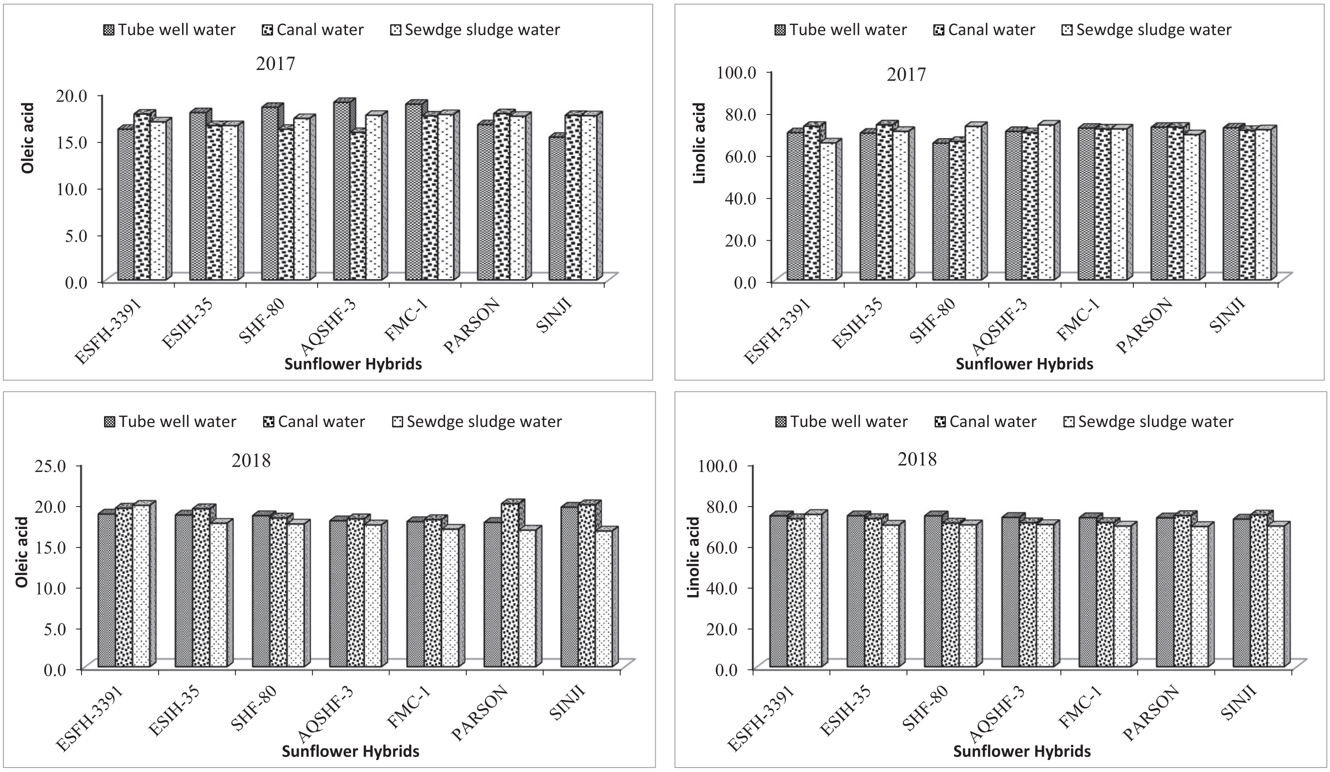

Fig. 3. Effect of various irrigation sources on oleic acid and linoleic of different sunflower hybrids.

4. Discussion

This study indicated that the sunflower grown in arid and semi-arid areas has good crop productivity and oil quality after being applied with different sources of irrigation (tube well, canal and sewage sludge water irrigation). The nutrients in canal and sewage sludge water are greater than the tube well water. The crops grown under these sources of water is more vigorous and have minimum need of nitrogen fertilizers because the nutrients in these sources of water are maximum. Sunflower yield increased significantly with the use of canal water and sewage sludge water. According to (Tanan et al., 2019), the enhancement in yield of plants owning to the use of canal and sewage sludge water can be attributed to the increase in nutrient accessibility and the improvement in the soil physical properties, chemical, and biological conditions, which are produced by the adding the soil organic matter from the sewage water. The canal irrigation sources performed well in this study as compared to the tube well water (Abdou et al., 2011; Surucu et al., 2020). The sewage sludge water also performed well in that area. The field study indicated that canal irrigation water and sewage sludge water play a key role in enhancing the yield and yield attributes (Moradi et al., 2016).

Sunflower hybrids significantly differ for morphological and yield-connected attributes. In this regard, the hybrid 'AQSFH-3' produced the maximum achene yield and have a high amount of oil and oleic contents. The plant height of sunflower was significantly higher with canal water irrigation and minimum plant height was observed in tube well water irrigation, as reported earlier by (Shah et al., 2013). The maximum achene yield in this hybrid was the outcome of a greater number of leaves, maximum head diameter and the maximum 1000 achene weight. More number of leaves in hybrid results in the development of the most effective plant canopy which enhance the interception of photosynthetically active radiations and reduce the weed emergence by giving shade (Araus and Cairns, 2014) and improve the grain partitioning which causes better crop growth and yield as was observed in this study. Moreover, the differences in the morphological and yield attributes among many different sunflower hybrids in this study are attributed to the differences in the genetic make-up of these hybrids for these traits. The plant height is greatly affected by the canal water source as compared to the tube well and sewage sludge water source.

Among the water irrigation sources, the maximum achene yield and oil contents were recorded in canal water irrigation and sewage sludge irrigation owing to the production of the greater number of leaves per plant, the highest head diameter, the maximum achene per head and biological yield which might have improved the root growth, soil aeration, and uptake of water and nutrients in the ridge sown sunflower (Noorka et al., 2013). The maximum use of treated wastewater in irrigation led to an increase in soil chemical properties particularly soil EC and SAR values for both growing seasons; the same trend was found by (Sakellariou-Makrantonaki et al., 2011) who stated that the irrigation with treated wastewater may influence negatively on some soil properties particularly EC, SAR and Na% values, which needs continues observing of these characteristics for long-term.

The yield of crops was reduced from 3 to 15 % in the fields where the tube well water was used as irrigation compared with the canal water. In another study, the yield of crops was not affected by tube well water having EC up to 5.17 dS m^{-1} because the aquifers have the sandy and clay layer (Shakir et al., 2011) and due to the crop management adopted by the farmers (Pangga et al., 2013). Sewage sludge is known to be an essential source of nitrogen to the plants, which is the factor element in the calculation of fertilization, as documented by the CONAMA Resolution n^0 375 (Moretto et al., 2012). However, depending on soil fertility, it usually needs to be complemented by fertilization with other nutrients (Nascimento, 2012).

The increase in sunflower yield by the canal water and wastewater can be attributed to the presence of not only readily available adequate amount of N, P and K but also enough organic matter which improves the soil structure and the other soil characteristics related to the accessibility of nutrients and water (Zake et al., 2015). Basharat (2012) also stated that the application of wastewater also enhances the total nitrogen along with its microbial activity and total carbon in the soil. Ayoub et al. (2016) stated that the application of wastewater tends to increase the density of soil micro-organisms including bacteria, fungi and actinomycetes that help inaccessibility to plants. In agriculture, wastewater is extensively used because it is a rich source of essential elements and provides all moisture necessary for plant growth. Most crops give higher potential yields with wastewater irrigation, reducing the need of chemical fertilizers, and ultimately resulting in net cost savings to the farmers.

The leaching of these salts below the root zone may cause soil and groundwater pollution. The effect of wastewater on agricultural soil is mainly due to the presence of high nutrient contents (NP), high total dissolved solids and other constituents such as heavy metals, which are added to the soil over time (Geetha et al., 2012). Better performance of sunflower hybrids under ridge sowing is due to loosening fertile soil of the plants (Hussain et al., 2010). Among the irrigation sources, the canal and sewage sludge water have good effects on the productivity and oil quality of sunflower hybrids.

5. Conclusion

It was concluded from this experiment that different irrigation resources showed significant effects on various yield parameters such as achene yield, oil contents and fatty acid composition of different sunflower hybrids. Canal irrigation water was found to be more significant than other water resources used in the experiment. Sunflower hybrid 'AQSHF- 3' produced maximum achene yield among all hybrids sown for the experiment. As it is concluded that sunflower hybrid 'AQSHF- 3' should be grown with canal irrigation water for better growth and achene yield as well as better oil quality. However, further experimentation is needed for the assessment of canal irrigation water for sunflower production and yield under miscellaneous environmental conditions across the world.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abdou, S.M.M., El-Latif, K.A., Farrag, R.M.F., Yousef, K.M.R., Latif, K.M.A.E., 2011. Response of sunflower yield and water relations to sowing dates and irrigation scheduling under middle Egypt condition. Adv. Appl. Sci. Res 2, 141–150.
Al-Qubaie, A.I., 2012. Response of sunflowers cultivar Giza-102 (Helianthus annuus, L) plants to spraying some antioxidants. Nat. Sci.
Araus, J.L., Cairns, J.E., 2014. Field high-throughput phenotyping: The new crop breeding frontier. Trends Plant Sci. https://doi.org/10.1016/j.tplants.2013.09.008.
Ayoub, S., Al-Shdiefat, S., Rawashdeh, H., Bashabsheh, I., 2016. Utilization of reclaimed wastewater for olive irrigation: Effect on soil properties, tree growth, yield and oil content. Agric. Water Manag. https://doi.org/10.1016/j.agwat.2016.05.035.
Baawain, M., Sana, A., Al-Yahyai, R., Amoatey, P., 2019. Sustainable reuse options of treated effluents: A case study from Muscat, Oman. J. Environ. Eng. Sci. https://doi.org/10.1680/jenes.19.00019.
Basharat, M., 2012. Spatial and temporal appraisal of groundwater depth and quality in LBDC command-issues and options. Pakistan J. Eng. Appl. Sci. 11, 14–29.
Chen, J.Y., Miao, Y., Sato, S., Zhang, H., 2008. Near infrared spectroscopy for determination of the protein composition of rice flour. Food Sci. Technol. Res. https://doi.org/10.3136/fstr.14.132.
de Freitas, C.A.S., da Silva, A.R.A., Bezerra, F.M.L., de Andrade, R.R., Mota, F.S.B., de Aquino, B.F., 2012. Growth of irrigated sunflower under different water sources and nitrogen fertilization. Rev. Bras. Eng. Agrícola e Ambient. 16, 1031–1039.
Douaoui, A.E.K., Nicolas, H., Walter, C., 2006. Detecting salinity hazards within a semiarid context by means of combining soil and remote-sensing data. Geoderma 134, 217–230. https://doi.org/10.1016/j.geoderma.2005.10.009.
Farooq, S., Hussain, M., Jabran, K., Hassan, W., Rizwan, M.S., Yasir, T.A., 2017. Osmopriming with CaCl2 improves wheat (Triticum aestivum L.) production under water-limited environments. Environ. Sci. Pollut. Res. 24, 13638–13649. https://doi.org/10.1007/s11356-017-8957-x.
Farooq, S., Shahid, M., Khan, M.B., Hussain, M., Farooq, M., 2015. Improving the productivity of bread wheat by good management practices under terminal drought. J. Agron. Crop Sci. 201, 173–188. https://doi.org/10.1111/jac.12093.
García-López, J., Lorite, I.J., García-Ruiz, R., Ordoñez, R., Dominguez, J., 2016. Yield response of sunflower to irrigation and fertilization under semi-arid conditions. Agric. Water Manag. https://doi.org/10.1016/j.agwat.2016.05.020.
Geetha, A., Suresh, J., Saidaiah, P., 2012. Study on response of sunflower (Helianthus annuus L.) genotypes for root and yield characters under water stress. Curr. Biot. 6, 32–41.
GOP, 2021. Economic Survey of Pakistan.
Hussain, M., Farooq, M., Jabran, K., Rehman, H., Akram, M., 2008a. Exogenous glycinebetaine application improves yield under water-limited conditions in hybrid sunflower. Arch. Agron. Soil Sci. 54, 557–567. https://doi.org/10.1080/03650340802262086.
Hussain, M., Farooq, M., Jabran, K., Wahid, A., 2010. Foliar application of glycinebetaine and salicylic acid improves growth, yield and water productivity of hybrid sunflower planted by different sowing methods. J. Agron. Crop Sci. 196, 136–145. https://doi.org/10.1111/j.1439-037X.2009.00402.x.
Hussain, M., Farooq, M., Shehzad, M., Khan, M.B., Wahid, A., Shabir, G., 2012. Evaluating the performance of elite sunflower hybrids under saline conditions. Int. J. Agric. Biol. 14, 131–135.
Hussain, M., Farooq, S., Hasan, W., Ul-Allah, S., Tanveer, M., Farooq, M., Nawaz, A., 2018. Drought stress in sunflower: Physiological effects and its management through breeding and agronomic alternatives. Agric. Water Manage. https://doi.org/10.1016/j.agwat.2018.01.028.
Hussain, M., Farooq, S., Jabran, K., Ijaz, M., Sattar, A., Hassan, W., 2016a. Wheat sown with narrow spacing results in higher yield and water use efficiency under deficit supplemental irrigation at the vegetative and reproductive stage. Agronomy 6, 22. https://doi.org/10.3390/agronomy6020022.
Hussain, M., Malik, M.A., Farooq, M., Ashraf, M.Y., Cheema, M.A., 2008b. Improving drought tolerance by exogenous application of glycinebetaine and salicylic acid in sunflower. J. Agron. Crop Sci. 194, 193–199.
Hussain, M., Waqas-Ul-haq, M., Farooq, S., Jabran, K., Farroq, M., Farooq, M., Farroq, M., 2016b. The impact of seed priming and row spacing on the productivity of different cultivars of irrigated wheat under early season drought—Corrigendum. Exp. Agric. 52, 477–490. https://doi.org/10.1017/S0014479716000053.
Ijaz, M., Sattar, A., Sher, A., Ul-Allah, S., Mansha, M.Z., Khan, K.A., Shahzad, M.A., Al-Sadi, A.M., Arif, M., Aljuaid, B.S., El-Shehawi, A.M., Farooq, S., 2021. Sulfur application combined with planomicrobium sp. Strain MSSA-10 and farmyard manure biochar helps in the management of charcoal rot disease in sunflower (Helianthus annuus L.). Sustain. https://doi.org/10.3390/su13158535.
M. Kiziloglu, F., Turan, M., Sahin, U., Angin, I., Anapali, O., Okuroglu, M., 2007. Effects of wastewater irrigation on soil and cabbage-plant (brassica olerecea var. capitate cv. yalova-1) chemical properties. J. Plant Nutr. Soil Sci. 170, 166–172.
Malik, M.A., Saleem, M.F., Sana, M., Rehman, A., 2004. Suitable level of N, P and K for harvesting the maximum economic returns of sunflower (Helianthus annuus L.). Int. J. Agric. Biol.
Moradi, S., Heidari, H., Saeidi, M., Nosratti, I., 2016. Effect of sewage-contaminated water on seed production, heavy metals accumulation and seedling emergence in oat. Glob. NEST J. 18, 329–338.
Moretto, D.L., Panta, R.E., Costa, A.B. da, Lobo, E.A., 2012. Calibration of water quality index (WQI) based on Resolution n° 357/2005 of the Environment National Council (CONAMA). Acta Limnol. Bras. https://doi.org/10.1590/s2179-975x2012005000024.
Nascimento, A.L., 2012. Produtividade, nutrição mineral e teores de metais pesados no solo e em girassol adubado com lodo de esgoto.
Noorka, I.R., Batool, A., AlSultan, S., Tabasum, S., Ali, A., 2013. Water stress tolerance, its relationship to stem reserve mobilization and potence ratio in spring wheat. Am. J. Plant Sci. https://doi.org/10.4236/ajps.2013.42030.
Pangga, I.B., Hanan, J., Chakraborty, S., 2013. Climate change impacts on plant canopy architecture: Implications for pest and pathogen management. Eur. J. Plant Pathol. https://doi.org/10.1007/s10658-012-0118-y.

Rasheed, H., Badshah, S., Ashraf, M., Ahmad, M., Rehman, S., 2021. Comparative Assessment of Changa Pani and Traditional Water Supply Schemes (Bhalwal, District Sargodha, Punjab). Pakistan Council of Research in Water Resources (PCRWR), Islamabad. All rights Reserv. by PCRWR. authors Encourag. fair use this Mater. non-commercial Purp. with proper Cit. 44.

Sakellariou-Makrantonaki, M., Giouvanis, V., Bota, V., Koliou, A., 2011. Reuse of wastewater in sunflower. Water saving. In: Proceedings of the 3rd International CEMEPE and SECOTOX Conference Skiathos, pp. 19–24.

Salehi, M., 2022. Global water shortage and potable water safety; today's concern and tomorrow's crisis. Environ. Int. https://doi.org/10.1016/j.envint.2021.106936.

Shah, N.A., Aujla, K.M., Ishaq, M., Farooq, A., 2013. Trends in sunflower production and its potential in increasing domestic edible oil production in Punjab, Pakistan. Sarhad J. Agric.

Shakir, A.S., ur Rehman, H., Khan, N.M., Qazi, A.U., 2011. Impact of canal water shortages on groundwater in the Lower Bari Doab Canal System in Pakistan. Pakistan J. Eng. Appl. Sci.

Soare, E., Chiurciu, I.-A., 2018. Considerations concerning worldwide production and marketing of sunflower seeds. Sci. Pap. Ser. Manag. Econ. Eng. Agric. Rural Dev.

Steel, R.., Torrei, J., Dickey, D., 1997. Principles and Procedures of Statistics A Biometrical Approach, A Biometrical Approach.

Surucu, A., Marif, A.A., Majid, S.N., Farooq, S., Tahir, N.A.-R., 2020. Effect of different water sources and water availability regimes on heavy metal accumulation in two sunflower species. Carpathian J. Earth Environ. Sci. 15, 289–300. https://doi.org/10.26471/cjees/2020/015/129.

Tanan, T.T., Da Silva, A.L., De Oliveira, U.C., Neto, L.P.G., Do Nascimento, M.N., 2019. Effect of nitrogen sources on fruit characteristics and seed physiological quality of physalis angulata L. Pesqui. Agropecu. Trop. https://doi.org/10.1590/1983-40632019v4955074.

Zake, J., Pietsch, S.A., Friedel, J.K., Zechmeister-Boltenstern, S., 2015. Can agroforestry improve soil fertility and carbon storage in smallholder banana farming systems? J. Plant Nutr. Soil Sci. https://doi.org/10.1002/jpln.201400281.