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Integrating Fish Farm Effluents with Mineral Fertilization and Their Impacts on Growth, Yield, and Fruit Quality of Squash Plants

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Abstract. An open field split plot experiment was conducted using a complete randomized block design with 3 replicates at Research and Training Station of KFU, KSA, aiming to evaluate the effects of integrating various irrigation water types (IWT) of fish farm effluents (shrimp (SW), catfish (CatW), carp (CarW), tilapia (TW), and their mixture (MiW)) and normal well water (NW, control) with different rates of applied mineral NPK fertilizer (MF, 0 (control), 25, 50, and 100 kg ha^{-1}) on growth (plant height, fourth leaf area, and dry leaves weight), yield (fruit no/plant, fruit weight, yield, marketable fruit ratio, and firmness), and yield quality (total soluble solids, total acidity, ascorbic acid, and acid-sugar ratio) traits of squash plants (*Cucurbita pepo* L., c.v. Agro top). The IWT and MF treatments occupied the main and sub- main plots, respectively. Obtained results revealed that there were significant differences between treatments and their interactions. The values of treatments irrigated with fish farm effluents and fertilized with MF were significantly higher than those of controls. The best values were generally under the treatment of MiW and 50 kg ha^{-1} MF rate. Such results suggest the reliable use of these effluents as non-conventional irrigation water and their environmental, economic, and social values. Their utilization as irrigation water will intensify surface and underground freshwater sustainability, particularly in water scarce countries, such as KSA. Also, their use promotes agricultural production, contributing to food security. Finally, further investigations to evaluate their impact on other plants and on soil health and quality are recommended. Some agricultural extension programs are required to enhance the perception of farmers and end users toward their reliable and efficient use as alternative irrigation water.
Keywords: Fish Farm Effluents; NPK, Squash; Yield; Yield Quality; Irrigation.

Introduction

Sustainable food production in arid and semi-arid regions is challenged with numerous issues, among which, and probably the most devastating one, is the dearth of irrigation water (Rathmore et al., 2019; Golla, 2021; Qader et al., 2021). The Kingdom of Saudi Arabia (KSA) is a vast country that completely lies within such regions between the latitudes of 16º 21' 58" – 32º 9' 57" N and the longitudes of 34º 33' 48" – 55º 41' 29" E (ElNesr et al., 2010; El-Rawy et al., 2023). The Saudi authority is immensely seeking to attain national sustainable food security (Fiaz et al., 2018; Alamri and Al-Duwais, 2019; Almadini, 2024). However, food security in the country greatly relies on food imports (i.e., 70-80%) (Baig et al., 2019; Alrobaish et al., 2021; Althumiri et al., 2021;

Almadini, 2024). The limited food production in the KSA is crucially dictated by water scarcity and shortage (Borgomeo et al., 2020; Almadini, 2024; Elzaki and Al-Mahish, 2024;).

Saudi agriculture is the topmost water consuming sector (i.e., 80-90%), as compared with the other sectors of municipal and industrial (Al-Zahrani and Baig, 2011; Chowdhury and Al-Zaharani, 2015; Ghanim, 2019; Alodah, 2023; Suhail et al., 2024; Turk and Zeineldin, 2024). In the KSA, the agricultural sector, however, relies on irrigation water that is exclusively supplied from nonrenewable groundwater resources dating back to nearly 10,000-32,000 years ago (i.e., the Ice era). The heavy water consumption by agricultural activities caused a marked decline in water levels of these nonrenewable resources (MAW, 1984; Chowdhury and Al-Zaharani, 2015; Baig et al., 2020). Thus, it should pursue other alternative systems that contribute to producing more foods without compensating groundwater resources, to promote the country's sustainable food security.

Several studies showed that reutilizing fish farm effluents as irrigation water has proved to enhance plant growth, yield and yield quality (Danaher et al., 2013; da Rocha et al., 2017; Hundley et al., 2018, Omeir et al., 2019; Payebo and Ogidi, 2020; Diatta et al., 2023). For example, Omeir et al (2019) indicated that irrigating with fish farm effluents alone or mixed with river water significantly improved the growth and yield of both basil and purslane plants as compared with irrigating with river water only. Also, the contents of essential nutrients significantly increased in both plants under fish water effluent irrigation. Comparable findings were also observed with other valuable crops such as: maize (Silva et al., 2018; Payebo and Ogidi, 2020); sweet marjoram (Kimera et al., 2021); potato, soybean, and onion (Abdelraouf, 2019); French beans (Meso et al., 2004); cherry tomato (Castro et al., 2006); and cactus pear (Pedrosa et al., 2024).

In addition, other studies revealed that irrigating cultivated lands with fish farm effluents have positively improved their soil fertility properties enhancing their productivity and hence boosting crop production (Valencia et al., 2001; Abdul-Rahman et al., 2011; Cerozi et al., 2022). On the other hand, irrigation practices using fish farm effluents have gained further global acceptance due to their environmental, social, and economic benefits, as well as their essential shareholding in food security (Onada and Ogunola, 2016; Brye, 2023).

In the KSA, it ought however to indicate that there are two types of fish farming (MEWA, 2022). They are distinguished based on the quality of water in where fishes are grown (i.e., saline and fresh water). Fish farming activities have already gained numerous interests in the country and great supports by the Saudi government to support the national food security (MEWA, 2022). The number of fish farms has steadily increased between 2012 and 2022 (Figure 1). The figure shows that the number of fish farms projects of fresh water increased more than 6 folds in the same period (i.e., 5,073 to 30,863, respectively). This suggests that the amounts of their effluents are growing up, initiating the necessity to plan for their appropriate reuse. Therefore, this investigation aims to evaluate the effects of integrating various irrigation water types (IWT) of fish farm effluents (i.e., shrimp (SW), catfish (CatW), carp fish (CarW), tilapia fish (TW), and their mixture (MixW)) and normal well water (NW) in the presence of different rates of applied mineral NPK fertilizer (i.e., 0, 25, 50, and 100 kg ha^{-1}) on growth development and yield quality of squash crop grown in an open field.

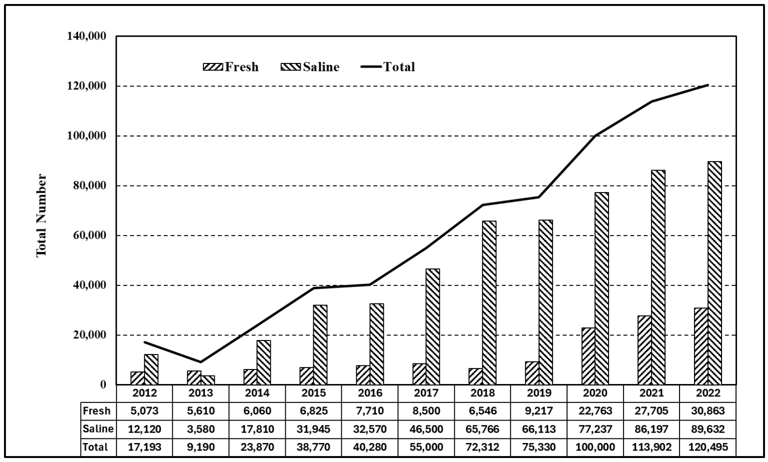

Figure 1: The development of fish farm numbers in the KSA between 2012 and 2022 (MEWA, 2022).

2. Materials and Methods

2.2 Experimental design and set-up

The experiment was carried out with squash plants (*Cucurbita pepo* L., c.v. Agro top) grown in an open field in the winter season of 2020 at the Research and Training Station of KFU, KSA. The regional climate has a mean annual rainfall of about 100 mm and a mean winter temperature of about 27°C. The experimental design was split plots in randomized complete blocks with 3 replicates. The main plots were designated for 6 types of irrigation water types (IWT), while the sub-main plots were allocated for 4 rates of mineral fertilizer (MF) of 20-20-20 NPK, giving a total of 72 experimental units (i.e., 6 x 4 x 3). Each experimental unit was made up of 5 rows that were separated from each other by 50 cm. In every row, established plants were also parted by 50 cm distance, giving every plant an area of 0.25 cm^2. Also, there were 2 spaces between each plot that remained unplanted as guarding areas.

The various IWT included 5 different fish farm effluents that were individually collected in tanks from fish breeding ponds of shrimp (SW), tilapia (TW), catfish (CatW), carp (CarW), and their mixture (MiW) in addition to the normal irrigation water (NW) from an underground well of 450 m deepth, which is commonly used in the station for agricultural (i.e., irrigation water) purposes. This NW treatment was as a control. These effluents were collected from the Research Center of Fish Resources, KFU, located in the station. A water pump was connected to the outlet of every tank to regulate the irrigation process, which was conducted by a drip irrigation system with drippers of 4 liters per hour. Irrigation water was applied for 5 minutes every day.

Meanwhile, the mineral NPK was of 20-20-20 water soluble fertilizer. It was applied at different 4 rates, taking into consideration the essential plant nutrients available in the fish farm effluents. These rates were 0, 25, 50, and 100 kg ha^{-1}. The 0 kg ha^{-1} rate was used as a control treatment. Every fertilization rate was applied in different equal dosages. The first dosage was applied prior to seeding, while the other dosages were applied every 20 days after seeding. All other farming practices for squash plants were accomplished following the recommended ones indicated in the Agricultural Notebook (MEWA, 2019).

Fruits of grown squash plants were collected twice weekly during the maturity stage (45 days after planting) and maintained in polyethylene bags to minimize water loss. Then, they were transferred to the laboratory within 30 minutes. They were immediately preserved for 1-2 hours at 6°C during which measurements and analyses of the fruit quality traits were done. The growth, yield, and yield quality traits of these plants were recorded as follows:

2.2 Growth traits

The growth development traits of squash plants included plant height (cm), fourth leaf area (cm^2), and dry leaves weight (g), which were recorded for every treatment. These traits were measured as follows:

- Plant height was measured for every plant at the end of the experiment using a measuring meter. Results were expressed in centimeters (cm).
- The fourth leaf area was measured following the method described by Fargo et al. (1986). Results were expressed in square centimeters (cm^{-2}).
- Dry leaves were determined using a precision laboratory Mettler balance (model of SB 16100 Mettler Toledo GmbH, Switzerland) with 1 g readability after drying them in oven at 70ºC for 48 hr. Results were expressed in grams (gm).

2.3 Yield traits

The yield traits of squash plants included fruit number per plant, fruit weight (g/fruit), yield (ton ha^{-1}), marketable fruit ratio, and firmness (N). All these traits were determined for every treatment. These traits were determined as follows:

- Number of fruits per plant were done by counting all fruits produced by each plant. Values were expressed as fruit no./plant.
- Fresh fruit weight was done by weighing each fruit using a precision laboratory Mettler balance (model of SB 16100 Mettler Toledo GmbH, Switzerland) with 1 g readability. Results were expressed in grams (gm).
- Plant yield was determined by weighing the total fruits produced by a plant after their collections, and then calculated based on hectare. Values were then expressed in tons per hectare (ton ha^{-1}).
- Fruit firmness was measured after harvesting using the pressure measurement tester of Effegi type (Bishop) FT-327.

2.3 Fruit quality traits

Fruits quality traits of squash plants included total soluble solids (TSS), titratable acidity (TA) ascorbic acid (AA), and sugar-acid ratio (SAR) were measured for all treatments. The measurements and analyses of these traits were accomplished as follows:

- The total soluble solids (TSS) were determined in an aliquot of juice extracted from five fruits for each treatment. It was done using a hand refractometer by placing 1-2 drops of clear juice on its prism and the reading was recorded. Between readings, the prism was well cleaned using tissue paper soaked in methanol, washed with deionized water, and dried before use. The refractometer was also standardized using deionized water. The final value of TSS was then calculated using the following equation (1) according to Pisello et al. (2021):

$$\boldsymbol{TSS\ (Brix) = dilution\ factor\ (3) \times Reading\ in\ refractometer} \qquad \text{(Eq 1)}$$

- The titratable acidity (TA) was estimated following the method described by Seyoum et al. (2011). A 5 ml clear aliquot of diluted fruit juice (i.e., 30 ml water / 1 g of chopped fruit) was titrated with standard 0.1N NaOH in the presence of few drops of phenolphthalein indicator until complete neutralization indicated by the appearance of persisted pale pink color for 10 to 15 seconds. According to Workneh et al. (2011), equation (2) was then used to calculate TA that was expressed as a percentage of citric acid (% citric acid):

$$\boldsymbol{TA}\ \% = \frac{\boldsymbol{volume\ of\ NaOH \times 0.1N \times acidic\ form\ (citric{=}192.124) \times dillution\ factor \times 100}}{\boldsymbol{volume\ of\ sample\ x\ 1000}} \qquad \text{(Eq 2)}$$

- The amount of vitamin C (Ascorbic Acid, AA%) was determined in a diluted aliquot of fruit juice (i.e., 1 g of chopped fruit to 30 ml of deionized water) following the method described by AOAC (2000). The final values of AA were then calculated using equation (3) and then expressed in percentage (AA%):

$$\boldsymbol{AA}\ \% = \frac{\boldsymbol{volume\ of\ titration \times 111 \times diluation\ factor \times 100}}{\boldsymbol{volume\ of\ sample \times 1000}} \qquad \text{(Eq 3)}$$

- The sugar-acid ratio (SAR) was calculated using equation (4), which was denoted by Jayasena et al. (2019):

$$\boldsymbol{Sugar - acid\ ratio = TSS/\ TA} \qquad \text{(Eq 4)}$$

2.5 statistical analysis

All obtained data were statistically analyzed the CoHort softeware 2004. The least significant difference at 5% ($LSD_{5\%}$) tests were also calculated to differentiate the significant differences between the means of treatments (Steel and Torries, 1980).

3. Results

3.1 Chemical properties of irrigation water types (IWT)

Table 1 illustrates the chemical properties of the irrigation water types, including the different fish farm effluents (i.e., shrimp pond (SW), tilapia pond (TW), cat-fish pond (CatW), carp-fish pond (CarW) and a mixture of these ponds (MiW)) and the normal underground water (NW) that were used in this study. As previously indicated, this underground water is the common irrigation water used in the Training and Research Experimental Station of KFU, being used here as a control treatment. It is noticed from the data presented in Table 1 that all values of these chemical properties (i.e., pH, EC, and nutrients of P, N, K, Fe, Mn, Cu, and Zn) of the used irrigation water in this study were within the values of usual ranges of irrigation water indicated by Ingram (2014). The findings of these irrigation water samples showed small differences between their means as presented by the values of standard deviations. This suggests that these irrigation water samples are closely similar in their chemical properties and acceptably valid for irrigation purposes without any hazard to plant growth.

Table 1: The chemical properties of used irrigation water types (i.e., fish farm effluents of shrimp (SW), tilapia (TW), catfish (CatW), carp fish (CarW), and their mixture (MiW) as well as normal irrigation water (NW)), with values of usual range in irrigation water (URIW) by Ingram (2014).

Irrigation Water Types	pH	EC†	P	N	K	Fe	Mn	Cu	Zn
		dS m^{-1}	mg L^{-1}						
SW	7.54	1.47	0.70	5.75	10.72	0.325	0.325	0.025	0.26
TW	6.79	1.36	0.56	5.10	7.97	0.316	0.313	0.027	0.28
CatW	6.56	1.34	0.48	4.69	8.01	0.318	0.314	0.024	0.27
CarW	6.73	1.39	0.62	4.82	8.46	0.316	0.315	0.023	0.24
MiW	6.29	1.41	0.75	6.29	11.54	0.315	0.318	0.023	0.23
NW	6.47	1.23	0.20	4.62	6.17	0.313	0.311	0.020	0.21
SD††	0.43	0.08	0.02	0.67	1.98	0.004	0.005	0.025	0.02
URIW	6.0-8.5	< 3	< 2	< 15	< 10	< 5	< 2	< 0.2	< 0.3

Notes: †EC: electrical conductivity**;** ††SD: standard deviation.

3.2 Growth development traits

Results of plant growth traits were affected by treatments of irrigation water types (IWT), NPK fertilizer (MF), and their interactions (IWT × MF), comprising of plant height, fourth leaf area, dry leaves weight, fruit number/ plant, yield/ plant, fruit market yield/ plant, and the ratio of fruit market/ fruit yield. These effects are as follows:

3.2.1 Analysis of variance of growth development traits

Analysis of variance of the squash growth development traits under the effects of six irrigation water types (IWT), four mineral fertilization (NPK) rates (MF), and their interaction are presented in Table 2. Results showed that significant effects were found in the AWT and MF fertilization treatments to plant height, fourth leaf area, dry leaf weight, fruits number/plant, fruit weight ($p<0.01$), yield ($p<0.01$) and marketable fruit ratio ($p<0.01$), and firmness of fruits ($p<0.01$).

3.2.2 Effect of irrigation water types (IWT) treatments on growth traits of squash plants

The results in Table 2 also illustrate the effects of irrigation water type treatments on plant height (cm), fourth leaf area (cm^2/leaf) and dry leaf weight (g) of squash. The results revealed a highly significant effect on the values of plant length (cm), fourth leaf area, and dry leaf weight ($p<10^{-4}$). The data showed significant differences between applied irrigation water type treatments (NW, SW, TW, CatW, CarW, and MiW) regarding plant length (cm), fourth leaf area (cm^2/leaf), and dry leaves weight (g). Concerning the length of squash plants, the highest value (56.32 cm) was observed at MiW being significantly different from other treatments. The shortest plants (42.78 cm) were obtained in plants irrigated with NW treatment, which may be explained by the low levels of nutrients in such irrigation water (Table 2). The mean values of the fourth leaf area under the effect of different types of irrigation treatments showed significant effects between the studied treatments (Table 2). The values of such characters were in the following order MiW (62.96 cm^2) > SW (60.39 cm^2) > TW (53.54 cm^2) > CarW (52.36 cm^2) > CatW (47.36 cm^2) > NW (35.46 cm^2). The same order of the treatment effects was also found on dry leaf weights (i.e., MiW (93.50g) > SW (89.64g) > TW (85.94g) > CarW (83.14g) > NW (70.85g) > CatW (77.91g)) with exceptions of both NW and CatW.

Table 2: Effect of irrigation water types (IWT) and mineral NPK fertilization (MF, kg ha^{-1}) treatments on growth development traits of squash plants.

Treatments	Plant height (cm)	Fourth Leaf Area (cm^2)	Dry Leaf Weight (g)
Irrigation Water Types (IWT)			
NW	42.78^{d}	35.46^{d}	70.85^{d}
SW	53.99^{ab}	60.39^{a}	89.64^{a}
TW	51.77^{b}	53.54^{b}	85.94^{b}
CatW	46.96^{cd}	47.36^{c}	77.91^{c}
CarW	50.08^{bc}	52.36^{b}	83.14^{cd}
MiW	56.32^{a}	62.96^{a}	93.50^{a}
$LSD_{0.05}$	4.33	3.94	7.30
NPK Fertilization (MF) rates (kg ha^{-1})			
0	43.34^{b}	48.67^{b}	71.84^{b}
25	56.43^{a}	54.51^{a}	93.67^{a}
50	56.62^{a}	55.97^{a}	93.98^{a}
100	44.87^{b}	48.89^{b}	74.49^{b}
$LSD_{0.05}$	2.73	0.55	4.43
Interaction between IWT and MF			
IWT x MF	NS	NS	NS
$LSD_{0.05}$	9.77	6.73	4.91
Probability	$<10^{-3}$	>0.05	$<10^{-4}$
CV%	8.668	7.881	14.602

Notes: Means in the same column followed by different letters are significantly different at $p < 0.05$ for every treatment separately. ***, **** indicate significance at the 0.001 and 0.0001 levels, respectively, and NS means no significant difference at level $p < 0.05$. $LSD_{0.05}$ is the least significant difference at a 0.05 level of significance. $P < 0.05$, 10^{-2}, 10^{-3} and 10^{-4} refer to the probability of significance.

3.2.2 Effect of irrigation water types (IWT) treatments on growth traits of squash plants

The results in Table 2 demonstrate the effects of irrigation water type treatments on plant height (cm), fourth leaf area (cm^2/leaf), and dry leaf weight (g) of squash. The results revealed a highly significant effect on the values of plant length (cm), fourth leaf area, and dry leaf weight ($p<10^{-4)}$). The data showed significant differences between applied irrigation water type treatments (NW, SW, TW, CatW, CarW, and MiW) regarding plant length (cm), fourth leaf area (cm^2/leaf), and dry leaves weight (g). These results agree with the findings obtained by Concerning the length of squash plants, the highest value (56.32 cm) was observed at MiW being significantly different from other treatments. The shortest plants (42.78 cm) were obtained in plants irrigated with NW treatment, which may be explained by the low levels of nutrients in such irrigation water (Table 2).

The mean values of the fourth leaf area under the effect of different types of irrigation treatments showed significant effects between the studied treatments (Table 2). The values of such characters were in the following order MiW (62.96 cm^2) > SW (60.39 cm^2) > TW (53.54 cm^2) > CarW (52.36 cm^2) > CatW (47.36 cm^2) > NW (35.46 cm^2). The same order of the treatment effects was also found on dry leaf weights (i.e., MiW (93.50g) > SW (89.64g) > TW (85.94g) > CarW (83.14g) > NW (70.85g) > CatW (77.91g)) with exceptions of both NW and CatW.

3.2.3 Effect of mineral NPK fertilization (MF) treatments on growth traits of squash plants

The results in Table 2 indicate that there are significant effects of treatments of mineral NPK fertilization (MF) rates on plant height (cm), fourth leaf area (cm^2/leaf), and dry leaf weight (g). These effects were highly significant on all these plant growth characters ($p<10^{-4)}$) (Table 2). The values of the plant morphological traits increased with increasing fertilization rates up to 50 kg NPK ha^{-1} and then decreased at 100 kg NPK ha^{-1}. Obtained results also showed that the plant height (cm) differed significantly under the influence of the various NPK treatments, with the highest value (56.62 cm) observed at treatment of 50 kg of NPK ha^{-1} and the lowest (43.34 cm) was at 0 NPK kg ha^{-1}. The results showed no significant differences between 0 and 100 kg NPK ha^{-1} treatments, and between 25 and 50 kg NPK ha^{-1} treatments. Also, the data in Table 2 revealed that the highest and lowest means of fourth leaf area (55.97 m^2 and 43.34 m^2, respectively) were observed for plants receiving 50 and 0 NPK kg ha^{-1}, respectively. Similarly, the values of the highest and lowest dry leaf weights (93.98 g and 71.84 g, respectively) were also observed for the application treatments of 50 and 0 kg NPK ha^{-1}, respectively (Table 2).

3.2.3 The Interaction effect between IWT and MF treatments

The obtained data shown in Table 2 and Figure 2 revealed that the interactions between the IWT and MN treatments for the values of plant height (Figure 2A), fourth leaf area (Figure 2B), and dry leaf weight (Figure 2C) showed no significant differences between these studied treatments. However, the highest values of the above traits were observed in plants irrigated with mixed fish farm effluent water (MiW) interacting with 50 kg NPK ha^{-1} applied MN fertilization rate (Table 2 and Figure 2). Under both treatments (MiW and 50% MN), these growth traits showed increases of 93.3, 104.75, and 158.88%, respectively, as compared with plants irrigated with NW and 0% kg

NPK ha^{-1}. This displays the rule of fish farm effluents to supply growing squash plants with essential nutrients to meet their requirements, hence reducing the amount of applied mineral fertilizer. Thus, it may be presumed from these findings that reusing fish farm effluents as a source of irrigation water feasibly results in social, environmental, and economic advantages.

A

B

C

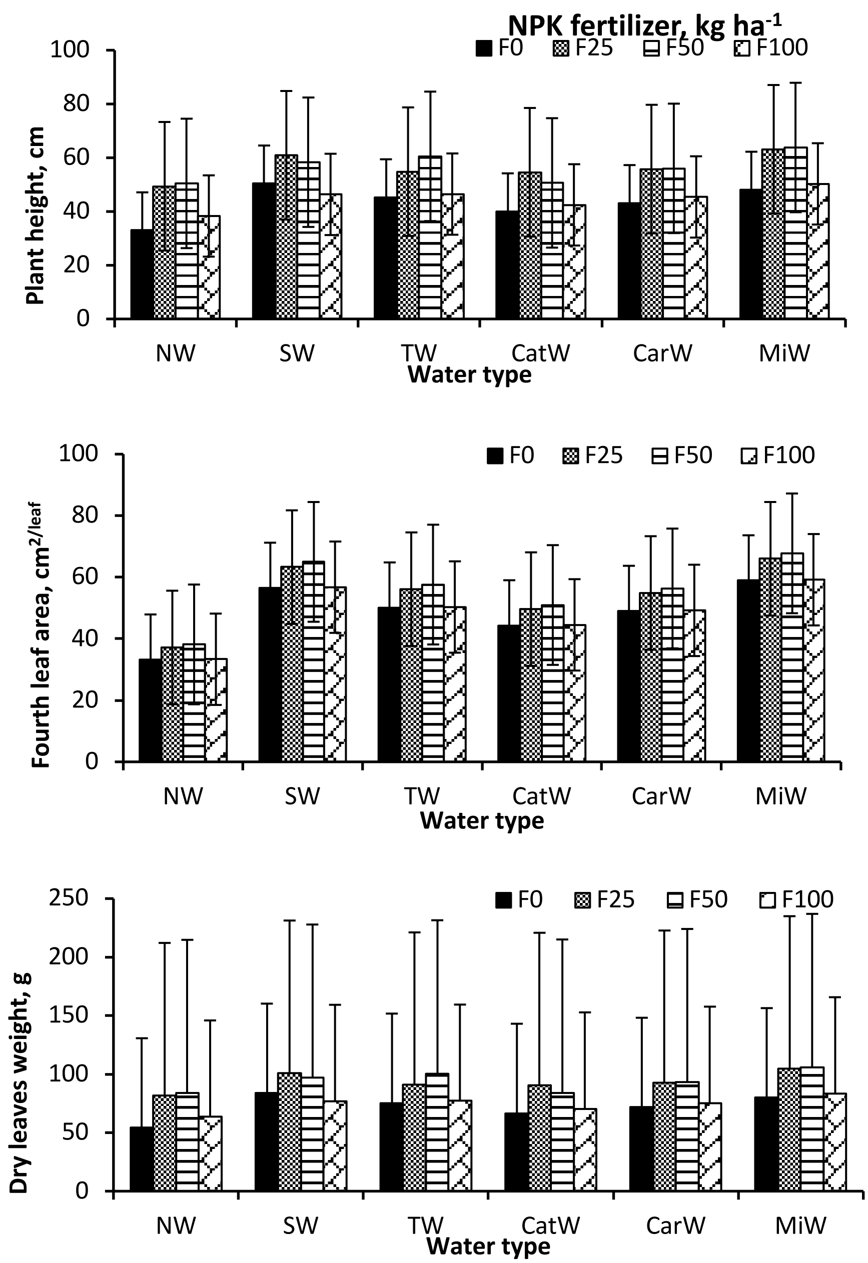

Figure 2: The interaction effects between irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of growth development traits of squash plants.

3.3 Analysis of variance of yield traits of squash fruits

Analysis of variance of the number of fruits/plant, fruit weight, yield, marketable fruit ratio and firmness of fruits (N) of squash fruits under the treatment effects of irrigation water types (5 different fish farm effluents, and normal water, NW as control), four rates of NPK fertilizer (MF), and their interaction are presented in Table 3. The results revealed that there are significant differences due to the use of irrigation water types and MF regarding the number of fruits/plant, fruit weight, yield, marketable fruit ratio and firmness of fruits (Table 3). Also, the results in Table 3 revealed that the interactions between IWT and MF showed significant effects on fruit weight, yield, and marketable fruit ratio, yet insignificant effects on fruit number per plant and firmness. This suggests that the various irrigation water types and application rates of NPK fertilizer had different effects on the fruit quality of grown squash plants.

Table 3: Effect of irrigation water types (IWT) and mineral NPK fertilization (MF, kg ha^{-1}) treatments on yield traits of squash plants.

Treatments	Fruit No. per plant	Fruit Weight (g fruit^{-1})	Yield (ton ha^{-1})	Fruit Marketable Ratio	Firmness (N)
Irrigation Water Types (IWT)					
NW	9.99^{d}	100.88^{d}	14.26^{d}	0.725^{d}	10.69^{d}
SW	12.58^{ab}	127.91^{ab}	18.07^{ab}	0.922^{ab}	13.55^{ab}
TW	12.14^{b}	122.68^{b}	17.36^{b}	0.880^{b}	13.00^{b}
CatW	10.98^{cd}	111.07^{cd}	15.70^{cd}	0.798^{cd}	11.77^{cd}
CarW	11.74^{bc}	118.63^{bc}	16.78^{bc}	0.851^{bc}	12.57^{bc}
MiW	13.17^{a}	133.26^{a}	18.85^{a}	0.957^{a}	14.12^{a}
$LSD_{0.05}$	0.995	10.288	1.452	0.075	1.088
NPK Fertilization (MF) rates (kg ha^{-1})					
0	9.54^{d}	110.95^{b}	15.60^{b}	0.825^{b}	11.75^{d}
25	10.72^{c}	119.62^{a}	15.80^{b}	0.862^{ab}	12.24^{bc}
50	12.46^{b}	124.56^{a}	17.55^{a}	0.878^{a}	12.80^{b}
100	14.36^{a}	121.15^{a}	18.40^{a}	0.857^{ab}	13.69^{a}
$LSD_{0.05}$	0.775	6.979	1.033	0.047	0.769
Interaction between IWT and MF					
IWT × MF	NS	**	**	*	NS
$LSD_{0.05}$	1.990	20.574	2.904	0.149	2.17
CV%	10.24	10.47	10.45	10.55	10.45

Notes: Means in the same column followed by different letters are significantly different at $p < 0.05$ according to every treatment separately. ***, **** indicate significant at 0.001 and 0.0001 level, respectively, and NS means no significant at level $p < 0.05$. $LSD_{0.05}$ is the least significant difference at a 0.05 level of significance. Pr > 0.05, and 10^{-4} means the probability of significance

3.3.1 Effect of irrigation water types (IWT) treatments on yield traits of squash plants

Table 3 also presents the mean values of the investigated fruit quality characters of the squash plants under the various IWT and MF treatments. The presented results showed that the highest values of fruit number, fruit weight, yield, marketable fruit ratio and firmness of squash fruits were 13.17, 133.26 g/fruit, 18.85-ton ha^{-1}, 0.957, and 14.12 N, respectively, for plants irrigated with

MiW water type. On the opposite side, the lowest values of these parameters were for plants irrigated with NW. The MiW effluent increased the fruit number, fruit weight, yield, marketable fruit ratio, and firmness by 31.83, 32.09, 32.19, 32, and 32.09%, respectively, as compared with plants irrigated with NW water type. This signifies the effects of fish farm effluents on plant fruit quality.

3.3.2 Effect of NPK fertilizer rates (MF) treatments on yield traits of squash plants

The various studied fruit quality parameters of the squash plant showed an ascending trend with increasing application of MF from zero up to 50 kg of ha^{-1}, yet these parameters decreased at the fertilization rate of 100 kg NPK ha^{-1} (Table 3). The 50 kg of MF ha^{-1} treatment gave the highest yield, which was 17.95% more than for plants receiving no NPK fertilizer. This implies that growing plants need only 50% of the full maximum applied rate when irrigated with fish farm effluents, which proposes that these effluents can compensate for the nutrient requirements at such a rate to be optimum. In other words, under irrigating practices with such fish farm effluent water, additions of MN over this 50 kg ha^{-1} exceed the optimum requirement by growing squash plants, causing a decline in their characteristics of yield and yield components. Also, it is inferred from these findings the economic and environmental benefits of reusing such fish farm effluents by reducing the application of MN.

3.3.3 The interaction effects between IWT and MF treatments

Table 3 comprises the results of interaction effects between the various irrigation water types (IWT) with mineral NPK mineral fertilization rates (MF) treatments on fruit number/plant (Figure 3), fruit weight (g/fruit, Figure 4), yield (ton ha^{-1}, Figure 5), fruit marketable ratio (Figure 6), and fruit firmness (N, Figure 7). The results of these fruit quality characteristics responded differently to the interactions between the IWT and MF treatments. While the values of fruit weight and yield showed highly significant differences, the values of fruit of marketable ratio were only significantly different, and the values of fruit number/plant and fruit firmness displayed no significant differences. This discloses that combining IWT with MF imposes variable effects on these fruit yield traits of squash plants. However, the best values of these traits were for plants irrigated with MiW yet varied between MF rates of 50 kg ha^{-1} (i.e., fruit weight/plant (Figure 4) and fruit marketable ratio (Fruit 6)) and 100 kg ha^{-1} (i.e., fruit number/plant (Figure 3), yield (Figure 5), and firmness (Figure 7)). This implies that the influence of mixed fish farm effluents on fruit quality traits depends on applied MF rates. However, it is plausible to suggest that fruit weight per plant and fruit marketable ratio are crucially considered the most economical advertised yield traits. Therefore, it may be concluded that MiW type and 50 kg ha^{-1} MF rate are the best treatment giving the utmost profitable fruits. In addition, this treatment provides an advantage in reducing the applied amount of mineral fertilizer inducing further environmental and social benefits.

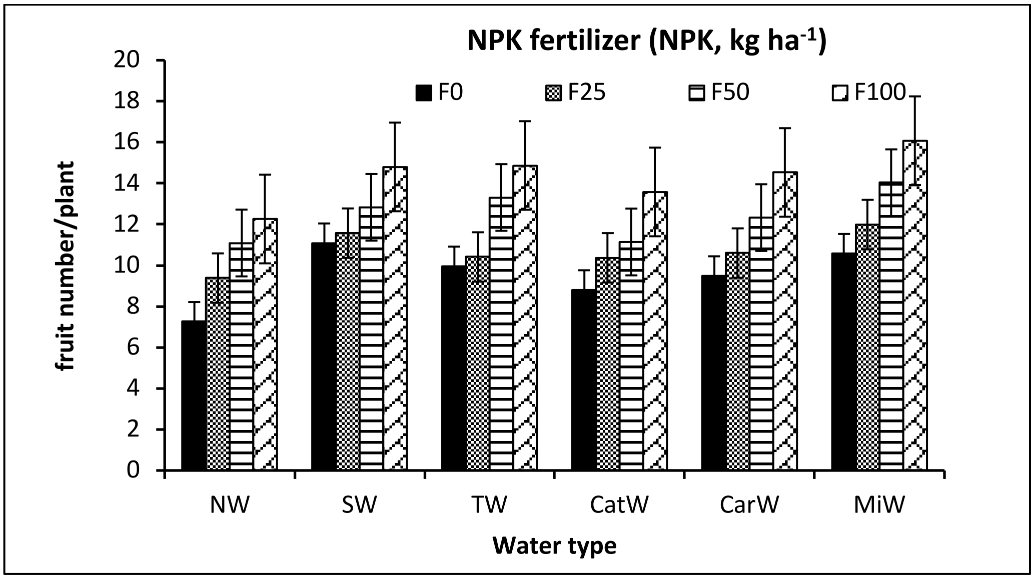

Figure 3: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of fruit number/plant of squash plants**.**

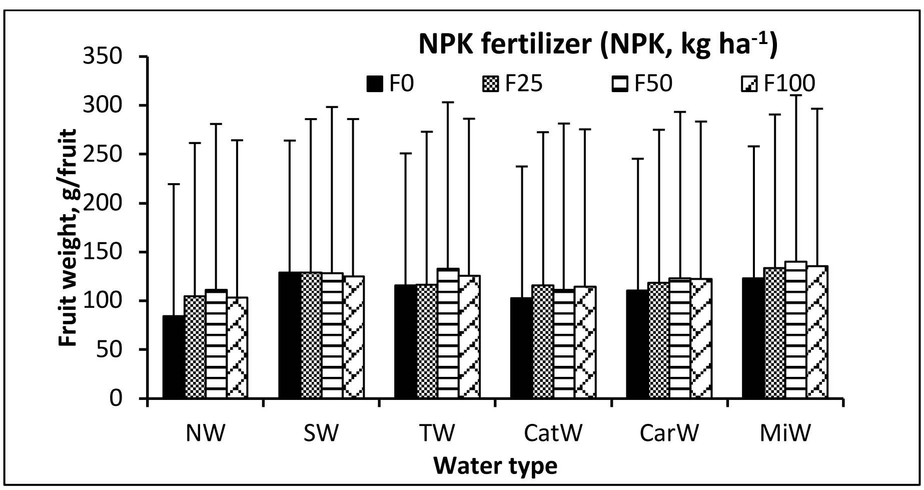

Figure 4: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of fruit weight (g/fruit) of squash plants.

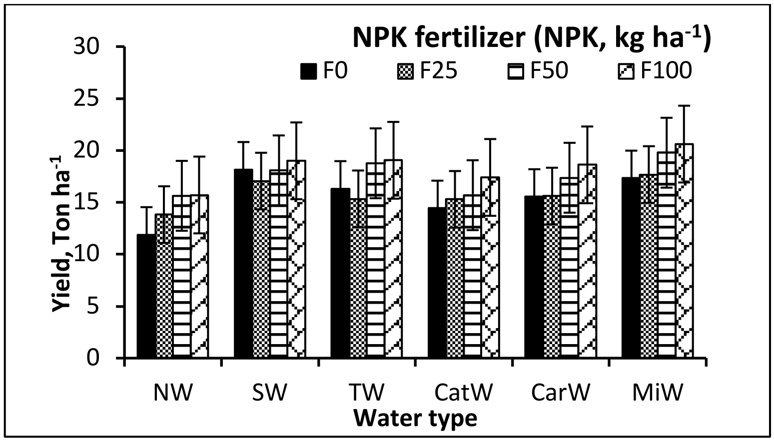

Figure 5: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of yield (ton ha^{-1}) of squash plants.

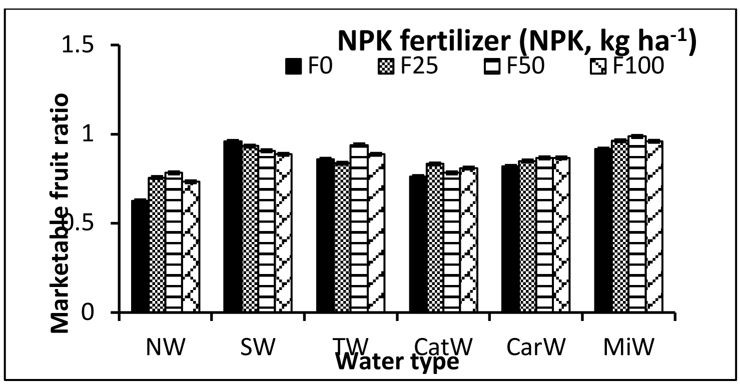

Figure 6: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of fruit marketable ratio of squash plants.

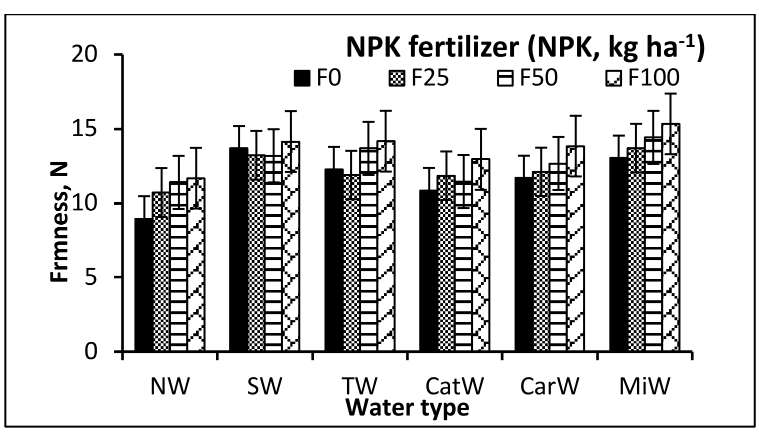

Figure 7: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) of fruit firmness (N) of squash plants.

3.4 Analysis of variance of fruit yield quality traits of squash fruit

Analysis of variance data of the squash fruit quality traits (i.e., total soluble solids (TSS, Brix), total acidity (TA, %), ascorbic acid (AA, %), and acid sugar ratio (ASR)) under the effects of six irrigation water types (IWT), four NPK mineral fertilization rates (MF) treatments and their interaction are summarized in Table 4. The results revealed that there were highly significant differences ($p < 0.01$) between the soluble solids (TSS, Figure 8A), total acidity (TA, Figure 8B), ascorbic acid (AA, Figure 8C), and acid-sugar ratio (ASR, Figure 8D) traits as a result of IWT or MF treatments. In addition, highly significant and significant differences were found in the interaction effects between treatments for the AA and TA properties, respectively. On the other hand, there were no significant differences observed in both TSS and ASR parameters for the study quality of squash fruits (Table 4). This suggests that IWT and MF had variable effects on squash fruit quality parameters.

Table 4: Effects of irrigation water types (IWT) and mineral NPK fertilization rates (MF, kg ha^{-1}) treatments on yield quality traits of squash fruits.

Treatments	Total Soluble Solids (TSS, Brix)	Total Acidity (TA, %)	Ascorbic Acid (AA, mg 100g^{-1})	Acid–Sugar Ratio (ASR)
Irrigation Water Types (IWT)				
NW	8.15^{b}	0.480^{d}	7.469^{b}	9.911^{ab}
SW	8.95^{a}	0.474^{d}	7.193^{c}	10.265^{a}
TW	7.19^{d}	0.493^{bcd}	7.018^{d}	9.236^{b}
CatW	6.98^{e}	0.520^{ab}	7.380^{b}	9.285^{b}
CarW	8.18^{b}	0.513^{abc}	7.476^{b}	9.848^{ab}
MiW	7.88^{c}	0.533^{a}	7.891^{a}	9.089^{b}
LSD0.05	0.074	0.035	0.109	0.850
Probability	<0.0001	<0.001	<0.0001	<0.05
NPK mineral Fertilization (MF) (kg ha^{-1})				
0	7.51^{c}	0.445^{c}	7.000^{c}	9.048^{b}
25	7.65^{b}	0.483^{b}	7.240^{b}	9.012^{b}
50	8.16^{a}	0.511^{b}	7.037^{c}	9.700^{b}
100	8.22^{a}	0.569^{a}	8.336^{a}	10.662^{a}
LSD0.05	0.061	0.028	0.089	0.694
Probability	<0.0001	<0.001	<0.0001	<0.05
Interactions between IWT and MF				
IWT × MF	NS	*	****	NS
LSD0.05	0.104	0.048	0.153	1.201
Probability	>0.05	<0.05	<10^{-4}	>0.05

Notes: Means of treatments in the same column followed by different letters are significantly different at $p < 0.05$. *** and **** indicate significant differences at the 0.001 and 0.0001 levels. NS means insignificant at level $p < 0.05$. $LSD_{0.05}$ refers to the least significant difference at 0.05 level. Pr < 0.05, 10^{-2}, 10^{-3}, and 10^{-4} means the probability of significance.

3.4.1 Effect of irrigation water types (IWT) treatments on yield quality traits of squash plants

The results presented in Table 4 revealed that there are variable significant differences between the values of total soluble solids (TSS, Brix), total acidity (TA, %), ascorbic acid (AA, mg 100 g^{-1}), and acid sugar ratio (ASR) under the various treatments of irrigation water types (NW, SW, TW, CatW, CarW, and MiW). However, the highest values of TA (0.533%), and AA (7.891 mg 100g^{-1}) were obtained under MiW treatment, while the lowest values of both traits (0.474% and 7.018 mg 100g^{-1}) were under the SW and TW types of irrigation water, respectively. Meanwhile, the highest values of TSS (8.95 Brix) and ASR (10.265) were found when plants were irrigated with SW water types and the lowest values of both parameters (6.98 Brix and 9.089) were under irrigation water types of CatW and MiW, respectively. The TA values ranged between 0.474% (SW) and 0.533 % with MiW treatment. AA values varied from 7.018 mg/100g^{-1} under irrigation TW water type to 7.891 mg/100g^{-1} when irrigated with MiW water type. These findings indicate the variable effects of irrigation water types on these characteristics of the studied squash fruit chemical traits.

3.4.2 Effect of mineral NPK fertilization (MF) treatments on yield quality traits of squash plants

Table 4 includes the summary of the values of total soluble solid (TSS, Brix), total acidity (TA, citric acid %), ascorbic acid (AA, mg 100 g^{-1}), and sugar- acid ratio (ASR) of squash fruits because of mineral fertilization various rates (0, 25, 50, and 100 kg NPK ha^{-1}). The data in Table 4 showed that all values of studied fruit chemical parameters increased with increasing applied NPK rates. These values also showed variable significant differences, indicating their unlikely responses to applied mineral NPK fertilization rates. The TSS, TA, and AA values ranged from 7.51 to 8.22 Brix, 0.445 to 0.569%, and 7.000 to 8.336 mg 100g^{-1} at MF application rates of 0 and 100, respectively. Whereas the values of ASR ranged between 9.012 and 10.662 at 25 and 100 MF rates of 25 and 100 kg ha^{-1}. Nonetheless, it ought to indicate that both values of ASR at 0 and 25 kg NPK ha^{-1} rates were insignificantly different (Table 4). Thus, these findings signify the crucial impacts of MF on the studied fruit chemical traits of squash fruits.

3.4.3 The interaction effects between treatments

The interaction effect values of IWT and MF on the chemical components of squash fruits (i.e., total soluble solid (TSS, Brix), total acidity (TA, citric acid %), ascorbic acid (AA, mg 100 g^{-1}), and sugar- acid ratio (ASR)) are outlined in Table 4. The values in the table showed that both AA and TA had significant differences at diverse levels, meanwhile, the TSS and ASR values had no significant differences due to the interactions between IWT and MF treatments (Table 4). It is also observed that the MiW irrigation water type and 100 kg NPK ha^{-1} fertilization rate caused increases of 53.1%, 31.32%, 27.5%, and 17.49% for TSS, TA, AA, and ASR as compared to NW irrigation water type and 0 kg NPK ha^{-1} MF rate (Figures 8A, 8B, 8C, and 8D). These outcomes specify the vital impacts of irrigation with fish farm effluents with MF on the chemical characteristics of growing squash fruits.

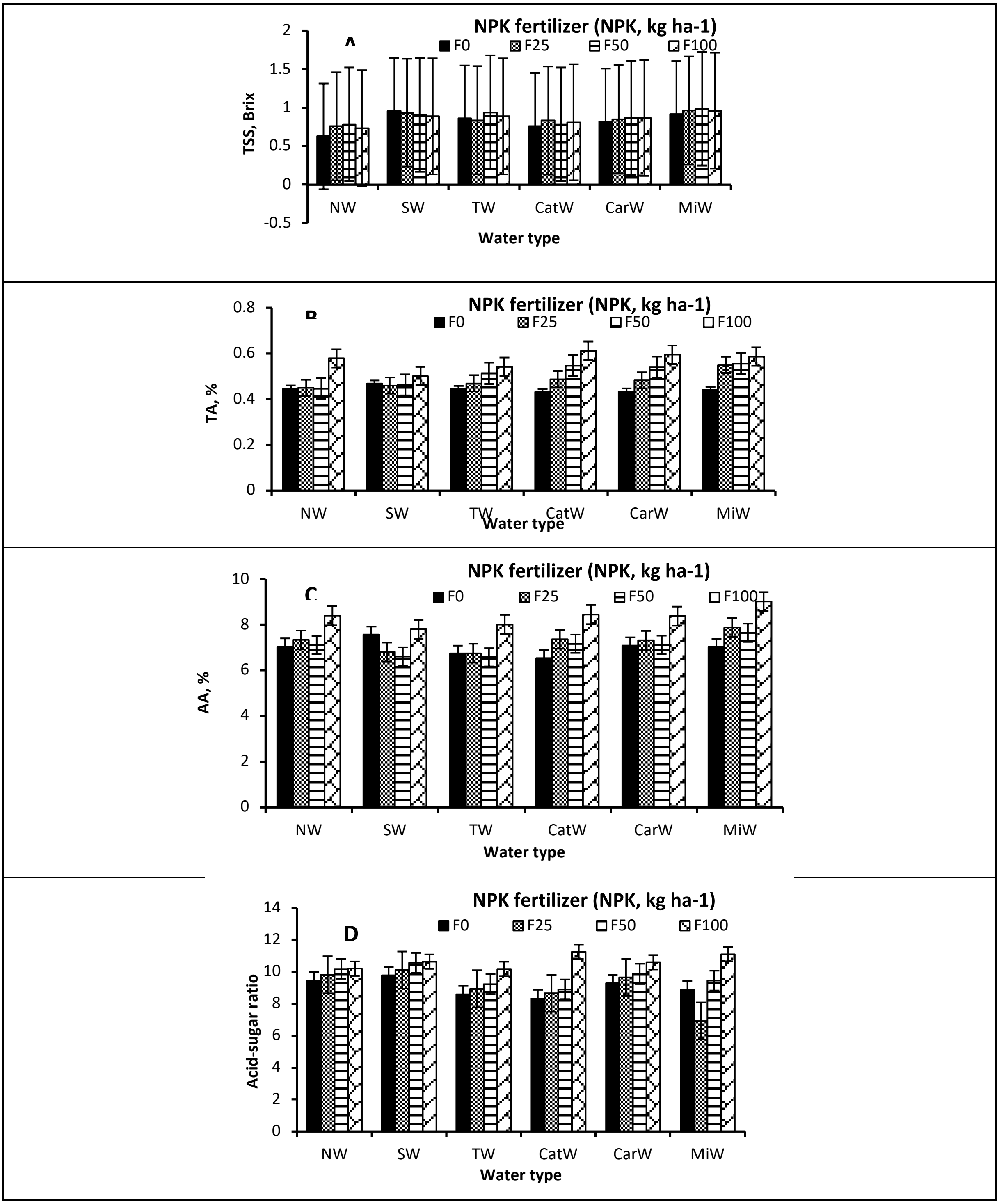

Figure 8: The interaction effects of irrigation water types (IWT) and mineral NPK fertilization (MF) rates of fruit yield quality traits of squash plants.

4. Discussion

Fish farm effluents have been used as non-conventional water resources providing irrigation water to enhance agricultural production. In the current study, squash crop was irrigated with six irrigation water types (IWT) including fish farm effluents (i.e., shrimp (SW), catfish (CatW), carp fish (CarW), tilapia fish (TW), and their mixture (MixW)) and the normal water (NW, as control) as well as fertilized with four rates of mineral NPK fertilizers (i.e., MF, 25, 50, 100 kg ha^{-1}, and 0 kg ha^{-1} as control). The findings of this study showed that all measured traits of cultivated squash growth (plant height, fourth leaf area, and dry leaf weight), yield (fruit no. per plant, fruit weight, yield, fruit marketable ration, and fruit firmness) and yield quality (total soluble solids, total acidity, ascorbic acid, and acid-sugar ratio) had exhibited significant improvements under treatments irrigated with fish farm effluents and applied MF as compared with treatments irrigated with NW and 0 kg NPK ha^{-1}. These obtained results agree with various findings by several investigators (Abdelraouf and Ragab, 2017; Silva et al., 2018; Abdelraouf, 2019; Omeir et al., 2019; Pattillo et al., 2020; Kimera et al., 2021; Cerozi et al., 2022). Thus, the outcomes of this study suggest that these fish farm effluents are a suitable source of irrigation water to enhance the growth of plants and their yield and yield components, ultimately implying they are a feasible alternative irrigation water for areas with scarce water resources, as arid and semi-arid regions.

Water scarcity is a globally critical challenging issue, particularly in arid and semi-arid regions (Döll et al., 2012; Siebert et al., 2010; Schwabe and Connor, 2012; Golla, 2021; Morante-Carballo et al., 2022). It imposes marked pressure on agricultural production adversely affecting food security (Garrido et al., 2005; Siebert et al., 2010; Zhang et al., 2019; Mitter and Schmid, 2021). Therefore, the countries in these regions are obligated to search for alternative water resources from non-conventional supplies to provide irrigation water for agricultural productions (FAO, 2012; Schwabe and Connor, 2012; Golla, 2021; Roldán-Cañas and Moreno-Pérez, 2021; Morante-Carballo et al., 2022; Ingrao et al., 2023).

The KSA is one of the countries sited within these arid and semi-arid regions, and enormously suffers from water scarcity, lacking permanent surface freshwater resources, as lakes and rivers (Gutub et al., 2013; Chowdhury and Al-Zaharani, 2015; MEWA, 2018; Almadini, 2024; Abdella et al., 2024; Arrehedi et al., 2024). The KSA agricultural sector consumes the largest portion of water in the country (Figure 9), which is mainly provided from non-renewable fossil groundwater resources (Al-Ibrahim, 1990; Al-Zahrani and Baig, 2011; Zaharani et al., 2011; Mahmoud and Abdallh, 2013; MEWA, 2018; Ghanim, 2019; Arrehedi et al., 2024; Suhail et al., 2024). These resources have already experienced over-extraction, resulting in a marked decline in their groundwater levels (Al-Ibrahim, 1991; Mahmoud and Abdallh, 2013; Chowdhury and Al-Zaharani, 2015; Almadini, 2024; Suhail et al., 2024). Ghanim (2019) suggested that the sustainable options to cope with the water crisis in the KSA should incorporate two key solutions, which are the amendment of present management practices for available water resources and the optimization of supplies from conventional and non-conventional water sources. In addition, other investigators advocated that planning and implementing friendly green technologies are viable means to sustain groundwater resources in the KSA (Zaharani et al., 2011; Abdella et al., 2024). In the meantime, Quon and Jiang (2023) defined the non-conventional (i.e., alternative) water resources as those systems that sustainably provide water from resources other than fresh surface water and/or groundwater to compensate for and lessen the demands for such freshwaters.

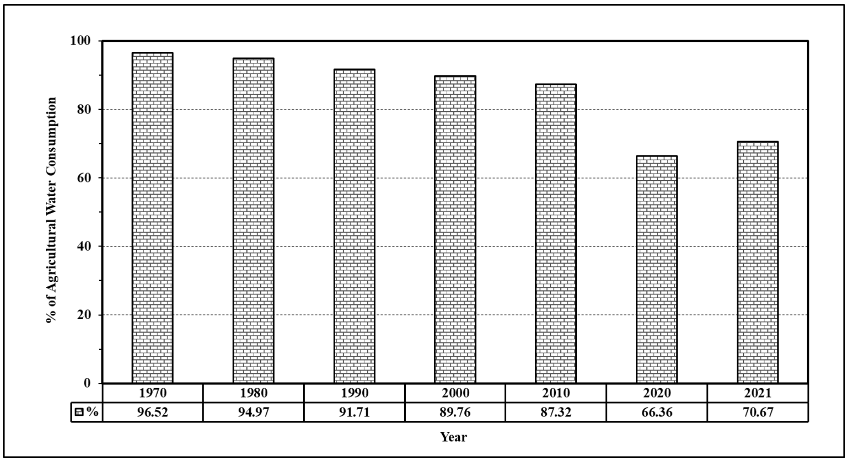

Figure 9: Variations in percentages of KSA agricultural water consumption from the year 1970 to the year 2021 (Suhail et al., 2024).

Furthermore, the findings of the current study showed that the best values of squash growth, yield, and yield quality were generally under treatment irrigated with MiW of IWT and applied MF rate of 50 kg ha^{-1}. This suggests that grown squash plants irrigated with such fish farm effluent require a smaller amount of MF (i.e., 50%) than the maximum applied rate (i.e., 100 kg ha^{-1}). This is likely due to the nutrient contents in such effluent irrigation water (Table 1) that will plausibly compensate for the additional needs of nutrients above the applied rate of 50 kg ha^{-1}. Thus, it is possibly implied from these outcomes that using such fish farm effluents displays environmental, economic, and social advantages by reducing the applied MF. These outcomes thoroughly comply with findings of other studies (Abdelraouf and Ragab, 2017; Islam et al., 2018; Omeir et al., 2019; Rathmore et al., 2019; Pattillo et al., 2020; Singanan, 2020; Kolozsvári et al., 2021; Cerozi et al., 2022; Diatta et al., 2023; Al-Wabel et al., 2024), which concluded that required fertilizers by growing plants irrigated with fish farm effluents were less (i.e., up to 50% of maximum rate) than by plants irrigated with freshwater (i.e., normal water).

In addition, the outcomes of the present study showed that these fish farm effluents are viable water for irrigation, in line with their chemical properties that are within the values of normal ranges of irrigation water as indicated by Ingram (2014) (Table 1). Likewise, other studies observed similar results, implying that such effluents are compatible with irrigation purposes (Mustapha and El Bakali, 2020; Ibrahim et al., 2023a and b; Al-Wabel et al., 2024; Pedrosa et al., 2024). This means that they are a reasonable alternative as a non-conventional irrigation water source to sustain surface and/or underground freshwater, which signifies that their uses in countries with scarce water resources, as the KSA, possess merits to provide irrigation water to enhance agricultural production and hence support food security attainment. Thus, the use of such fish farm effluents in KSA should receive substantial consideration, as the number of fish farm projects of freshwater in the country illustrates an increasing trend in the period between 2012 and 2022, with a growing percentage above 500% (i.e., 5,073 to 30,863, respectively) (Figure 1).

Worldwide, agricultural irrigation is the topmost freshwater-consuming sector with 70% or more depending on climatic conditions (FAO, 2003; UN-Water, 2018). UN-Water (2018) also affirmed that estimated 3.6 billion people are living in potentially water-scarce areas for at least one month annually, with the number projected to reach 5.7 billion by the year 2050. This clarifies that there will be additional demands on freshwater for food production. Numerous studies indicated that agriculture is globally the prime source of agricultural production aiming to achieve food security (FAO, 2003; HLPE, 2016; FAO, 2017; Pawlak and Kołdziejczak, 2020, Zwane, 2020; Erickson and Fausti, 2021; Viana et al., 2022). Therefore, it may be asserted that water is a decisive factor for most of the global food production that is determined by a broad range of agricultural schemes. In summary, the findings of this study however proved that it is trustworthy to investigate the use of fish farm effluents as a non-conventional irrigation water resource to advance food production and hence food security, particularly for countries suffering from lack of permanent freshwater sources.

5. Conclusion

The current investigation achieved its designated aim to evaluate the effects of integrating various irrigation water types (IWT) of fish farm effluents (i.e., shrimp (SW), catfish (CatW), carp fish (CarW), tilapia fish (TW), and their mixture (MixW)) as well as normal well water (NW, control) in presence of different rates of applied mineral NPK fertilizer (i.e., MF, 0 (control), 25, 50, and 100 kg ha^{-1}) on growth, yield, and yield quality traits of squash plants grown in an open field. The obtained data showed that there are significant improvements in all measured plant traits of treatments irrigated with fish farm effluents and fertilized with MF as compared with control treatments. These effluents also contain several essential plant nutrients, that reduce the requirement of applied MF (i.e., 50% of maximum rate). In conclusion, it is possible to suggest that these fish farm effluents are compatible to be used as an alternative non-conventional irrigation water, which will contribute to sustaining the surface and underground freshwater, particularly in water scarce regions, such as the KSA. They also showed some environmental, economic, and social values, resulting from their capability to reduce MF application rates. These fish farm effluents proved their capability to enhance agricultural production contributing to food security achievement. Finally, it is recommended to conduct further investigations to evaluate their impact on other plants and soil health and quality. Also, assessing Saudi farmers' willingness to use these effluents ought to be carried out before generalizing their use. Some agricultural extension programs are well needed aiming to improve the perception of farmers and end users toward their reliable and efficient irrigation water use to replace conventional irrigation freshwater.

6. Conflict of Interest

The authors declare that there is no conflict of interests.

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إضافة مياه صرف المزارع السمكية والسماد المعدني وتأثيرها على نمو، وإنتاجية، وجودة إنتاج نبات الكوسة

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مستخلص. أجريت تجربة حقلية بنظام القطع المنشقة بتصميم الأحواض كاملة العشوائية بثلاث مكررات في محطة التدريب والأبحاث بجامعة الملك فيصل، المملكة العربية السعودية. هدفت التجربة إلى تقييم تأثير تكامل أنواع من مياه ري مختلفة (IWT) تضم مياه صرف مزارع أسماك (جمبري (SW)، قرموط (CatW)، شبوط (CarW)، بلطي (TW)، وخليطها (MiW)) وماء جوفي (NW، شاهد) مع معدلات إضافة مختلفة لسماد معدني مركب NPK (MF)، 0 (شاهد)، 25، 50، و100 كجم هـ$^{-1}$) وذلك على صفات نمو (طول النبات، مساحة الورقة الرابعة، والوزن الجاف للأوراق)، وإنتاج (عدد الفاكهة للنبات، وزن الفاكهة، الناتج، معدل الفاكهة قابلة التسويق، والصلابة)، وجودة إنتاج (المواد الصلبة الكلية القبالة للذوبان، الحموضة الكلية، حمض الأسكوربيك، معدل الحامض للسكر) نبات الكوسة (*Cucurbita pepo* L., c.v. Agro top). خصصت معاملات IWT وMF

للقطاعات الرئيسية والفرعية، توالياً. أشارت النتائج المتحصل عليها إلى وجود فروقات معنوية بين المعاملات وتفاعلاتها. وتفوقت معنوياً المعاملات المروية بمياه صرف مزارع الأسماك والمسمدة بالسماد المعدني على معاملات الشاهد. وعموماً، كانت القيم الأعلى للمعاملات المروية بمياه MiW والمسمدة بمعدل 50 كجم هـ$^{-1}$. تقترح هذه النتائج موثوقية استخدام مياه صرف مزارع الأسماك كمصدر ري غير تقليدي وإلى قيمتها البيئية، والاقتصادية، والاجتماعية. وأن استخدامها كمياه ري سيساهم في تعظيم استدامة المياه السطحية والجوفية العذبة، خاصة في الدول شحيحة مصادر المياه، كالمملكة. كما أن استخدامها سيحسن الإنتاج الزراعي بما يساهم في الأمن الغذائي. في النهاية، التوصية بمزيد من الدراسات لتقييم تأثيرها على محاصيل أخرى وصحة وجودة التربة. كما يلزم عمل بعض برامج الإرشاد الزراعي لتحفيز قبول المزارعين والمستخدمين تجاه مصداقية وفاعلية استخدامها كمياه ري بديلة.

كلمة دالة: مياه صرف مزارع الأسماك؛ نيتروجين–فسفور–كالسيوم؛ الكوسة؛ الإنتاج؛ جودة الإنتاج؛ الري.