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Response of genotypes of (*Hibiscus sabdariffa* L.) to NPK and zeolite fertilizer and their effect on physiological traits and yield

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ABSTRACT

A field experiment was conducted in 2024 at a private farm in the Al-Hor Rajab area, Baghdad Governorate, to evaluate the effect of compound fertilizer and zeolite on the growth, yield, and active compounds of four roselle (*Hibiscus sabdariffa* L.) genotypes: Hit Black, Sudan 3, Areeb, and Hit Red. The treatments included: control (no fertilization), zeolite at a rate of 100 kg ha^{-1}, compound NPK fertilizer (20:20:20) at a rate of 250 kg ha^{-1}, and a combination of both. The experiment was laid out in a two-factor randomized complete block design (RCBD) with three replications (48 experimental units).No significant differences were recorded among the genotypes in the number of days to 50% flowering or full maturity, while significant differences were observed among the treatments. The Hit Black genotype outperformed others in most traits, recording the following values: leaf area index (6.30), total chlorophyll (9.12 mg g^{-1}), dry calyx capsule weight (2.29 g plant^{-1}), and dry calyx yield (683.48 kg ha^{-1}). while Areeb achieved the highest number of seeds per capsule (22.53 seeds capsule^{-1}). The combined NPK fertilizer + zeolite treatment significantly enhanced all studied traits, yielding: days to 50% flowering (162.83 days), days to maturity (182.33 days), leaf area index (6.57), total chlorophyll (10.10 mg g^{-1}), dry capsule weight (2.61 g plant^{-1}), number of seeds per capsule (24.18 seeds capsule^{-1}), and dry calyx yield (799.61 kg ha^{-1}). The interaction between Hit Black and the combined fertilization recorded the highest absolute values, while Sudan 3 with the same treatment recorded the highest number of seeds per capsule (24.46 seeds capsule^{-1}), with no significant difference from Hit Black (24.16 seeds capsule^{-1}) and Areeb (24.30 seeds capsule^{-1}).

KEYWORDS: Roselle; (*Hibiscus sabdariffa* L.); Genotypes; Growth traits; NPK fertilizer; Zeolite.

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استجابة تراكيب وراثية من الكجرات (*Hibiscus sabdariffa* L.) للسماد المركب NPK والزيولايت وأثرهما في الصفات الفسلجية والحاصل

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الملخص

أُجريت تجربة حقلية في عام 2024 في مزرعة خاصة بمنطقة هور رجب، محافظة بغداد، بهدف تقييم تأثير السماد المركب والزيوليت على النمو والحاصل والمركبات الفعالة لأربعة تراكيب وراثية من الكجرات (***Hibiscus sabdariffa* L.**): هيت أسود، سودان 3، عريب، وهيت أحمر. اشتملت المعاملات على: معاملة ضابطة (بدون تسميد)، زيولايت بمعدل 100 كغم هـ$^{-1}$، سماد مركب **NPK** (20:20:20) بمعدل 250 كغم هـ$^{-1}$، والمزيج بينهما. نُفذت التجربة وفق تصميم **RCBD** بعاملين وثلاث مكررات (48 وحدة تجريبية). لم تُسجَّل فروق معنوية بين التراكيب الوراثية في عدد أيام التزهير حتى 50% وعدد أيام النضج الكامل، فيما كانت الفروق معنوية بين المعاملات. تفوق التركيب الوراثي هيت أسود في معظم الصفات، مسجّلًا: دليل المساحة الورقية (6.30)، كلوروفيل **a** (3.75 ملغم غم$^{-1}$)، كلوروفيل كلي (9.12 ملغم غم$^{-1}$)، وزن الجوز الجاف (2.29 غم نبات$^{-1}$)، وحاصل الأوراق الكاسية الجافة (683.48 كغم هـ$^{-1}$). في حين حقق عريب أعلى عدد بذور في الجوزة الواحدة (22.53 بذرة جوزة$^{-1}$). أما معاملة السماد المركب **NPK** + زيولايت فقد تميزت بتحسين جميع الصفات معنويًا، حيث بلغت: عدد أيام التزهير حتى 50% (162.83 يوم)، عدد أيام النضج (182.33 يوم)، دليل المساحة الوراقة (6.57)، كلوروفيل كلي (10.10 ملغم غم)، وزن الجوز الجاف (2.61 غم نبات$^{-1}$)، عدد البذور في الجوزة (24.18 بذرة جوزة$^{-1}$)، وحاصل الأوراق الكاسية (799.61 كغم هـ$^{-1}$). أظهر التداخل بين هيت أسود والتسميد المزدوج أعلى القيم المطلقة، بينما سجل سودان 3 مع نفس المعاملة أعلى قيمة عدد بذور (24.46 بذرة جوزة$^{-1}$) دون اختلاف معنوي عن هيت أسود (24.16 بذرة جوزة$^{-1}$) وعريب (24.30 بذرة جوزة$^{-1}$).

الكلمات المفتاحية: الكجرات، النمو؛ ***Hibiscus sabdariffa* L.**؛ التراكيب الوراثية؛ صفات النمو؛ الزيولايت.

INTRODUCTION

Roselle (*Hibiscus sabdariffa* L.) is a medicinal and aromatic plant belonging to the Malvaceae

family. It is naturally adapted to tropical and subtropical climates and is widely valued for its nutritional, pharmaceutical, and economic importance. The plant's calyces are rich in bioactive compounds, especially glycosides, among which hibiscin is prominent for its therapeutic functions such as enhancing cardiac activity, reducing blood viscosity, regulating the nervous system, relieving gastrointestinal disorders, lowering cholesterol levels, aiding in weight reduction, and acting as a potent antioxidant with anti-cancer and hepatoprotective properties (Almajid *et al*., 2023). In Iraq, it is known as "Karkadeh" or "Kajarat," and its cultivation is increasingly expanding in semi-arid areas.

Genetic variation plays a critical role in the agronomic and biochemical performance of roselle. Different genotypes show varying degrees of adaptability, growth characteristics, and ability to synthesize active compounds under different environmental conditions. Assessing the response of genotypes under specific agronomic treatments provides a foundation for selecting superior lines that combine both high yield and bioactive compound accumulation. According to Khalil *et al*. (2021), selecting high-performing genotypes can significantly improve productivity, stress tolerance, and therapeutic compound content, especially in dry or nutrient-deficient soils.

Fertilization is another major factor affecting plant growth and yield. Compound NPK fertilizer provides essential macronutrients—nitrogen (N), phosphorus (P), and potassium (K)—which are directly involved in physiological processes such as chlorophyll formation, root development, energy transfer, and enzyme activation. Several studies reported that the application of NPK at rates ranging from 100 to 200 kg ha^{-1} enhances vegetative traits like plant height, leaf number, and biomass, which in turn improve the overall productivity of medicinal plants, including roselle (Al-Sayed *et al*., 2019; Rahman *et al*., 2017).

In addition to macronutrients, natural soil amendments like zeolite have gained attention for their ability to improve soil physical and chemical properties. Zeolite, a crystalline aluminosilicate, increases soil cation exchange capacity (CEC), enhances moisture retention, and reduces leaching of nutrients. These characteristics help maintain nutrient availability over time and improve fertilizer efficiency. Farooq *et al*. (2009) demonstrated that using zeolite at rates between 5 and 10 tons ha^{-1} improved the physiological performance of various crops by enhancing nutrient uptake, stress tolerance, and antioxidant enzyme activity. Furthermore, its ability to release potassium, calcium, and magnesium gradually supports vital processes such as photosynthesis, osmotic regulation, and reproductive development.

Therefore, this study aims to evaluate the response of different roselle genotypes to compound NPK fertilizer and zeolite under field conditions, focusing on their effects on physiological traits and yield. The outcomes are expected to provide insights into optimizing agronomic practices for this

valuable medicinal crop under semi-arid environments.

MATERIALS AND METHODS

A field experiment was conducted during the 2024 agricultural season on a private farm located in the Hor Rijab area, within the '5 Dunum' region of Baghdad Governorate, approximately 18 km south of the city center. The site selection was based on the chemical and physical properties of the soil in the area, as described by Khairo.(2024)

Table 1. Chemical and physical properties of the experimental soil

Soil Texture	**Sandy Loam**
Clay (%)	2.0
Silt (%)	41.6
Sand (%)	56.4
Properties	
Organic Matter (O.M) (%)	1.42
$CaCO_3$ (%)	22.5
Potassium (K) ppm	326.0
Phosphorus (P) ppm	6.0
Nitrogen (N) ppm	38.5
pH (1:1)	7.55
EC (1:1) Dc/cm^{-1}	4.88

field experiment was conducted during the 2024 growing season using a randomized complete block design (RCBD) with a factorial arrangement and three replications. The first factor consisted of four hibiscus (*Hibiscus sabdariffa* L.) genotypes: Black Heet, Sudan 3, Areb, and Red Heet. The second factor consisted of four fertilizer treatments: control, 250 kg/ha-1 of NPK (20:20:20), 100 kg/ha-1 of zeolite, and a combined treatment of NPK with zeolite, following the methodology described in. The seeds used in the study were obtained from the Department of Field Crops, College of Agriculture, Tikrit University.

The experimental site, covering an area of 288 m² (6 × 48 m), was divided into 48 plots, each 6 m² (3 × 2 m). Each plot consisted of six rows spaced 50 cm apart, with five plants per row and 50 cm between plants. Sowing was carried out on April 25, 2024, at a density of 2–3 seeds per hole, which was subsequently thinned to one plant per hole after the plants reached 15 cm in height. Weed control was carried out manually when necessary. Irrigation was applied evenly across all plots through a surface flooding system using one main channel and three sub-channels. Vegetative growth traits and yield components were measured during different growth stages of hibiscus (*Hibiscus sabdariffa* L.). The number of days from sowing to 50% flowering and the number of days from

sowing to full maturity were recorded. Total chlorophyll content was measured, and yield-related traits were evaluated. The dry capsule weight and number of seeds per capsule were recorded, and the total dry yield per cup was calculated. The experiment was analyzed as a factorial experiment using a randomized complete block design (R.C.B.D), and trial means were compared according to Duncan's multiple range test at the 0.05 probability level using SAS software.

RESULTS AND DISCUSSION

The analysis of variance for this trait showed no significant differences among the roselle (*Hibiscus sabdariffa* L.) genotypes. However, Table (2) indicates significant differences among genotypes under the fertilization treatment of NPK at 250 kg ha^{-1} combined with zeolite at 100 kg ha^{-1}. The control treatment (no fertilization) recorded the lowest number of days to reach this stage, with a mean of 151.16 days, which was not significantly different from the zeolite-only treatment (154.16 days) or the NPK-only treatment (152.50 days). In contrast, the combined treatment (NPK 250 kg ha^{-1} + zeolite 100 kg ha^{-1}) showed the highest mean value for this trait, reaching 162.83 days.

The interaction effect was significant for the number of days to 50% flowering among the genotypes. The Hit Black genotype recorded the longest duration to reach this stage (165.66 days) under the combined NPK and zeolite treatment, while the Hit Red genotype under the control treatment (no fertilization) recorded the shortest duration (145.00 days) These results are consistent with the findings of studies that reported significant effects of genotypes on this trait (Wachamo & Gessese, 2022).

The superiority of NPK + zeolite treatment can be attributed to the essential role of macronutrients in plant biosynthesis processes, and their importance in regulating enzyme activity, proteins, nucleic acids, chlorophyll formation, and energy transfer. Furthermore, zeolite improves natural soil properties, increases nutrient availability, and enhances their uptake by plants. Deficiencies of these elements lead to delayed plant growth, small size, few branches, and yellowing of leaves, as confirmed by Abu Dahi and Al-Younis (1988) and (Elayan *et al*., 2015).

Table 2. Effect of Genotypes, NPK fertilization, and zeolite on Days to 50% Flowering

Fertilization (kg h^{-1})	**Genotypes**				**Average of Treatments**
	Hit Black	**Sudan 3**	**Areb**	**Hit Red**	
Control	154.66 c-f	150.33 e-g	154.66 c-f	145.00 g	151.16 b
Zeolite(100)	148.66 eg	157.66 b-d	154.00 c-f	156.33 b-e	154.16 b
NPK(250)	152.33 d-f	152.66 d-f	150.00 e-g	155.00 c-f	152.50 b
Zeolite + NPK (100+250)	165.66 a	160.33 a-c	162.66 ab	162.66 ab	162.83 a
Average genotypes	155.33 a	155.25 a	155.33 a	154.75 a	

At 5% of DMRT, means with the same litters for each factor and interaction do not differ significantly

The Table (3), showed the fertilization factor had a significant effect on the number of days to maturity. The control treatment (without fertilization) recorded the lowest number of days to reach this stage, with a mean of 170.91 days, compared to the fourth treatment (NPK at 250 kg ha^{-1} + zeolite at 100 kg ha^{-1}), which recorded the highest mean of 182.33 days.

The interaction between genotypes and the fourth fertilization treatment (NPK 250 kg ha^{-1} + zeolite 100 kg ha^{-1}) had a significant effect on this trait. The Hit Red genotype under the control treatment (no fertilization) recorded the shortest time to maturity, with 163.66 days, while the Hit Black genotype under the fourth treatment recorded the longest duration, reaching 186.33 days.

The superiority of the fourth treatment in delaying maturity may be due to the longer time required to reach 50% flowering, which prolongs the overall growth period. The effect of NPK and zeolite in delaying maturity is attributed to their role in improving nutrient availability and environmental conditions surrounding the roots. Compound fertilizer provides essential elements (NPK) in balanced quantities, which promotes vegetative growth and accelerates the physiological growth stages. In turn, zeolite improves the physical and chemical properties of the soil, enhances the efficiency of nutrient absorption, and reduces nutrient loss, supporting balanced plant growth (Abdul Falih *et al*., 2024) .

Table 3. Effect of Genotypes, NPK Fertilization, and Zeolite on Days from Planting to Maturity

Fertilization (kg h^{-1})	**Genotypes**				**Average of Treatments**
	Hit Black	**Sudan 3**	**Areb**	**Hit Red**	
Control	175.00 b-e	171.33 d-f	173.66 c-e	163.66 f	170.91 a
Zeolite(100)	171.33 d-f	173.66 c-e	173.66 c-e	177.66 b-e	174.08 a
NPK(250)	169.33 ef	177.00 b-e	172.00 de	173.66 c-e	173.00 a
Zeolite + NPK (100+250)	186.33 a	178.66 a-d	182.33 ab	182.00 a-c	182.33 a
Average genotypes	175.50 a	175.16 a	175.41 a	174.25 a	

The results shown in the Table (4) indicated that there were significant differences in the average leaf area index (LAI) due to the effects of genotype, fertilization with compound fertilizer, and zeolite. The genotype "Heat Black" recorded the highest average value, 6.30, compared to the genotype "Sudan 3", which showed the lowest average value, 6.05. Fertilization levels also had a significant effect on the average leaf area, as the combined application of NPK fertilizer (250 kg/ha) and zeolite (100 kg/ha) resulted in the highest average value, 6.57, while the control treatment (without fertilization) recorded the lowest average value, 5.70. The interaction between genotypes and fertilizer showed a significant effect, with both genotypes "Hit Black" and "Areib" under the combined fertilization treatment (NPK 250 kg ha^{-1} + zeolite 100 kg ha^{-1}) recording the highest leaf

area index (LAI) value of 6.61. These values did not differ significantly from other genotypes under the same treatment. On the other hand, the genotype "Hit Red" under the control treatment recorded the lowest LAI value of 5.54. LAI plays a significant role as the plant grows, indicating that the combination of the combined fertilizer and zeolite was more responsive than the other treatments. This was reflected in an increase in LAI, consistent with the results of Fahmy and Hassan.(2019)

Table 4. Effect of Genotypes, NPK fertilization, and zeolite on leaf area index

Fertilization (kg h^{-1})	Genotypes				Average of Treatments
	Hit Black	Sudan 3	Areb	Hit Red	
Control	5.86 d-g	5.74 e-g	5.67 fg	5.54 g	5.70 d
Zeolite(100)	6.31 bc	5.82 d-g	6.21 b-d	5.73 e-g	6.02 c
NPK(250)	6.42 a-c	6.07 c-f	6.13 c-e	6.82 a	6.36 b
Zeolite + NPK (100+250)	6.61 ab	6.58 ab	6.61 ab	6.48 a-c	6.57 a
Average genotypes	6.30 a	6.05 b	6.16 ab	6.14 ab	

The data shown in Table (5) indicated that there were no significant differences between the two genotypes 'Hit Black'. and 'Hit Red' in terms of total chlorophyll content, as both recorded the highest values, reaching a mean of 9.12 mg g^{-1} fresh leaf tissue, with no significant difference between them. In contrast, the 'Sudan 3' genotype recorded the lowest mean value of 8.29 mg g^{-1} fresh leaf tissue. The same table also revealed significant differences in total chlorophyll content due to fertilization treatments. The combined application of NPK (250 kg ha^{-1}) and zeolite (100 kg ha^{-1}) recorded the highest mean value of 10.10 mg g^{-1}, whereas the control treatment (no fertilization) gave the lowest value of 7.29 mg g^{-1}.

The interaction between genotypes and the combined fertilization treatment also showed significant effects, although the differences among genotypes within this treatment were not significant. All

genotypes under the combined NPK + zeolite treatment recorded higher chlorophyll content values. The 'Hit Black' genotype under this treatment showed the highest value of 10.21 mg g^{-1} fresh tissue, while the 'Sudan 3' genotype under the control treatment recorded the lowest value of 5.75 mg g^{-1}.

The increase in chlorophyll content in leaves This is due to genetic differences between genotypes, with 'Hit Black' generally exhibiting superior vegetative growth traits. These combined factors likely contributed to the increased chlorophyll content. The compound fertilizers, containing nitrogen, phosphorus, and potassium, provide a favorable environment for plant development. The

availability of these nutrients in adequate amounts enhances nutrient uptake, regulates plant nutrition, and increases chlorophyll synthesis. this finding is consistent with Ghabour *et al*. (2022), who studied the chemical properties of *Hibiscus sabdariffa* L. under different levels (25%, 50%, and 100%) of recommended mineral fertilizers in various soil types and found that nutrient availability significantly increased chlorophyll content and plant metabolism.

Furthermore, the interaction between NPK and zeolite plays a crucial role in nutrient availability. While NPK fertilizers supply essential macronutrients for balanced plant growth, zeolite improves nutrient retention and water-holding capacity due to its porous structure. It also facilitates the gradual release of nutrients and enhances root-zone moisture, particularly under drought conditions. Zeolite's ability to adsorb and slowly release both macro- and micronutrients has proven beneficial for sustainable agriculture, as confirmed by Cataldo *et al*. (2021), who highlighted the potential agricultural applications of natural zeolite and its role in improving agroecosystem sustainability .

Table 5. Effect of genotypes, NPK fertilization, and zeolite on leaf total chlorophyll content (mg g^{-1} leaf tissue)

Fertilization (kg h^{-1})	Genotypes				Average of Treatments
	Hit Black	Sudan 3	Areb	Hit Red	
Control	7.74 e	5.75 f	7.70 e	7.97 e	7.29 d
Zeolite(100)	8.94 d	8.06 e	8.00 e	8.74 d	8.44 c
NPK(250)	9.58 bc	9.41 c	9.64 bc	9.57 c	9.55 b
Zeolite + NPK (100+250)	10.21 a	9.93 ab	10.08 a	10.20 a	10.10 a
Average genotypes	9.12 a	8.29 c	8.85 b	9.12 a	

The results presented in Table (6) indicate significant differences among the studied factors. A significant effect was observed among genotypes, with the 'Hit Black' genotype recording the highest average dry calyx weight per capsule (2.29 g), while the 'Hit Red' genotype recorded the lowest (2.18 g). The superiority of some genotypes over others is likely due to genetic factors that are less influenced by environmental conditions.

A significant interaction was observed between compound fertilizers and zeolite, with the Sudan 3 genotype in the eighth treatment (genotype × fertilizer interaction) recording the highest pod dry weight of 2.78 g pod^{-1}. This value did not differ significantly from that of the Heat Black genotype, which recorded 2.68 g pod^{-1}. In contrast, the Heat Red genotype in the control treatment (without fertilization) showed the lowest value of 1.73 g pod^{-1}. The superiority of the compound

fertilizer/zeolite interaction in affecting this trait is attributed to the role of NPK fertilizers in enhancing the plant's efficiency in absorbing water and nutrients, with nitrogen playing a crucial role in this process. Phosphorus plays a role in stimulating and encouraging the growth of fibrous and adventitious roots, in addition to increasing flower and fruit development, as confirmed by (Al-Enzy *et al*. 2024). This combination also proved superior in promoting vegetative growth and improving physiological traits, which positively impacted the increase in dry pod weight. The improved capsule weight resulting from the addition of zeolite is attributed to its physiological role in improving soil properties and increasing the availability of nutrients and water, which improves photosynthetic efficiency and stimulates the production of plant hormones responsible for growth and fruit formation. These effects contribute positively to the accumulation of dry matter in the capsules and their weight increase. This was confirmed by the results of Faleh *et al*. (2024), who highlighted the positive effects of zeolite on the growth and productivity of hibiscus by improving root zone conditions and nutrient uptake. Al-Jumaili and Al-Mohammadi (2023) revealed that the hot black color was prevalent in most of the studied traits in hibiscus.

Table 6. Effect of Genotypes, NPK fertilization, and zeolite on dry nut weight (g capsule^{-1})

Fertilization (kg h^{-1})	Genotypes				Average of Treatments
	Hit Black	**Sudan 3**	**Areb**	**Hit Red**	
Control	1.90 hi	1.93 f-h	1.91 g-i	1.73 i	1.86 d
Zeolite(100)	2.13 ef	2.10 e-g	2.16 de	2.07 e-h	2.12 c
NPK(250)	2.46 c	2.34 cd	2.37 c	2.43 c	2.40 b
Zeolite + NPK (100+250)	2.68 ab	2.78 a	2.46 e-h	2.50 bc	2.61 a
Average genotypes	2.29 a	2.28 b	2.22 ab	2.18 b	

The results presented in Table (7) revealed significant differences among genotypes for this trait. The ‘Areb’ genotype recorded the highest average number of seeds per capsule (22.53), without a significant difference from ‘Hit Black’ (22.42). ‘Hit Red’ (21.77) recorded the lowest value. This superiority may be attributed to the higher efficiency of ‘Areb’ and ‘Hit Black’ in converting photosynthetic products into assimilates transferred to the capsules and seeds. Notably, ‘Hit Black’ excelled in most vegetative growth traits, contributing to increased assimilate accumulation and seed number. The fertilization treatment with NPK (250 kg ha^{-1}) combined with zeolite (100 kg ha^{-1}) had a significant effect, recording the highest mean (24.18 seeds capsule^{-1}), while the control treatment gave the lowest (20.25 seeds capsule^{-1}). Furthermore, under the combined treatment, the genotypes ‘Hit Black’, ‘Areb’, and ‘Sudan 3’ did not significantly differ, with ‘‘Sudan 3’ recording the highest value (24.46 seeds capsule^{-1}). The lowest was noted for ‘Areb’ under the control treatment (19.80

seeds capsule^{-1}). The improved seed number can be attributed to the role of NPK fertilizers—nitrogen being essential in synthesizing proteins, enzymes, nucleic acids, and chlorophyll, while potassium regulates stomatal function. Zeolite also enhanced nutrient availability, particularly phosphorus, which is crucial for flower formation and ovule development. Additionally, its ability to retain soil moisture and balance plant hormones (e.g., gibberellins and cytokinins) stimulated reproductive tissue growth, promoting fertilization and seed formation. Who reported that zeolite positively influenced the reproductive traits of roselle (*Hibiscus sabdariffa* L) (Fleih *et al*. 2024).

Table 7. Effect of Genotypes, NPK fertilization, and zeolite on the number of seeds per nut (seeds capsule^{-1})

Fertilization (kg h^{-1})	Genotypes				Average of Treatments
	Hit Black	**Sudan 3**	**Areb**	**Hit Red**	
Control	20.80 fg	20.46 fg	19.80 g	19.96fg	20.25 d
Zeolite(100)	22.06 de	21.10 ef	22.46 cd	20.75 g	21.59 c
NPK(250)	22.66 cd	22.86 b-d	23.56 a-c	22.6 cd	22.92 b
Zeolite + NPK (100+250)	24.16 a	24.46 a	24.30 a	23.80 ab	24.18 a
Average genotypes	22.42 a	22.22 ab	22.53 a	21.77 b	

The results in Table (8) showed significant differences among the study factors and their two-way interactions. The genotype ‘Hit Black’ recorded the highest mean calyx yield (683.48 kg ha^{-1}), without significant difference from ‘Sudan 3’ (665.85 kg ha^{-1}). The lowest mean was recorded by ‘Areb’ (648.30 kg ha^{-1}), which did not significantly differ from ‘Hit Red’ (655.26 kg ha^{-1}). The superiority of 'Hit Black' and 'Sudan 3' in this trait can be attributed to their genetic potential and superior performance in vegetative and production-related traits, such as dry capsule weight and number of seeds per capsule Table (6-7) , which positively affected calyx yield. Fertilization treatments involving NPK and zeolite significantly improved calyx yield. The combined application of NPK (250 kg ha^{-1}) and zeolite (100 kg ha^{-1}) recorded the highest mean value of 799.61 kg ha^{-1}, whereas the control treatment (no fertilization) recorded the lowest value of 586.55 kg ha^{-1}. In the two-way interaction between genotypes and fertilization, the ‘Hit Black’ genotype under the combined treatment (NPK + zeolite) showed the highest calyx yield (863.07 kg ha^{-1}), while the ‘Areb’ genotype under the control treatment recorded the lowest value (563.47 kg ha^{-1}). The positive effect of NPK is attributed to its essential role in plant growth by supplying major nutrients, enhancing nutrient uptake, and increasing their internal concentration in plant tissues. These nutrients are crucial for energy production, protein synthesis, vegetative growth, and improving carbon assimilation and cell division. Zeolite contributed to the improvement in dry calyx yield by enhancing the rhizosphere environment due to its high cation exchange capacity and ability to retain moisture and nutrients over

time. This ensured a consistent and balanced supply of macro- and micronutrients, especially nitrogen, which is vital for protein and chlorophyll synthesis, thereby boosting photosynthetic efficiency. This enhanced nutritional and moisture status promoted vegetative growth through increased cell division and elongation, which in turn increased the plant's ability to synthesize and accumulate dry matter. Additionally, zeolite improved water balance and enzymatic activity in the plant, reducing environmental stress and increasing net photosynthetic rate, ultimately resulting in heavier and drier calyces at harvest. Rahmani *et al* (2023).

Table 8. Effect of genetic compositions, NPK fertilization, and zeolite on the yield of anther leaves (kg ha^{-1})

Fertilization (kg h^{-1})	Genotypes				Average of Treatments
	Hit Black	Sudan 3	Areb	Hit Red	
Control	585.20 ef	581.67 ef	563.47 f	615.87 de	586.55 d
Zeolite(100)	587.40 ef	622.30 de	585.60 ef	637.30 d	608.15 c
NPK(250)	698.27 c	630.77 c	627.10 de	678.20 c	658.58 b
Zeolite + NPK (100+250)	863.07 a	828.67 ab	817.03 b	689.70 c	799.61 a
Average genotypes	683.48 a	665.85 a	648.30 b	655.26 b	

CONCLUSION:

The results showed significant differences between genotypes for all studied traits, with the "Hit Black" genotype showing superiority in vegetative growth characteristics and yield components. Fertilization with compound fertilizer and zeolite (NPK at 250 kg/ha-1 + zeolite at 100 kg/ha-1) resulted in significant increases in the number of days from planting to 50% flowering, the number of days to maturity, leaf area index, total chlorophyll (a + b) content in leaves, the number of seeds per capsule, capsule dry weight, and total anther yield. The interaction between the "Hit Black" genotype and fertilizer treatment recorded the highest values for all studied traits.

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