International Journal of Biological Engineering and Agriculture
ISSN: 2833-5376
Volume 06 Number 01 (2027)
Impact Factor: 9.51
SJIF (2023): 3.916

www.inter-publishing.com

Article

Effect of Wheat Residue Management and Mycorrhizal Biofertilization on the Growth and Yield of Three Sunflower (*Helianthus annuus L.*) Varieties

Atheer Saber Mustafa[1], Manal Ali Marai[2], Wesam Hamad Hassuein Al-jubory[3]

1. Field Crops Department, College of Agriculture, Tikrit University
2. Field Crops Department, College of Agriculture, Tikrit University
3. Field Crops Department, College of Agriculture, Tikrit University

* Correspondence: atheragriculture@tu.edu.iq, manal_ali@tu.edu.iq, wesam_hamad@tu.edu.iq

Abstract: The experiment was conducted in Salah al-Din Governorate – Samarra District – Al-Mu'tasim Sub-district during the 2024 summer growing season to study the effect of wheat residue management (leaving, removing, burning) and mycorrhizal biopollination (no pollination) using three sunflower varieties (Aqmar, Flami, and Kuban). A randomized complete block design (RCBD) with three replications was employed. The results showed that the residue burning treatment resulted in a significant advantage in most of the studied traits. Plant height reached 198.1 cm, dry weight 46.40 g plant^{-1}, grain yield 6297 kg ha^{-1}, and bio-yield 17920 kg ha^{-1}. Oil concentration also increased to 36.89%, and protein concentration to 27.71%. Mycorrhizal inoculation also showed a clear positive effect on improving vegetative characteristics, yield, and its components. The inoculation values reached (193.5 cm plant height, 42.96 g plant^{-1} dry weight, 5655 kg ha^{-1} grain yield). The results for the varieties showed the superiority of the Kuban variety in most characteristics, with an average grain yield of (5870 kg ha^{-1}), a biological yield of (16429 kg ha^{-1}), and an oil concentration of (35.17%). Meanwhile, the Aqmar variety outperformed others and recorded the highest protein concentration at (26.31%). Significant differences were found between the two-way and three-way inoculations. The treatment combining crop residue burning + mycorrhizal inoculation + Kuban variety recorded the highest values for all traits (plant height 198.6 cm, dry weight 50 g plant^{-1}, grain yield 7154 kg ha^{-1}, biological yield 20991 kg ha^{-1}, oil 39.97%, protein 30.03%), while the lowest values were recorded in the treatment combining crop residue removal + no inoculation + moons. The results show that the combination of wheat residue burning, mycorrhizal inoculation, and the selection of the Kuban variety represents the best treatment for increasing growth and yield.

Keywords: Wheat residues, biofertilizer, mycorrhizae, sunflower

Citation: Mustafa, A. S, Marai, M. A, Al-jubory, W. H. H. Effect of Wheat Residue Management and Mycorrhizal Biofertilization on the Growth and Yield of Three Sunflower (*Helianthus annuus L.*) Varieties. International Journal of Biological Engineering and Agriculture 2027, 6(1), 1-16

Received: 13th Aug 2026
Revised: 28th Sep 2026
Accepted: 15th Oct 2026
Published: 05th Nov 2026

Copyright: © 2027 by the authors. Submitted for open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/)

1. Introduction

Sunflower is an oilseed crop of immense nutritional and industrial/value composition, having seeds rich in proteins and oils and important minerals. The protein content may reach 33% and fat 50% and the seeds also contain essential fatty acids such as oleic and linoleic acids. These are linked with better cholesterol levels and heart health, along with antioxidants, vitamin E, and minerals such as zinc and copper [1].

Writing from the angle of genetics & agriculture, sunflower varieties display high genetic diversity; studies using genomic indicators - SSR, ISSR or phenotypic assessment of different varieties display large variability in yield parameters, oil content, and seed size these demonstrate the need to select the appropriate variety and right environment to stabilize performance and quality [2]

Agricultural waste management promotes environmental and agricultural sustainability that enhances soil's fertility and improves microbial activity in the soil. This management is variable according to method used with previous crop residues; e.g. residues can be left on the soil surface to mulch, reducing evaporation and erosion and improving soil structure. In some areas, removal of vegetation for agriculture or industrial use, or even burning is still common despite it being bad for the environment. Due to the exertion of different damage, these methods affect soil organic matter content and microbial activity, biological processes and nutrient cycling. [3]

Fires in agricultural fields are one of the most common practices worldwide. It has a double effect. There is a loss of carbon and nitrogen due to their volatilization in the form of gases (CO_2, N_2O). This contributes to the greenhouse effect. On the other hand, it favours the decomposition of organic matters and their turnover into ash which is rich in readily available mineral elements [4]. Burning can also temporarily sterilise the soil, which will allow beneficial microorganisms to flourish upon the addition of organic or biofertilisers due to no predators. In contrast, retaining the residues on the soil surface has important environmental and agricultural benefits, such as retaining moisture in the soils, increasing the organic content of the soil and facilitating the activity of microorganisms. As a result, growth and productivity improve. The research found that the management of wheat residue affected the growth and yield of sunflower. Specifically, the treatment without the residue left was higher than the burning treatment, while the best performing treatment was burning with the addition of organic fertilizer. This was due to the interaction of microorganisms with the sterilized soil and the improvement of its environment [5].

Mycorrhizal biofertilization is one of the most modern approaches in sustainable agriculture because these fungi are responsible for increasing the availability of phosphorus and macro and micro elements by means of the secretion of organic acids and enzymes that dissolve insoluble compounds. It also broadens the scope of root absorption. Moreover, the appearance of the Trichoderma fungus in some biological preparations means the addition of one more essential component that promotes resistance to root pathogens and stimulates growth by the secretion of natural growth regulators [6].

The integration of agricultural waste management with biofertilization, along with the variability of certain sunflower varieties, seems to be an optimistic alternative to improving soil properties and plant growth in arid or semi-arid regions for the sustainable cultivation of strategic crops such as sunflowers. Given this, the present research intends to study the effect of wheat residue management and mycorrhizal biofertilization on growth and yield of three sunflower varieties.

2. Materials and Methods

Study Factors

The first factor (waste management) consisted of three measures, comprising of waste leaving and turning into the soil, waste removal and waste burning and turning into the soil.

The second factor (biofertilization) consisted of two treatments: no inoculation, as well as inoculation with the bio-product Bio Green Mycorrhizae.

Three types: The third factor (flower varieties) included three types: Aqmar, Flami, and Kuban.

Number of treatments = 3 × 2 × 3

Number of treatments = 18

Each treatment was repeated 3 times

Number of experimental units = 54 experimental units

Implementation of the Experiment

The site for the experiment was chosen before the commencement of field operations. This is a newly harvested field that has been grown with wheat. The straw mass calculation tests per ton were measured using a wooden frame measuring 1 m, with the straw mass per hectare of 12 tons of an experiment 1998. Subsequently, we randomly sampled five different soils from the surface horizon (0-30 cm). For the autumn season of

2024, one of the agricultural fields in Salah al-Din Governorate / Samarra District, Al-Mu'tasim sub-district was sampled. The samples were mixed together to obtain one composite sample representing the whole field. After being air-dried, the sample was crushed and passed through a 2 mm sieve. Soil physical and chemical properties assessment of some of the soil (Table 1) carried out ploughing, harrowing and levelling using a disc harrow. The separations of about Two meters were maintained between the three sections after dividing the field (RCBD design). Each section then subdivided into 16 plots (experimental units) measuring 3 x 3 m^2. A total of (9) m2 was used in each treatment plot. 1 m distance was kept between two plots. Thus, a total of 54 experimental units were raised. In the holes, sunflower seeds of the three varieties were sown on 15/7/2024 at a rate of (2-3) seeds per hole and at a depth of (3-5) cm in rows with a distance of 75 cm between rows and 25 cm between holes. Each plot consisted of 4 rows, after thinning and replanting (one plant per hill) they consisted of 12 plants. The experiment was irrigated with fresh Tigris river water used through drip irrigation. For the nitrogen source, urea fertilizer (46%) was applied at the rate of 320 kg ha-1 in two splits, the first at germination, second 45 days after the first application. The fertilizer was used in quantity as being studied. The potassium source used in this study was potassium sulfate fertilizer with 43% K, applied at 200 kg ha^{-1} [7]. TSP 120 kg P ha^{-1} was added as phosphorous source by bunding as well as mixing in the soil.

For biofertilization, we used the Bio Green Mycorrhizae preparation, which consists of various strains of mycorrhizal fungi mycorrhiziae (arbuscular mycorrhizal fungi, AMF), which facilitate the plants' root growth and nutrient absorption. Along with the application of a sticker or adhesive (Arabic gum), it was included in the seed at the rate of 150 g/acre. The seeds were initially combined with Arabic gum, which water had diluted. Then the preparation was stirred until all the seeds were coated with fungus. Next, the seeds were shade-dried for 20 minutes and then sown directly as per the recommendations of the manufacturer, Bio Green Planet.

Table 1. Some physical and chemical properties of the study soil.

Adjective	Unit	Value
Sand		421
Clay		230
Gilt	g Kg^{-1}	349
Structure		Loam
CEC	cXML Kg^{-1}	15.88
pH (1.1)		7.41
Ec (1.1)	Desmans $.m^{-1}$	2.54
$CaSO_4$		10.01
$CaCO_3$	g Kg^{-1}	190
O.M		7.22
Available nitrogen		17.53
available phosphorus	mg kg^{-1}	7.23
available potassium		112.00

3. Results

Studied Characteristics

Plant Height (cm)

The average height measurement was made directly from the soil surface to the tip of the head at maturity. The average height of ten protected plants taken from intermediate plants of each experimental unit was measured first and then averaged.

Dry weight of the vegetative parts (g plant^{-1})

The stem and leaves dry weight were measured at 75 days after germination (flowering stage). The samples were put in perforated paper bags and stored in an electric oven at a temperature of 70ºC, for a period of 72 hours. They were weighed several times using a sensitive balance until stable weight was achieved [8].

Weight of 300 seeds (g): 300 sunflower seeds were weighed.

Grain yield (kg ha^{-1})

The yield of ten plants taken from each experimental unit was determined and afterwards divided by the number of plants to obtain yield per plant by adjusting weight at 15.5% moisture. [8]:

Grain yield (kg ha^{-1}) = Yield per plant × Plant density

Biological yield (kg ha^{-1})

From the middle rows of each experimental unit, five plants were selected at random, air dried and weighed on a sensitive balance. The overall yield of each individual plant was calculated first, followed by the biological yield, according to this equation.Biological yield (kg ha^{-1}) = Yield per plant × Plant density

Percentage of protein (%): A Kjeldahl micrometer was used to calculate the nitrogen content in the seeds, then the equation was applied.

% of protein = % of nitrogen × 6.25

Percentage of oil (%): Measured random units of grains were taken.

Percentage of oil (%): Samples of the grains were taken at random and the percent of oil was estimated using S0xhlet device as reported in [9] the laboratory of the Field Crops Department – College of Agriculture – Tikrit University.

Design and Statistical Analysis

A Randomized Complete Block Design (RCBD), in which the split was performed twice. Waste management formed the primary units, while biofertilizer treatment made up the secondary units. The varieties were located in the secondary-secondary units. For the average results, a statistical analysis was performed using the SAS statistical program. The averages were compared by Duncan test at a probability level of 0.05 [10].

Plant Height (cm)

The data presented in Table (2) verifies that the management of wheat residue had a significant effect on height of Helianthus annuus (sunflower). The treatment burning residues which recorded the maximum height of 198.6 cm was better than the treatment removing residues which gave the lowest height of 179.1 cm. This superiority may be due to burning crop residues which accelerates the breakdown of organic matter and the availability of nutrients in the topsoil layer. This was probably responsible for better plant growth. It was additionally mentioned in a review that crop residue management helps in bettering plant nutrition and efficiency of agricultural inputs' use [11].

With regard to biofertilization by inoculation with mycorrhizae, it also caused significant effects. The average height of Funnelform mosseae and other Arbuscular Mycorrhizal Fungi inoculated plants, which reached about 193.5 cm, compared to uninoculated plants with 181.9 cm. The above improvement occurs because mycorrhizal fungi improve water and nutrient absorption from the soil by roots, thus improving growth. A study noted the inoculation with AMF increased the plant height of sunflower[12].

In terms of the variety, the sunflower varieties were not significantly different. The highest average height was found in the Kuban variety (188.7 cm), Aqmar (187.3 cm), and Flami (187.0 cm).

When the interaction between waste management and mycorrhizal inoculation (R × B) was examined, the "waste incineration with mycorrhizal inoculation" treatment

recorded the highest mean (198.6 cm) and was significantly greater than the other treatments. The practice of "removals of debris without pollination" proved to have the shortest height (179.1 cm). The good interaction was owing to improving the environment of the soil (debris removal) as well as promoting the root growth (mycorrhizae) jointly improves the growth. As per the mycorrhizal literature, pollination improved the plant height and nutrient uptake here.

The study showed that in the interaction between variety and waste management, Cobban with waste incineration treatment gave the highest height (190.6 cm) while Aqmar with waste removal gave the lowest height. This verifies that the efficient variety benefits more from a better waste management system.

According to mycorrhizae-cultivars (B × V) interactions, the mycorrhizal-inoculated Kuban cultivar gave the maximum height (about 194.7 cm), while the Aqmar cultivar gave a lower response. It indicates that some cultivars respond positively to mycorrhizal inoculation due to variations in root formation or activity of mycorrhizal fungi.

The treatments experimental effects among the tripartite interactions waste management, mycorrhizal inoculation and varieties (R×B×V). The highest plant height was obtained in treatment "burning waste × mycorrhizal inoculation × flami" where plant height reached approximately 200.1 cm. This shows the three factors have synergistic interactions to improve environment of the root, the soil and the plant itself.

Table 2. Effect of wheat residue management and biofertilization on plant height of three sunflower varieties (cm).

Waste Management (R)	**Biofertilization B**	**Sunflower varieties V**			**R × B**
		Aqmar	Flami	Coban	
Waste removal	None vaccination	179.0 c	180.0 c	179.1 c	178.2 c
	Mycorrhizal vaccination	189.5 b	190.2 b	189.4 b	188.4 b
Waste burning	None vaccination	179.2 c	181.1 c	180.3 c	180.5 c
	Mycorrhizal vaccination	**197.5 a**	**200.1 a**	**198.6 a**	**198.1 a**
Leaving waste	None vaccination	185.3 b	187.2 b	186.3 b	186.5 b
	Mycorrhizal vaccination	191.5 ab	193.8 ab	192.5 ab	192.3 ab
					R average
R × N	Waste removal	179.0 c	180.0 c	179.1 c	178.2 b
	Waste burning	179.2 c	181.1 c	180.3 c	180.5 b
	Waste disposal	185.3 b	187.2 a	186.3 ab	186.5 a
					B average
N × B	None vaccination	181.7 b	181.2 b	182.8 b	181.9 b
	Mycorrhizal vaccination	**192.9 a**	**192.8 a**	**194.7 a**	**193.5 a**
Varieties Average		187.3 a	187.0 a	188.7 a	

Means with similar letters show no significant differences according to Duncan's test.

Dry weight (g plant^{-1})

As can be seen from Table 3, sunflower plants significantly responded to various factors of study. According to the average of waste treatment, the treatment "waste burning" gave the highest plant dry weight of 43.29 g/plant. Accordingly, the highest was "leaving residues" at 41.67 g. On the other hand, "removing residues" was the lowest at

38.04 g/plant. In contrast to the previous application of burning, the use of burning at the beginning of the wet season is better for the rice crop. This advantage is due to the fact that burning sterilizes the soil, reducing some micro-organisms, but on the other hand, it accelerates the rate of decomposition of organic matter and the rapid release of nutrients to the plant, resulting in better use of nutrients by plants as it is in accordance with [13].

In terms of the effect of mycorrhizal inoculation, the inoculated plants recorded the highest average dry weight (42.96 g per plant) as compared to uninoculated plants (39.03 g). The improvement in root absorption of nutrients and water, as well as biomass of plants, is the result of mycorrhizal fungi[14].

The varieties showed a significant difference, where variety "Kuban" was found having the maximum average dry weight in the plant of 44.66g, followed by "Flami" having 41.54g, and then "Aqmar" having 36.8g, showing the genetic variability of the varieties in their capacity to benefit from waste management, mycorrhizal pollution and increase in biomass. The genetic selection of varieties is a significant issue impacting the response of plants to diverse agricultural practices [15].

It is noticed, that the interaction of R × B was positively significant, whereby the sterility of the soil due to burning lessens competition with soil microbes, making room for mycorrhizae to grow and expand, further enhancing the efficiency of nutrient uptake and enhancing the dry weight of the plant. The highest dry weight of 46.40g plant-1 was recorded in treatment burning waste + mycorrhizal inoculation while the lowest 33.52g plant-1 treatment removing waste + no inoculation. According to binary interactions, R × V interaction showed that burning waste with Kuban variety produced maximum dry weight 47.56 g plant-1 whereas waste removal with Aqmar variety resulted in minimum dry weight 33.76 g plant-1. Based on the interaction results of mycorrhizal inoculation of (B × V) varieties, Kuban variety inoculated plants achieved the highest dry weight (46.15 g plant-1). This was significantly higher than the uninoculated plants of Aqmar variety (34.43 g).

The highest dry weight (50g plant-1) was recorded in the "treatment of burning waste + mycorrhizal inoculation + Kuban variety" while the lowest dry weight (33.52g plant-1) was recorded in the "treatment of removing waste + no inoculation + Aqmar variety" for the triple interaction (R × B × V). Environmental conditions influence the nitrogen fertilizing potential of upland crops.

Table 3. Effect of wheat residue management and biofertilization on the dry weight of three sunflower varieties (g plant^{-1})

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	33.52 d	38.73 c	41.00 bc	37.75 c
	Mycorrhizal vaccination	34.00 d	40.19 bc	40.77 bc	38.32 c
Waste burning	None vaccination	34.51 d	41.01 bc	45.00 b	40.17 bc
	Mycorrhizal vaccination	**42.00 b**	**47.00 a**	**50.00 a**	**46.40 a**
Leaving waste	None vaccination	35.25 cd	38.76 c	43.00 b	39.17 bc
	Mycorrhizal vaccination	41 bc	43 b	47 a	44.16 b
					R average
R × N	Waste removal	33.52 d	38.73 c	41.00 bc	37.75 b
	Waste burning	34.51 d	41.01 bc	45.00 a	40.17 a
	Waste disposal	35.25 cd	38.76 c	43.00 ab	39.17 ab
					B average

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
N × B	None vaccination	34.43 d	39.50 c	43.00 b	39.03 b
	Mycorrhizal vaccination	**39.17 b**	**43.57 b**	**46.00 a**	
Varieties Average		38.04 c	43.29 a	41.67 b	

Means with similar letters show no significant differences according to Duncan's test.

Weight of 300 grains (g)

The information in Table 4 indicates that Helianthus annuus plants significantly responded to the factors of the study. The average weight of treatments discarded which is burning have the highest weight of 22.95 g for 300 grains, leaving the waste was 22.87 g, and removing the waste have the lowest weight of 20.76 g. With burning, events of decay and assimilations of nutrients in the surface layer of the soil occurs, which promotes the growth of the plant and nutrient absorption, and which is what [11] is consistent with.

In terms of the mycorrhizae inoculation effect, inoculated plants recorded 22.87 g 300 grains as the highest average compared to uninoculated plants which recorded only 21.51 g. The aforementioned is because the fungi AMF increase the absorption of nutrients and water by roots, thus increasing the accumulation of dry matter in the grains, which is in accordance with [14].

The assessment has revealed that the variety of 'Kuban' had a better thousand grain weight of 23.59 g followed by 'Flamy' at 22.07 g and 'Aqmar' at 20.91 g. The variation among the varieties shows that some will benefit more than others from waste management, mycorrhizal inoculation and increased grain mass.

The combination of waste management and inoculation (R×B) was found to produce the highest weight of 24.21 g for 'waste burning + mycorrhizal inoculation' while the lowest weight of 20.43 g was recorded for 'waste removal + no inoculation'. The interaction of waste management and varieties (R×V) showed that the highest yield of 24.62 g was for 'waste burning + Kuban variety' while the lowest yield was recorded at 19.74 g for 'Aqmar variety'. Moreover,the analysis of cross-pollination B×V indicated that the plants pollinated with the Kuban variety produced the highest yield of 24.38 g, while unpollinated plants of the Aqmar variety yield only 20.31 g.

Lastly, the weight of 300 grains (R×B×V) on this triple interaction was 26.11 g (burning waste + mycorrhizal inoculation + the Kuban variety) which is the highest, while the lowest was in the treatment which is the combination of removing waste + no inoculation + the Aqmar variety recorded a weight of 19.47 g. All this indicates that the treatment combination of burning waste + mycorrhizal inoculation + the variety leads to better accumulation of dry matter in the grains and yield improvement.

Table 4. Effect of wheat residue management and biofertilization on the weight of 300 grains (g).

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	19.47 d	20.15 cd	21.67 bc	20.43 D
	Mycorrhizal vaccination	20.00 cd	21.24 bc	22.03 b	21.09 CD
Waste burning	None vaccination	20.56 cd	21.38 bc	23.12 ab	21.69 C
	Mycorrhizal vaccination	22.49 b	24.03 a	26.11 a	24.21 A

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Leaving waste	None vaccination	20.91 cd	22.77 ab	23.59 ab	22.42 B
	Mycorrhizal vaccination	22.05 b	22.87 ab	25.01 a	23.31 AB
					R average
R × N	Waste removal	19.74 e	20.70 d	21.85 cd	20.76 b
	Waste burning	21.53 cd	22.71 bc	24.62 a	22.95 A
	Waste disposal	21.48 cd	22.82 b	24.30 ab	22.87 A
					B average
N × B	None vaccination	20.31 c	21.43 bc	22.79 ab	21.51 B
	Mycorrhizal vaccination	21.51 bc	22.71 ab	24.38 a	22.87 A
Varieties Average		20.91 b	22.07 ab	23.59 a	

Means with similar letters show no significant differences according to Duncan's test.

Grain yield (kg ha^{-1})

Results in Table 5 show that grain yield of Helianthus annuus plants was distinctly influenced by the three factors studied. The "burning waste" treatment produced the maximum yield of 5681 kg ha^{-1} while the "leaving waste" treatment produced a yield of 5472 kg ha^{-1} average waste management (R) treatments.

The least waste removal coefficient i.e. 4876 kg ha^{-1}. The superiority is likely because, when burning is done, the nutrients are released from the decomposing organic matter very quickly that helps the next crops. Also, partially sterilizes the soil thus preventing pathogens and predators from affecting the next set of plants and grains and creates a suitable environment for the activity of beneficial organisms such as mycorrhiza [16].

There was a yield advantage of mycorrhizal inoculation (B) which gave the inoculated plants a supreme yield of 5655 kg^{-1}. On the contrary, the uninoculated plants produced 5030 kg^{-1}. Increased final grain weight could take place since mycorrhizae improve the root absorption network of a plant; enhance the uptake of essential nutrients; increase the resistance to environmental stress [17].

The “Kuban” variety had an average of 5870 kg^{-1} and outperformed the other (N) varieties. It was followed by “Flami” 5342 kg^{-1}, and then “Aqmar” 4816 kg^{-1}. This indicates the varieties differ genetically in their ability to utilize mycorrhizae and manage waste (Salimi et al., 2021).

The interaction between R × B takes on a clear positive nature because treatment burning waste + mycorrhizal inoculation gives the highest yield of 6297 kg^{-1} while removing waste + no inoculation gives the least yield of 4819 kg^{-1}. Mycorrhizae benefit from burning as the soil sterilization reduces microbial competition and predation which could restrict mycorrhizal activity. The greater expansion of the beneficial fungus within the root system also improves nutrient uptake and increases grain yields.

The relationship of the treatment (waste management and varieties R x N) showed that the burning waste + two cup gave the highest yield (6282 kg 1) and removing waste + moons recorded the lowest yield (4545 kg 1). It indicates choosing the proper variety improves the plant benefits from the improvement in soil after waste management. This interaction between pollination and varieties (B×N) indicated that the highest yield of 6398 kg^{-1} was recorded from pollinated plants of Kuban variety. Also, the lowest yield of 4676 kg^{-1} was measured for unpollinated plants of Aqmar variety. This confirms the role of mycorrhizae in enhancing the productivity of high-potential varieties.

In the end, yield characteristics showed significant differences from the three-factor interaction (R × B × V), which presented benefits of increasing mean, where the treatment

burning waste + mycorrhizal inoculation + Copan was superior as evidenced by the highest yield recorded of 7154 kg^{-1}. Meanwhile, the treatment removing waste + no inoculation + Copan was inferior with a lowest yield of 4512 kg^{-1}.

This interaction indicates that burning (to sterilize the soil and release nutrients, mycorrhizae (to enhance absorption and improve biological activity) and right variety together can give the highest yield possible This reflects the complementary role of environmental and biological factors in sunflower plant performance improvement.

Table 5. Effect of wheat residue management and biofertilization on grain yield of three sunflower varieties (kg ha^{-1})

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	4512 c	4835 bc	5110 b	4819 c
	Mycorrhizal vaccination	4578 c	5032 b	5187 b	4932 c
Waste burning	None vaccination	4720 bc	5062 b	5410 b	5064 bc
	Mycorrhizal vaccination	5188 b	6550 a	7154 a	6297 a
Leaving waste	None vaccination	4795 bc	5325 b	5503 b	5208 b
	Mycorrhizal vaccination	5102 b	5250 b	6854 a	5735 ab
					R average
R × N	Waste removal	4545 c	4934 b	5149 b	4876 c
	Waste burning	4954 b	5806 a	6282 a	5681 a
	Waste disposal	4949 b	5288 b	6179 a	5472 ab
					B average
N × B	None vaccination	4676 bc	5074 b	5341 b	5030 b
	Mycorrhizal vaccination	4956 b	5611 a	6398 a	5655 a
Varieties Average		4816 c	5342 b	5870 a	

Means with similar letters show no significant differences according to Duncan's test.

Biological quotient (kg h^{-1}).

The data presented in Table (6) clearly indicates that biological yield (BY) was significantly affected with respect to the three factors wheat residue management (R), mycorrhizal inoculation (B), and variety. When looking at the average residues management practices, "residue burning" treatment showed the maximum average (15,765 kg^{-1}). After it, the "leaving residues" was recorded at 15,394 kg^{1} while the "removing residues" had the lowest at 12,767 kg^{1}. This superiority is explained by the fact that burning helps decompose organic matter and rapid release of nutrients in the soil as well as reduce pathogens and predator affecting plant growth. This improves the root environment as well as increased biomass production. These findings corroborate those of [5].

Mycorrhizal inoculation treatment has also clearly contributed. It has an average yield of 15,794 kg-1. This is more than the uninoculated treatment of 13,490 kg-1. This is because mycorrhizal fungi can extend root absorption area, improve absorption, promote the symbiotic relationship of the root with the fungus and greater production of Plant biomass.

The root system enhances absorption and the symbiotic relation of the root with fungus brings about more biomass production by the plant. Yet those varieties had different yields. The 'Kuban' variety had the highest yield with an average yield of 16,429 kg-1, followed by 'Flamy' (14,799 kg-1), and 'Aqmar' variety (12,699 kg-1). It shows that there was a genetic difference between the varieties to use waste management, mycorrhizal inoculation and large biomass production.

Now, looking at the binary interactions it is clear through the table that the R × B positive (waste management × inoculation). The treatment "waste burning + mycorrhizal inoculation" has the highest yield of 17920 kg^{-1} while the treatment "waste removal + no inoculation" has the lowest of 12629 kg^{-1}.

Thus, it strengthens our hypothesis that burning creates a suitable medium for the mycorrhizae as they are shielded from competition or predators which enables the fungus to soon colonise the root system allowing better nutrient uptake. Also, interaction waste management and cultivars (R × V) produced maximum 18,056 kg^{-1} with "burning waste + two cups" while "waste removal + satellites" produced minimum 11570 kg^{-1} which indicate that selection of right variety with waste management doubles the productive effect.

Similarly, the interaction of pollination and varieties (B × V) showed that the productivity of 18140 kg_1 was recorded for pollinated plants of "Kuban" variety in contrast with 13490 kg_1 for the unpollinated variety "Aqmar". This confirms that mycorrhizae are more effective in varieties with higher genetic response.

At last, the triple interaction (R × B × V) gave the highest value, treatment burning waste + mycorrhizal inoculation + Coban with 20,991 kg -1; while the treatment removing waste + no inoculation + moons yielded 11,457 kg -1 the lowest. This proves that the intensification of treatment with waste management, mycorrhizal inoculation and suitable variety selection gives the highest productive gain in biological yield of sunflower plant.

Table 6. Effect of wheat residue management and biofertilization on the biological yield of three sunflower varieties (kg ha^{-1}).

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	11457 c	12890 bc	13540 b	12629 bc
	Mycorrhizal vaccination	11682 c	13215 b	13820 ab	12906 bc
Waste burning	None vaccination	12100 bc	13610 b	15120 a	13610 b
	Mycorrhizal vaccination	14530 b	18240 a	20991 a	17920 a
Leaving waste	None vaccination	12375 bc	14830 ab	15490 a	14232 b
	Mycorrhizal vaccination	14050 b	16010 a	19610 a	16557 a
					R average
R × N	Waste removal	11570 c	13053 bc	13680 b	12767 c
	Waste burning	13315 b	15925 a	18056 a	15765 a
	Waste disposal	13213 b	15420 a	17550 a	15394 a
					B average
N × B	None vaccination	11977 c	13777 b	14717 ab	13490 b
	Mycorrhizal vaccination	13421 b	15822 a	18140 a	15794 a

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Varieties Average		12699 c	14799 b	16429 a	

Means with similar letters show no significant differences according to Duncan's test.

Oil concentration in seeds (%)

According to results presented in Table 7 the oil concentration in sunflower seeds was clearly influenced by the three factors namely management of wheat residue (R), mycorrhizal inoculation (B) and varieties.

The research results regarding waste management methods were analyzed in this study. The incineration was found to be the most effective because this method was able to record the highest average oil concentration of 34.07%. Meanwhile, leaving the waste was able to record the average oil concentration of 33.74%. While the lowest average recorded was the removal of waste with an average oil concentration of 29.47%. This finding can be explained by the fact that composting draws on the carbon present in organic waste. As a result, organic waste decomposes quickly and releases nutrients. To be sure, the burning of phosphorus and potassium is especially vital to oil formation in seeds. Soil burning also kills pathogens and predatory microbes which inhibit the root activity [18]. The combination of these aspects provides a more conducive environment for nutrient absorption and enhances the metabolic transformation of the seeds into oils.

Mycorrhizal biofertilization had a definite positive effect, the oil concentration in plants inoculated with mycorrhizae was in average 33.89% – in uninoculated plants it was 30.96%. Mycorrhizal fungi are advantageous for the soy. These fungi extend the root absorption area and enhance the uptake of phosphorus and micronutrients, which are crucial for the production of fatty acids and oil. Moreover, the microbes that live in seeds as a result of pollination intensify photosynthesis, particularly in plants in Okinawa.

Variety effect was clear in the oil concentrations as Kuban was the highest (35.17%), Flami came second (32.58%) and Aqmar was the least (29.54%). One strain is superior to the other due to its superior genetic make-up involving photosynthetic efficiency and carbon fixation to produce fatty acids and oils [20].

The results confirmed a definite interaction between waste management and inoculation (R × B) concerning the soil and crop system. The highest oil concentration of 36.89% was reached in the "waste burning + mycorrhizal inoculation" treatment whereas the lowest values were noted in "waste removal + no inoculation" with a mean of 29.04%. The sterilization of soil mycorrhizae and reduced competitor or predator organisms allow easy mycorrhizae colonization of the root by fire and increase nutrient uptake efficiency.

Regarding the interaction of waste management and varieties (R × V), the "waste burning + Cobban" treatment had an oil percentage of 37.11% which was the highest in the combination treatment, whereas "waste removal + Aqmar" treatment was the lowest "27.17%. This shows that combining optimal waste management with a variety with high genetic efficiency greatly improves oil quality.

According to interaction results between pollination and variety (B × V), we see that pollinated plants of the Kuban variety gave the highest oil concentration of 36.74 genotypically, however, this concentration was lowered for unpollinated plants to 33.59. This shows that the mycorrhizal response is varied owing to genetic characteristics of the variety.

The treatment combination of waste incineration, mycorrhizal inoculation and Coban was found to have the highest triplet interaction (R × B × V) with an oil concentration of 39.97%. In contrast, the lowest triplet interaction was found in 'waste removal, no inoculation, Coban' with an oil concentration of 26.88%. This verifies that [the treatment/product/organization] becomes more effective with combined waste management, bio-inoculation and suitable variety. Finally, the highest triplet interaction (R × B × V) was shown by the "waste incineration + mycorrhizal inoculation + Coban" treatment with an oil concentration of 39.97% while the lowest was shown by "waste removal + no inoculation + Coban" at 26.88%. This assures that integration of waste

management, bio-inoculation and selection of proper variety improves efficacy of [treatment/product/organization].

Table 7. Effect of wheat residue management and biofertilization on oil concentration of three sunflower varieties (%)

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	26.88 c	29.12 bc	31.12 b	29.04 bc
	Mycorrhizal vaccination	27.45 c	30.25 b	32.01 ab	29.90 bc
Waste burning	None vaccination	28.45 bc	31.05 b	34.25 a	31.25 b
	Mycorrhizal vaccination	33.20 b	37.50 a	39.97 a	36.89 a
Leaving waste	None vaccination	29.20 bc	33.18 ab	35.40 a	32.59 b
	Mycorrhizal vaccination	32.05 b	34.35 a	38.25 a	34.88 a
					R average
R × N	Waste removal	27.17 c	29.69 bc	31.57 b	29.47 bc
	Waste burning	30.83 b	34.28 a	37.11 a	34.07 a
	Waste disposal	30.63 b	33.77 a	36.83 a	33.74 a
					B average
N × B	None vaccination	28.18 c	31.12 b	33.59 ab	30.96 b
	Mycorrhizal vaccination	30.90 b	34.03 a	36.74 a	33.89 a
Varieties Average		29.54 c	32.58 b	35.17 a	

Means with similar letters show no significant differences according to Duncan's test.

Protein concentration in seeds (%).

As evidenced in Table 8, the factor present within the experiment which dramatically influenced protein concentration in sunflower was R (wheat residue management), B (mycorrhizal inoculation) and varieties.

The data in the same table indicates that waste burning and waste disposal treatments generated the highest values with averages of 25.70% and 25.65% respectively while waste removal gave the least average of 22.52%. Because burning releases nutrients more quickly, especially nitrogen and phosphorus, it is superior. Burnt plant remains encourage growth and protein accumulation in seeds. Furthermore, it disinfects the soil from pathogens and microbial competitors, allowing favorable root environment and uptake of more nutrients [21].

Conversely, the treatment of leaving residues also contributed to an increase in the protein due to the improvement of soil structure and the gradual increase of decomposed organic matter it provides a supply of nutrition continuously to the plant.

Mycorrhizal inoculation had a highly positive effect with the average protein concentration of the inoculated treatment being 25.82% as opposed to 23.43%. The increased absorption of nutrients can be credited to the presence of mycorrhizal fungi that help plants absorb nitrogen, phosphorus and micronutrients such as zinc and manganese. Amino acids and proteins are formed with the help of these things. The association of roots with mycorrhizae increased water, nutrient absorption and reduced the nutritional stress of the plant. This is reflected in the accumulation of proteins in the seeds [22].

When it comes to the varieties, there are clear and significant differences between them. The Aqmar variety had the highest protein content, with an average of 26.31%. The Flami variety came second, with an average of 24.53%. Finally, the lowest was the Kuban variety, with an average of 23.03%. The difference in the genetic capability of the varieties to absorb and re-distribute nitrogen in the seed tissues, as well as the difference in the activity of the enzymes which are responsible for fixing protein [23].

In the analysis of bilateral and ternary interactions, the interaction of waste management × inoculation (R × B) is evidently positive; the treatment of "waste burned + mycorrhizal inoculation" resulted in the maximum protein concentration of 27.71%, while the minimum values were recorded in "waste removed + no inoculation" averaging 22.05%. Burning causes a reduction in the predators of mycorrhizae. It helps the roots colonize and absorb more nitrogen. The Interaction of treatments (R × V) of the waste management experiment gave maximum protein concentration (27.70%) in the treatment of burning waste + moons and minimum (21.07%) in the treatment of removal of waste + Cobban.

Regarding the relationship between pollination and varieties, B × V of pollinated plants of Aqmar variety yielded the highest percentage of protein (27.63 %). Meanwhile 21.83 % was recorded in the unpollinated Kuban variety. This indicates the difference in the genetic response of the varieties to the mycorrhizae symbiotic relationship.

The test of three component interaction (R x B x V) showed that treatment waste incineration + mycorrhizal inoculation + moons recorded maximum protein concentration of 30.03% while waste removal + no inoculation + Cobban showed minimum of 20.38%. The outcome affirms that optimal waste and bio-inoculation with right variety result in enhanced protein accumulation in sunflower seeds due to improvement in nutrient uptake and metabolic activities of these responses responsible for protein synthesis.

Table 8. Effect of wheat residue management and biofertilization on protein concentration of three sunflower varieties (%).

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Waste removal	None vaccination	23.62 b	22.15 bc	20.38 c	22.05 bc
	Mycorrhizal vaccination	24.18 ab	23.04 b	21.76 bc	22.99 bc
Waste burning	None vaccination	25.36 a	23.41 b	22.27 bc	23.68 b
	Mycorrhizal vaccination	30.03 a	27.33 a	25.78 b	27.71 a
Leaving waste	None vaccination	26.02 a	24.78 ab	22.85 bc	24.55 b
	Mycorrhizal vaccination	28.67 a	26.45 a	25.11 b	26.74 a
					R average
R × N	Waste removal	23.90 b	22.60 bc	21.07 c	22.52 bc
	Waste burning	27.70 a	25.37 a	24.03 b	25.70 a
	Waste disposal	27.35 a	25.62 a	23.98 b	25.65 a
					B average
N × B	None vaccination	25.00 ab	23.45 b	21.83 c	23.43 b
	Mycorrhizal vaccination	27.63 a	25.61 a	24.22 b	25.82 a

Waste Management (R)	Biofertilization B	Sunflower varieties V			R × B
		Aqmar	Flami	Coban	
Varieties Average		26.31 a	24.53 b	23.03 c	

Means with similar letters show no significant differences according to Duncan's test.

4. Discussion

The findings of this study demonstrate that wheat residue management, mycorrhizal biofertilization, and sunflower variety selection collectively influence plant growth, yield components, and seed quality. Among the residue management treatments, burning generally produced higher values for plant growth and productivity than residue removal, while residue retention also showed favorable results. The burning treatment achieved an average grain yield of 5,681 kg ha^{-1}, compared with 5,472 kg ha^{-1} under residue retention and 4,876 kg ha^{-1} under residue removal. This improvement may be associated with the short-term availability of mineral nutrients released from burned residues, which could support plant development during critical growth stages. Similar findings were reported by Farhan et al. [5], who investigated the influence of wheat residue management and fertilization on sunflower growth and yield. However, the immediate productivity benefits of burning should be interpreted alongside its potential environmental consequences, including organic carbon losses, nutrient volatilization, and changes in soil microbial communities. As emphasized by Sarkar et al. [11], appropriate crop residue management is essential for maintaining agricultural productivity and improving resource-use efficiency. Therefore, the observed advantages of residue burning under the present experimental conditions should not be interpreted as evidence of its long-term superiority over residue retention.

Mycorrhizal biofertilization consistently improved several growth and yield characteristics across the investigated sunflower varieties. Inoculated plants attained an average height of 193.5 cm compared with 181.9 cm in uninoculated plants, indicating a positive response in vegetative development. Similarly, mycorrhizal inoculation increased grain yield from 5,030 to 5,655 kg ha^{-1} and biological yield from 13,490 to 15,794 kg ha^{-1}. These differences suggest that mycorrhizal associations may have contributed to improved nutrient acquisition and plant growth under the experimental conditions. Arbuscular mycorrhizal fungi can extend the effective nutrient-absorbing surface of plant roots, particularly facilitating phosphorus acquisition and supporting water uptake. Previous research by Suwarniati and Hanum [12] also demonstrated the beneficial effects of arbuscular mycorrhizal fungi on sunflower growth. The observed improvements in seed oil concentration from 30.96% to 33.89% and protein concentration from 23.43% to 25.82% further indicate that the response to inoculation extended beyond vegetative growth. Nevertheless, because root colonization and nutrient uptake were not directly quantified in this experiment, the proposed physiological mechanisms remain plausible explanations rather than experimentally confirmed pathways.

Differences among the three sunflower varieties further demonstrate the importance of genetic characteristics in determining crop responses to agricultural management practices. The Kuban variety exhibited the highest average grain yield (5,870 kg ha^{-1}), biological yield (16,429 kg ha^{-1}), and seed oil concentration (35.17%), indicating its favorable performance for seed and oil production. In comparison, the Flami variety produced intermediate values, while Aqmar generally showed lower productivity but achieved the highest protein concentration (26.31%). These differences suggest that yield potential and seed composition are not necessarily maximized within the same genotype. The superior productivity of Kuban may reflect its capacity to respond favorably to the available growing conditions and applied management treatments. In contrast, the higher protein concentration observed in Aqmar indicates that this variety may be particularly relevant when seed protein content is prioritized over total grain or oil yield. The variation in responses among varieties highlights the need to consider specific production objectives when selecting sunflower cultivars. Consequently, variety recommendations

should account for the intended agricultural application rather than relying exclusively on grain yield.

The interaction among wheat residue management, mycorrhizal inoculation, and sunflower variety revealed the importance of combining agricultural management practices to improve overall crop performance. The highest grain yield of 7,154 kg ha^{-1}, biological yield of 20,991 kg ha^{-1}, dry weight of 50.00 g $plant^{-1}$, and seed oil concentration of 39.97% were recorded under the combination of residue burning, mycorrhizal inoculation, and the Kuban variety. This treatment combination demonstrated the greatest productivity within the evaluated experimental treatments, suggesting that favorable residue management conditions and biological fertilization may complement the productive potential of selected sunflower varieties. However, the highest protein concentration of 30.03% was obtained from the combination of residue burning, mycorrhizal inoculation, and the Aqmar variety. These contrasting responses indicate that optimizing grain yield, oil concentration, and protein accumulation may require different cultivar choices. Although the results provide useful evidence for improving sunflower cultivation in the study area, the experiment was conducted during a single growing season at one location, limiting broader generalization. Further research involving multiple growing seasons, different soil conditions, direct measurements of mycorrhizal root colonization, and assessments of long-term soil health is necessary to determine whether the observed productivity advantages can be maintained sustainably.

5. Conclusion

1. The waste management method of burning or leaving was superior in growth characteristics, oil content and protein as compared to removal.

2. Mycorrhizal inoculation improved nutrient uptake and the oil and protein concentrations of sunflower seeds.

3. The Kuban variety is the best option as it was suitable in most of the studies.

4. The burning of crop residues along with mycorrhizal inoculation of the Kuban variety proved to be the best.

Recommendations

1. Studies have found that applying (mycorrhizal inoculation) can increase the growth and production of sunflower significantly especially when it is carried out in conjunction with the practices of waste management such as burning or leaving the waste.

2. People prefer Kuban variety fruit as it has better chemical and biological properties.

3. Using biofertilizers is a sustainable option. It reduces the dependence on chemical fertilizers and maintains soil fertility.

REFERENCES

[1] A. Petraru, F. Ursachi, and S. Amariei, "Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient," Plants, vol. 10, no. 11, Art. no. 2487, 2021, doi: 10.3390/plants10112487.

[2] S. Guo, Y. Ge, and K. Na Jom, "A review of phytochemistry, metabolite changes, and medicinal uses of the common sunflower seed and sprouts (Helianthus annuus L.)," Chemistry Central Journal, vol. 11, no. 1, Art. no. 95, 2017.

[3] S. B. Baloch et al., "Crop residue management for soil health and environmental sustainability: A comprehensive review," Journal of Soil Science and Plant Nutrition, pp. 1–21, 2025.

[4] A. M. Abu Rayan, Organic Agriculture, 1st ed. Dar Wael for Printing and Publishing, 2010. (In Arabic).

[5] M. J. Farhan, N. A. Hilai, and A. A. Saleh, "The effect of wheat residue management and organic and nitrogen fertilization on the growth and yield of sunflower (Helianthus annuus L.)," IOP Conference Series: Earth and Environmental Science, vol. 1371, no. 8, Art. no. 082038, Jul. 2024.

[6] M. Szczałba, T. Kopta, M. Gąstoł, and A. Sękara, "Comprehensive insight into arbuscular mycorrhizal fungi, Trichoderma spp. and plant multilevel interactions with emphasis on bio stimulation of horticultural crops," Journal of Applied Microbiology, vol. 127, no. 3, pp. 630–647, 2019.

[7] M. Q. Rashad, "Response of maize (Zea mays L.) to fertilizer type under different nitrogen levels in a gypsiferous soil," Master's thesis, College of Agriculture, Tikrit University, 2018.
[8] F. A. H. Al-Sahaf, Plant Nutrition. Baghdad, Iraq: College of Agriculture, University of Baghdad, 1997.
[9] Khasha' Mahmoud and Abdul Aziz Mohsen Khalafallah, Design and Analysis of Agricultural Experiments. Baghdad, Iraq: University of Baghdad, Ministry of Higher Education and Scientific Research, 1980.
[10] K. M. Al-Rawi and A. M. Khalaf Allah, Design and Analysis of Agricultural Experiments. Baghdad, Iraq: University of Baghdad, Ministry of Higher Education and Scientific Research, 1980.
[11] S. Sarkar et al., "Management of crop residues for improving input use efficiency and agricultural sustainability," Sustainability, vol. 12, no. 23, Art. no. 9808, 2020.
[12] S. Suwarniati and U. Hanum, "The effect of arbuscular mycorrhiza fungi and organic fertilizer on the growth of sunflower (Helianthus annuus L.) on critical land of former iron ore mine in Lhoong-Aceh Besar," Journal Natural, vol. 18, no. 2, pp. 77–84, 2018.
[13] P. Pradhan, A. K. Sinha, and T. K. Pandit, "The effect of stubble burning and residue management on soil properties: A review," International Journal of Plant & Soil Science, vol. 36, no. 6, pp. 36–49, 2024, doi: 10.9734/ijpss/2024/v36i64604.
[14] Y. Wu, C. Chen, and G. Wang, "Inoculation with arbuscular mycorrhizal fungi improves plant biomass and nitrogen and phosphorus nutrients: A meta-analysis," BMC Plant Biology, vol. 24, Art. no. 960, 2024, doi: 10.1186/s12870-024-05638-9.
[15] "Biochemical characterization of seed oil of Tunisian sunflower (Helianthus annuus L.) accessions with special reference to its fatty acid composition and oil content," Journal of Food Quality, Art. no. 2875072, 2022, doi: 10.1155/2022/2875072.
[16] R. Shinde et al., "Management of crop residues with special reference to the on-farm utilization methods: A review," Industrial Crops and Products, vol. 181, Art. no. 114772, 2022, doi: 10.1016/j.indcrop.2022.114772.
[17] M. Ramzan et al., "Modulation of sunflower growth via regulation of antioxidants, oil content and gas exchange by arbuscular mycorrhizal fungi and quantum dot biochar under chromium stress," BMC Plant Biology, vol. 23, Art. no. 629, 2023, doi: 10.1186/s12870-023-04637-6.
[18] S. S. Reddy and V. Chhabra, "Crop residue burning: Is it a boon or a bane?," Communications in Soil Science and Plant Analysis, vol. 53, no. 18, pp. 2353–2364, 2022, doi: 10.1080/00103624.2022.2071927.
[19] G. Wang, Z. Jin, T. S. George, G. Feng, and L. Zhang, "Arbuscular mycorrhizal fungi enhance plant phosphorus uptake through stimulating hyphosphere soil microbiome functional profiles for phosphorus turnover," New Phytologist, vol. 238, pp. 2578–2593, 2023, doi: 10.1111/nph.18772.
[20] S. Wu, Z. Shi, M. Huang, Y. Li, and J. Gao, "Effects of arbuscular mycorrhizal fungi on leaf N:P:K stoichiometry in agroecosystem," Agronomy, vol. 13, no. 2, Art. no. 358, 2023, doi: 10.3390/agronomy13020358.
[21] M. Lin and T. Begho, "Crop residue burning in South Asia: A review of the scale, effect, and solutions with a focus on reducing reactive nitrogen losses," Journal of Environmental Management, vol. 314, Art. no. 115104, 2022, doi: 10.1016/j.jenvman.2022.115104.
[22] B. Zhao et al., "Microbe-dependent and independent nitrogen and phosphate acquisition and regulation in plants," New Phytologist, vol. 242, no. 4, pp. 1507–1522, 2024, doi: 10.1111/nph.19263.
[23] A. Petraru, F. Ursachi, and S. Amariei, "Nutritional characteristics assessment of sunflower seeds, oil and cake. Perspective of using sunflower oilcakes as a functional ingredient," Plants, vol. 10, no. 11, Art. no. 2487, 2021, doi: 10.3390/plants10112487.