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Research Article

Green Synthesis of Nanofertilizers and Their Application as a Foliar for *Cucurbita pepo* L

Ahmed Shebl ,[1] A. A. Hassan,[1] Dina M. Salama,[2] M. E. Abd El-Aziz,[3] and Mohamed S. A. Abd Elwahed[4]

[1]*Chemistry Department, Faculty of Science, Ain Shams University, Abbassia, Cairo, Egypt*
[2]*Vegetable Research Department, National Research Centre, Giza, Egypt*
[3]*Polymers & Pigments Department, National Research Centre, Giza, Egypt*
[4]*Botany Department, National Research Centre, Giza, Egypt*

Correspondence should be addressed to Ahmed Shebl; a_ahmed@sci.asu.edu.eg

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The implementation of nanofertilizers in agriculture is the purpose in specific to decrease mineral losses in fertilizing and raises the yield during mineral management as well as supporting agriculture development. Hence, this experiment was conducted in Shebin El-Kom, El-Monifia governorate, Egypt, during two seasons 2017 and 2018 to study the effect of micronutrient oxide nanoparticles of zinc, iron, and manganese, as well as combination between these oxides as a foliar application on the growth, yield, and quality of squash plants. The obtained results showed that the spraying of manganese oxide nanoparticles on the plants led to the best vegetative growth characteristics, also, the characteristics of the fruits, yield, and the content of photosynthetic pigments. On the contrary, the content of organic matter, protein, lipids, and energy gave the highest value in squash fruits that have been sprayed with iron oxide nanoparticles.

1. Introduction

Nanotechnology is an interdisciplinary promising research field, opening a vast number of opportunities in fields like medicine, pharmaceuticals, electronics, and agriculture. The term nanomaterials are generally used to describe the materials having a size between 1 and 100 nm. The small size and enormous surface area of such characteristics give unique properties for nanomaterials like optical, physical, and biological [1–3].

Recently, a wide range of nanotechnology applications has been intensively studied in the agriculture research sector developing practices at both academic and industrial levels [4–6]. In fact, nanotechnology has the potential to improve the entire current agricultural and food industry, by developing new tools for plant disease treatments [7], pathogen detection [8], and improving the ability of plants to absorb nutrients [9, 10]. Furthermore, nanotechnology started to attract more intention in the agriculture field especially to produce new nanofertilizers for increasing the efficacy and bioavailability of such new fertilizers as well as decreasing the loss of these materials to the surrounding environment [11]. Many researchers illustrated that the agromorphological criteria, photosynthesis, and the yield of wheat plant [12] and common bean [11] were improved by the application of ZnO-NPs as a foliar fertilizer. Furthermore, Khodakovskaya et al. [13] found that carbon nanoparticles improve the plant criteria and the yield of the tomato.

Du et al. [14] represented that the ZnO-NPs were more significantly effective on the germination and growth of wheat rather than $ZnSO_4$. In addition, they showed that $ZnSO_4$ was more toxic than ZnO-NPs at higher dosages. In addition, Shaban et al. [15] showed that the common bean that is obtained from the plant treated by ZnO-NPs has no effect on the lipid parameters as well as the function of the kidney and liver of the rats that feed on this common bean.

Iron, manganese, and zinc are three essential elements for the growth of many plants including squash [16–19]. A

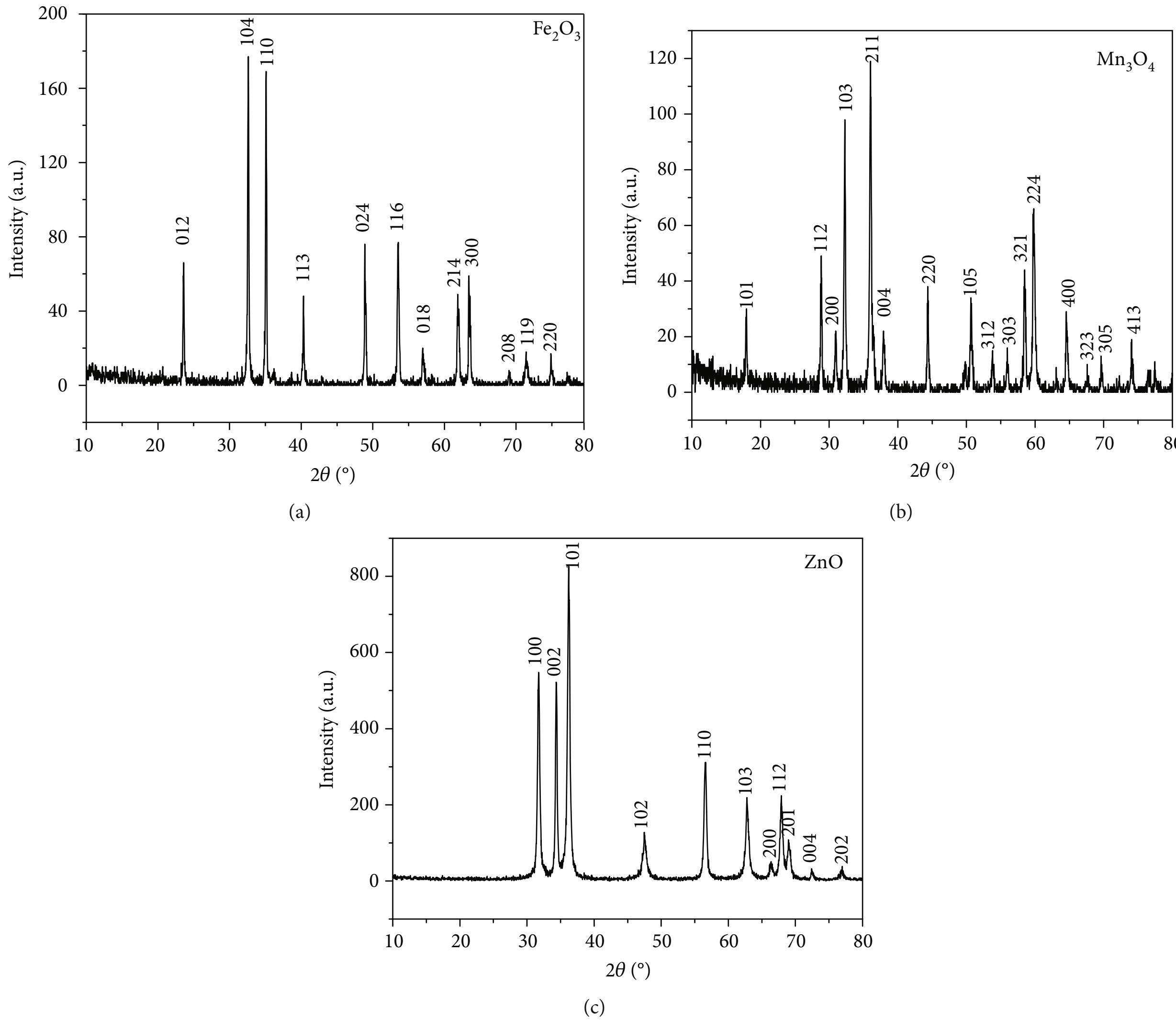

Figure 1: XRD patterns of the prepared nanooxides (a) Fe_2O_3, (b) Mn_3O_4, and (c) ZnO.

microwave-assisted hydrothermal synthesis technique has been chosen for the preparation of these elements in the form of their respective oxides as nanofertilizers in this study. It is a widely used technique in many areas of chemistry especially in metal oxide nanoparticle synthesis [20, 21]. This method is a facile, fast, secure, controllable, and energy-saving process [22, 23]. It also provides an effective way to control particle size distribution and macroscopic morphology during the synthesis process [20].

This study is aimed at investigating the efficacy of such nanofertilizers towards the growth and yield of squash. The fertilization process was accomplished using each nanooxide alone; besides, their combinations contained two oxides together: zinc-iron, zinc-manganese, and manganese-iron, as well as the three nanooxides mixed together.

2. Materials and Methods

2.1. Preparation of Nanofertilizers. Ferric, manganese, and zinc nitrate analytical grade salts were used as precursor for the preparation of the nanooxide fertilizers, using a green microwave-assisted hydrothermal method. The desire amounts of $Fe(NO_3)_3{\cdot}9H_2O$, $Mn(NO_3)_2{\cdot}4H_2O$, or $Zn(NO_3)_2{\cdot}6H_2O$ were dissolved in 50 mL water to obtain 0.2 M salt concentration. The pH of this solution was adjusted to 11 using 2 M NaOH solution and then transferred to 100 mL Teflon autoclave vessel. The vessel was then transferred to a 750 w advanced microwave synthesis lab station (Milestone MicroSYNTH). The microwave was adjusted to reach the desired temperature in 3 min, and then the temperature was held constant for 10 more minutes to ensure the production of the desired nanooxides. The holding temperatures were 100, 160, and 180°C for Mn_3O_4, ZnO, and Fe_2O_3, respectively. The obtained oxides were then washed 3 times with water to get rid of all the unreacted salts, dried at 100°C overnight, grinded, and then stored in a desiccator under anhydrous calcium chloride for further characterizations and studies.

2.2. Characterization of Nanofertilizers. A PHILIPS® X'Pert diffractometer, with the Bragg-Brentano geometry and copper tube, was used to collect the XRD patterns for

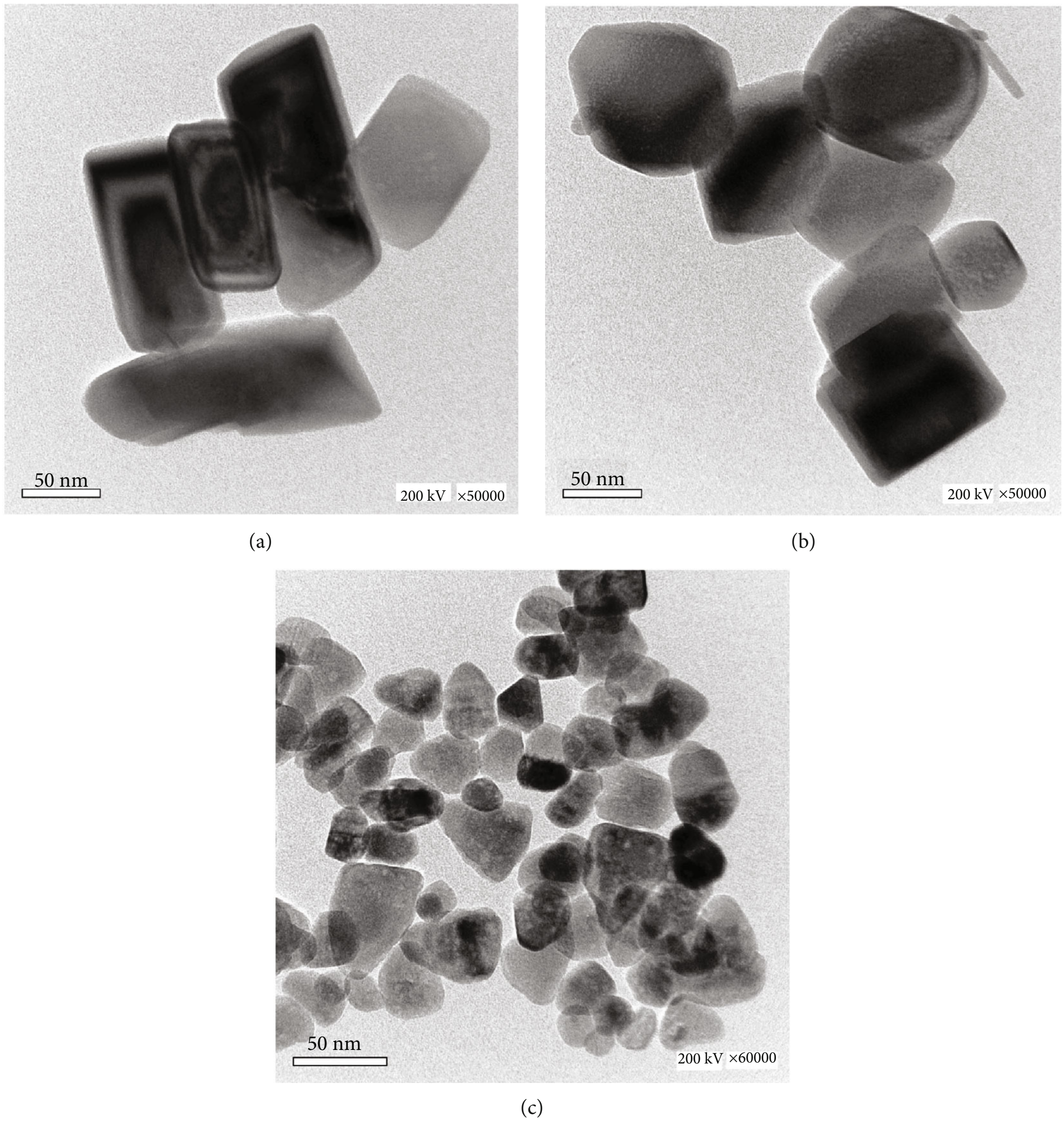

Figure 2: TEM diagrams for the prepared nanoparticles Fe_2O_3 (a), Mn_3O_4 (b), and ZnO (c).

the prepared nanooxide samples. The operating voltage was kept at 40 kV and the current at 30 mA. The divergence-slit angle = 0.5°, the receiving slit = 0.1°, the step scan size = 0.03°, and the scan step time = 2 seconds. The K_β radiation was eliminated using the secondary monochromator at the diffracted beam. The scanning electron microscope (SEM), model: Quanta 250, with high-resolution field emission gun (HRFEG, Czech), and high-resolution transmission electron microscope (HR-TEM), model: JEM2100, Japan, were used to study the morphology and particle size and shape of the prepared fertilizers. The adsorption-desorption isotherm of purified N_2 at 77 K was carried out using the BELSORP-mini apparatus (BEL Japan, Inc.) that allowed prior outgassing to a residual pressure of 10^{-5} Torr at 100°C overnight to remove all moisture adsorbed on sample surface and pores.

2.3. The Agriculture Processes. This study is aimed at assessing the effect of micronutrient oxide nanoparticles (zinc, iron, and manganese) as well as their combinations (zinc+iron, zinc+manganese, iron+manganese, and iron +manganese+zinc) as a foliar application on the growth, yield, and quality of squash plants.

2.3.1. Experiment Planning. Seeds of squash (cv. Eskandarani F1) were provided from the Agricultural Research Centre, Ministry of Agricultural and Land Reclamation. Seeds were sown on March 1st in clay soil in Shebin El-Kom, El-Monifia governorate, Egypt, during two seasons 2017 and 2018 and then sown at a rate of one seed per hill and 50 cm distance between the hills on one side of the ridge [24].

2.3.2. Experiment Treatments. Squash plants were sprayed with zinc, iron, manganese, zinc+iron, zinc+manganese, iron+manganese, and iron+manganese+zinc in the form of oxide nanoparticles with a concentration of 20 ppm for all treatments as compared to control. The experiment was set

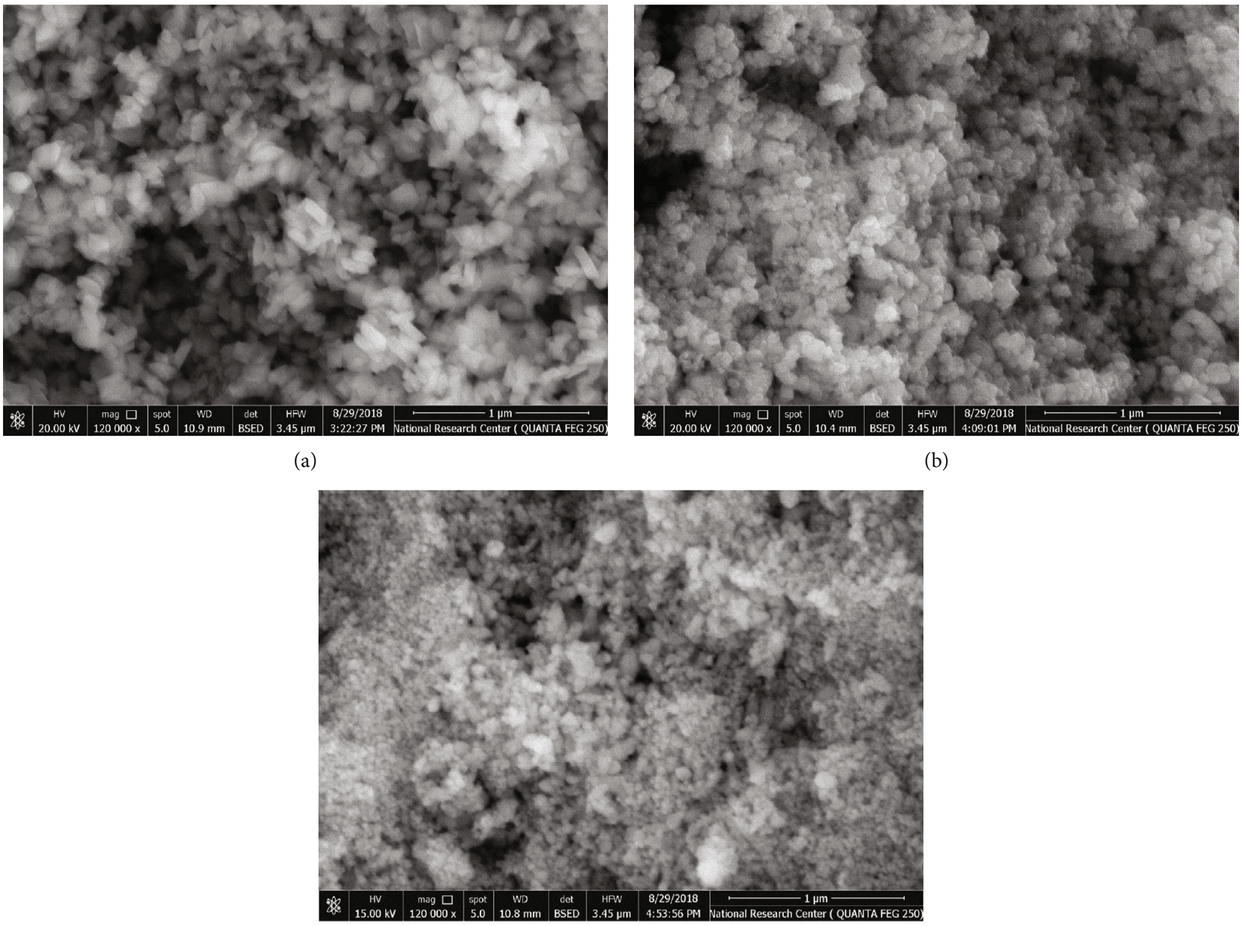

Figure 3: SEM diagrams for the prepared nanoparticles Fe_2O_3 (a), Mn_3O_4 (b), and ZnO (c).

Table 1: The BET surface characterization of nanooxides.

Oxide nanoparticles	Surface area (m^2 g^{-1})	Average pore radius (nm)	Total pore volume (cm^3 g^{-1})
Fe_2O_3	14.67	5.27	0.0387
Mn_3O_4	20.94	7.77	0.0814
ZnO	29.08	8.55	0.1244

in a complete randomized block design with three replicates for each particular treatment.

Squash plants were sprayed with treatments after 20 days from the sowing of the seeds. The fertilization, irrigation, and resistance to weeds and diseases of squash plants were carried out according to the recommendations of the Ministry of Agriculture.

2.3.3. Data Recorded. Five plants of squash plants were randomly taken from each experimental plot after 35 days from planting the seeds for measuring the vegetative growth parameters as expressed as plant length, the number of leaves/plant, leave area/plant, and fresh and dry weight of the whole plant. The plants were harvested to determine the fruit length, fruit diameter, yield/plant, and the yield (t/ha). The fruits of the squash plants were collected for a month after 40 days from sowing.

2.3.4. Chemical Analyses. Fresh samples of squash (leaves and fruits) were dried in an oven at 60°C till constant weight, and then dried sample was taken for proximate analysis (100 g dry weight basis) and mineral determination. The following chemical analyses were determined:

(1) Photosynthetic Pigments. Photosynthetic pigments were determined in fresh leaves (35 days from sowing) by a spectrophotometer according to Lichtenthaler and Wellburn [25].

(2) Proximate Analysis. Organic matter, carbohydrates, protein, lipids, ash, and fiber were determined according to AOAC [24, 26]. The energy value was calculated using the water factor method ((9 × fat) + (4 × carbohydrate) + (4 × protein)) [27].

(3) Mineral Determination. The minerals were determined according to the method described in the AOAC [24]. Where nitrogen was determined by Kjeldahl-N, phosphorus was determined by a spectrophotometer, while the iron, zinc, and manganese were analyzed by atomic absorption, and potassium was determined by a flame spectrophotometer.

2.4. Statistical Analysis. All data were subjected to statistical analysis according to the procedures reported Kobata et al. [28]. The data obtained were subjected to analysis of variance (ANOVA) and analyzed for statistically significant differences using the LSD test at a 5% level.

3. Results and Discussion

3.1. The Nanofertilizer Characterization

3.1.1. X-Ray Diffraction. The crystal structure of the prepared nanooxides was investigated using X-ray diffraction measurements, and the results are shown in Figure 1. The prepared iron oxide nanoparticles showed the patterns corresponding to Fe_2O_3 [29] such as (012), (104), and (110), as shown in Figure 1(a). On the other hand, the manganese XRD patterns displayed in Figure 1(b) matched well with tetragonal hausmannite demonstrating the successful preparation of Mn_3O_4 [30]. Figure 1(c) is showing the XRD patterns of the prepared zinc oxide. All the obtained crystal patterns matched the patterns corresponding to ZnO. The XRD patterns of all the samples confirm the purity of all prepared oxides, and no other impurities were detected [31].

The XRD study proves the successful preparation of pure Fe_2O_3, Mn_3O_4, and ZnO as nanoparticles. The average crystallite size of such materials was calculated using the Scherrer equation. The obtained crystallite size was 51.6, 56.0, and 36.8 nm for Fe_2O_3, Mn_3O_4, and ZnO, respectively. The values indicated that all the prepared materials were in the nanoscale range.

3.1.2. Oxide Nanoparticle Morphology and Textural Analysis. The transmission and scanning electron microscope diagrams of the prepared nanooxides are shown in Figures 2 and 3, respectively. The average particle size of the prepared nanooxides was around 20-60 nm. Although the materials showed a large particle size, it is still inside the nanorange below 100 nm. Such large size can be contributed to the absence of stabilizers during the synthesis process. This absence was necessary to avoid introducing any foreign component contaminated with the prepared nanooxides during the agriculture process.

The TEM diagrams of Fe_2O_3 and Mn_3O_4 nanoparticles showed a uniform diamond shape of such oxides as shown in Figures 2(a) and 2(b), respectively. However, the regularity in particle shape in case of Fe_2O_3 is clearly observed and much improved than in Mn_3O_4. This observation is supported by SEM images of Fe_2O_3 and Mn_3O_4 as illustrated in Figures 3(a) and 3(b), respectively, where the particles of F_2O_3 are aggregated forming a clear parallelepiped rectangle structure than in the case of Mn_3O_4.

On the other hand, the TEM image of ZnO nanoparticles exhibited a small size compared to the other nanoparticles; however, ZnO nanoparticles showed less uniform crystal shapes (Figure 2(c)). Moreover, the SEM image of ZnO (Figure 3(c)) reveals the ingathering of these small size particles constructing an enhanced close packing texture compared to other oxides.

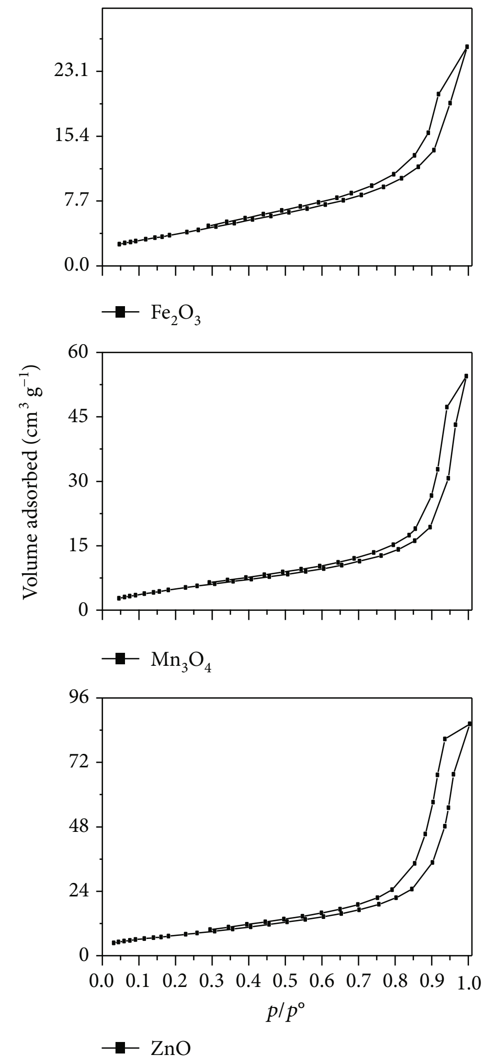

Figure 4: Adsorption-desorption isotherms of N_2 at 77 K on nanooxides.

3.1.3. Surface Area and Pore Structure Analysis of Prepared Oxide Nanoparticles. The main surface and pore structure characteristics of the synthesized nanooxides were studied using nitrogen gas adsorption at liquid nitrogen temperature (77 K), and the results are summarized in Table 1. The adsorption-desorption isotherms for all oxide nanoparticles exhibit type II according to the classification of Brunauer-Deming-Deming-Teller [32, 33], with an H3 hysteresis loop [33, 34] as shown in Figure 4. This type of hysteresis arises from the assemblage of loosely coherent particles of a plate-like form giving a rise to slit-shaped pores. Besides, the closure of the hysteresis loops at a low p/p° value (<0.4) indicates the presence of some pores of barely accessible entrances [35].

As expected, ZnO nanoparticles showed the highest surface area due to its small particle size compared to the two other nanooxides. Moreover, the small surface area of Fe_2O_3 nanoparticles could be due to the high holding temperature during the microwave synthesis process which caused

Table 2: Effect of nanooxides on vegetative growth characters of squash plant during two seasons 2017 and 2018.

Nanooxides	Plant length (cm)		No. of leaves/plant		Leave area/plant (m^2)		Plant weight (g/plant) Fresh		Plant weight (g/plant) Dry	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Control	44.4	44.2	18.0	17.7	0.57	0.57	216.6	214.0	27.1	27.0
Zn	50.7	50.4	16.7	17.0	0.86	0.88	286.8	282.3	27.1	27.1
Zn+Mn	53.0	52.1	15.4	15.7	0.96	0.97	291.2	295.1	27.9	27.8
Zn+Fe	55.1	54.7	16.7	16.7	1.01	0.95	339.8	330.1	33.4	33.3
Fe	56.4	56.0	20.0	19.7	0.91	0.94	368.5	364.2	34.6	34.5
Fe+Mn	53.5	53.4	21.7	22.0	1.01	1.01	312.6	307.0	34.4	34.0
Mn	58.2	57.7	24.4	24.0	1.20	1.19	381.8	387.9	24.4	24.1
Fe+Mn+Zn	45.6	45.4	14.4	14.7	0.67	0.67	247.7	247.0	25.5	25.3
LSD at 5%	**2.08**	**1.92**	**2.23**	**1.91**	**0.18**	**0.16**	**51.44**	**40.62**	**5.32**	**5.27**

Table 3: Effect of nanooxides on yield characters of squash plant during two seasons 2017 and 2018.

Nanooxides	Fruit Length (cm)		Fruit Diameter (cm)		Yield kg/plant		Yield t/ha	
	2017	2018	2017	2018	2017	2018	2017	2018
Control	11.3	11.2	2.37	2.35	0.85	0.83	34.05	33.36
Zn	11.2	11.2	2.60	2.58	1.10	1.11	43.81	44.32
Zn+Mn	12.3	12.2	2.68	2.67	0.90	0.92	36.06	36.69
Zn+Fe	12.1	12.0	2.65	2.63	0.96	0.97	38.24	38.83
Fe	12.8	12.7	2.62	2.60	1.09	1.06	43.80	42.53
Fe+Mn	11.6	11.6	2.70	2.70	1.00	1.00	40.11	40.05
Mn	12.0	11.9	2.70	2.72	1.14	1.16	45.43	46.29
Fe+Mn+Zn	11.8	11.8	2.48	2.47	0.97	0.98	38.92	39.28
LSD at 5%	**0.59**	**0.62**	N.S.	N.S.	**0.08**	**0.09**	**3.31**	**3.73**

N.S = not significant ($p < 0.05$).

the larger particle size as well as the sintering of the surface-active sites.

3.2. The Squash Planting Process

3.2.1. Effect of Nanooxides on Vegetative Growth Characters of Squash Plant. Data presented in Table 2 indicated that the oxide nanoparticles recorded a significant increase in vegetative growth characters of the squash plant. Plant length, number of leaves per plant, leaf area per plant, and plant fresh weight of squash plant were significantly increased by spraying plants with Mn nanooxide as compared to other treatments. On the contrary, plant dry weight is enhanced with Fe nanooxide and followed by Fe+Mn nanooxides. These results were well held in the two experimental seasons. These results might be due to the function of manganese. The manganese plays a vital role in chlorophyll synthesis, and its occurrence is important in photosystem II, also involved in cell division and plant development [36–38].

3.2.2. Effect of Nanooxides on Vegetative Growth and Yield Characters of Squash Plant. Results in Table 3 revealed that the best fruit length of squash plant is recorded with plants treated with Fe nanooxides compared with other treatments. On the other hand, fruit diameter and yield (kg/plant and t/ha) of fruit squash were significantly affected with Mn nanooxides during two successive seasons 2017 and 2018. At a significant level of 5%, all parameters showed significance, except for fruit diameter which was not significant. This result is due to the better results for vegetative growth with manganese as described in this study in Table 2 and also may be due to enhanced plant nutrition and mounting photosynthesis in squash plants; thus, yield and quality of squash plants may enhance by increasing photosynthetic efficiency [37]. These results were in harmony with those reported by [39] on potato, [40, 41] on potato, [37] on crop production, and [42] on pumpkin.

3.2.3. Effect of Nanooxides on Photosynthetic Pigments of Squash Leaves. Data recorded in Figure 5 showed clearly that the nanooxides as a foliar application increased the content of photosynthetic pigments expressed as chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids in squash leaves as compared to control. The application of manganese nanooxide as foliar on squash plants enhanced the content of chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids in the leaves followed by plants supplied with iron and zinc nanooxides compared with other treatments, during the seasonal study. This result might be attributed to the function of manganese in the process of photosynthesis, which turns the light of the sun into plant energy, which affects the formation

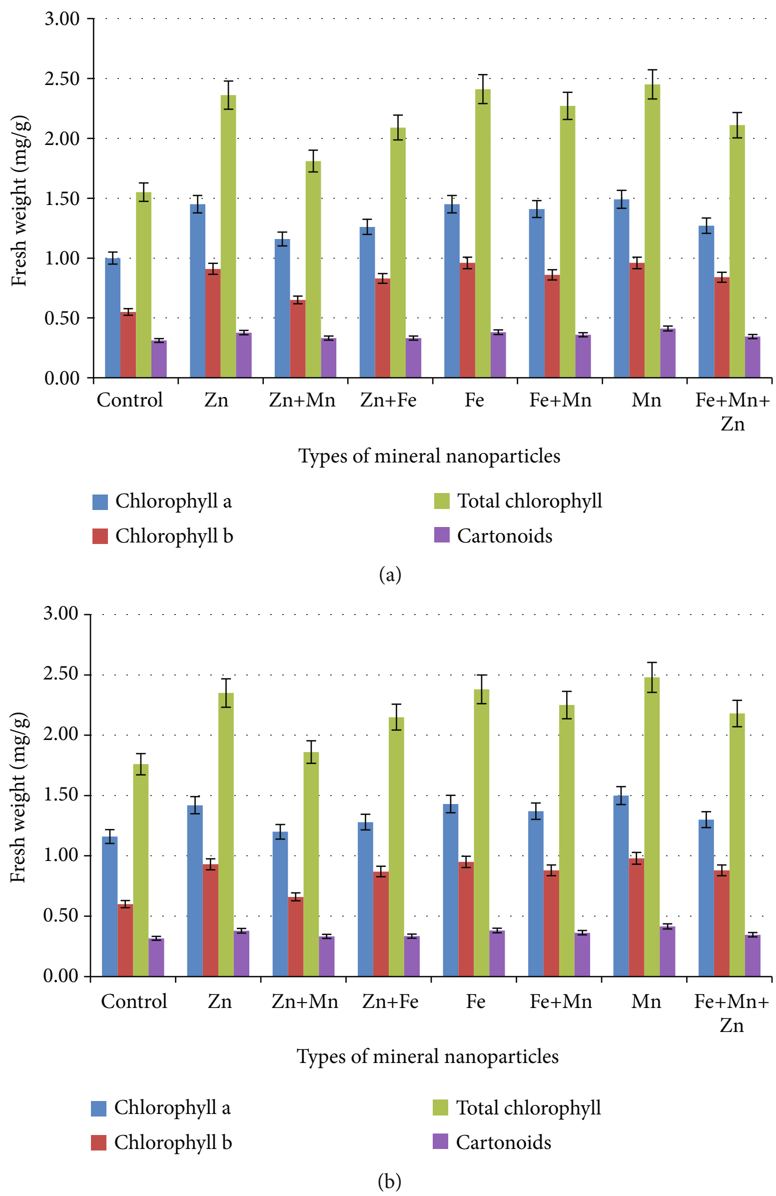

Figure 5: Effect of nanooxides on photosynthetic pigments of squash leaves during two seasons 2017 (a) and 2018 (b).

of green plastids in the leaves and the production of chlorophyll [38, 43].

3.2.4. Effect of Nanooxides on Proximate Components of Leaves and Fruits of Squash Plant. Data presented in Table 4 showed that the nanofertilizers foliar fertilizer significantly increased the proximate components of the leaves and fruits of squash plant, during two seasons 2017 and 2018. The content of organic matter, protein, and total energy recorded the higher levels in the leaves of squash plants that had been sprayed with manganese nanooxide. These results might be due to manganese which is used in plants as the main contributor to a variety of biological systems including photosynthesis, respiration, and nitrogen assimilation [37]. While the highest ash content percentage was obtained by using iron nanooxide, as for the fiber content in the leaves, it showed the best ratio with the treatment of iron+manganese nanooxides. Lipid ratio showed the best value in the leaves with plants treated with zinc+iron nanooxides. On the other hand, traditional agriculture (control) recorded the highest percentage of the carbohydrate content in leaves. This result might be due to the interaction between minerals and their effect on the metabolite translocation from the leaves to the other organs of the plant [37].

Data in Table 4 showed that the content of proximate components of squash fruits was affected by types of nanooxides. The highest value of carbohydrate and total energy is recorded with control in squash fruits. On the contrary, iron nanooxide showed the best percentage of organic matter, protein, and lipid in the fruits compared with other treatments. These results may be due to iron which is involved in protein metabolism in plants [44]. The fiber content in fruits was significantly increased by plants supplied with Zn+Mn nanooxides. On the other hand, the percentage of ash

Table 4: Effect of nanooxides on proximate components of squash leaves and fruits during two seasons 2017 and 2018.

Nanooxide	Organic matter (%)		Protein (%)		Fiber (%)		Lipids (%)		Carbohydrate (%)		Ash (%)		Total energy (K cal/g)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
							Leaves							
Control	69.47	69.33	21.43	21.40	9.69	9.70	1.72	1.70	36.63	36.53	30.53	30.67	247.72	247.02
Zn	68.60	68.55	21.19	21.20	10.89	10.90	1.77	1.75	34.75	34.70	31.40	31.45	239.69	239.35
Zn+Mn	70.82	70.65	23.19	23.20	10.71	10.70	2.09	2.00	34.83	34.75	29.18	29.35	250.89	249.80
Zn+Fe	69.12	68.96	21.30	21.26	10.14	10.00	2.71	2.70	34.97	35.00	30.88	31.04	249.47	249.34
Fe	66.79	66.98	21.79	21.80	12.06	12.10	1.59	1.88	31.35	31.20	33.21	33.02	226.87	228.95
Fe+Mn	67.40	67.00	22.36	22.30	13.62	13.50	1.55	1.50	29.87	29.70	32.60	33.00	222.87	221.50
Mn	70.93	70.80	28.41	28.40	10.61	10.60	2.24	2.20	29.67	29.60	29.07	29.20	252.48	251.80
Fe+Mn+Zn	70.80	70.50	24.81	24.80	11.64	11.60	2.35	2.30	32.00	31.80	29.20	29.50	248.39	247.10
LSD at 5%	**0.75**	**0.65**	**0.14**	**0.11**	**0.34**	**0.33**	**0.15**	**0.25**	**0.57**	**0.57**	**0.75**	**0.65**	**1.92**	**2.33**
							Fruit							
Control	76.13	75.74	27.75	27.58	15.98	16.23	1.79	1.85	30.61	30.07	23.87	24.26	249.55	247.31
Zn	75.81	75.53	29.79	29.78	19.07	19.10	2.95	2.98	24.00	23.67	24.19	24.47	241.72	240.64
Zn+Mn	73.02	73.10	25.18	25.15	22.02	22.03	3.00	3.10	22.82	22.82	26.98	26.90	219.00	219.78
Zn+Fe	72.80	72.75	25.47	25.41	21.11	21.07	2.56	2.56	23.66	23.71	27.20	27.25	219.56	219.51
Fe	76.07	76.01	30.20	30.23	19.40	19.50	3.48	3.39	22.99	22.89	23.93	23.99	244.08	242.97
Fe+Mn	71.61	71.69	28.00	28.10	20.03	20.01	2.47	2.51	21.11	21.07	28.39	28.31	218.70	219.25
Mn	73.36	73.34	27.25	27.15	19.85	19.85	2.84	2.86	23.42	23.48	26.64	26.66	228.25	228.25
Fe+Mn+Zn	73.92	73.85	29.40	29.30	20.09	20.03	2.63	2.65	21.80	21.87	26.08	26.15	228.47	228.55
LSD at 5%	**1.10**	**1.04**	**0.25**	**0.30**	**0.18**	**0.17**	**0.11**	**0.19**	**1.31**	**1.26**	**1.10**	**1.04**	**4.82**	**4.69**

showed the best value with Fe+Mn nanooxides. This result may be due to manganese function with other minerals zinc and iron [37].

3.2.5. Effect of Nanooxides on Mineral Content of Leaves and Fruits of Squash Plant. Data in Table 5 indicated that the nanooxides significantly increased the endogenous minerals in the leaves and fruits of squash plant during the two seasons of study. Nitrogen percentage appeared increment in squash leaves through plants spraying with manganese nanooxide compared to other nanooxide. This effect might be due to the relations between the different ions of the minerals and their translocation from the leaves to the fruits. The best content of manganese and iron in squash leaves showed with plants spraying with zinc nanooxide. This result might be due to manganese and iron concentrations enhanced significantly with the zinc application [37]. Zinc is led to iron transfer from root to shoot [45, 46]. While the squash plants, which were treated by Zn+Mn nanooxide, recorded the maximum percentage of phosphorus and potassium in leaves, iron+manganese nanooxide gave the highest value of zinc content in leaves. These results might be due to manganese interaction with other elements [38].

The effect of different nanooxides on the mineral content of squash fruit is presented in Table 5, spraying nanooxides on squash plants had a significant effect on squash fruit content of the elements. The iron nanooxide showed a significant effect on the content of nitrogen in the fruit of squash plants. The highest value of phosphorus was recorded with zinc +manganese nanooxides. In this trend, Fe+Mn nanooxides enhanced the content of potassium and iron in fruits, while Zn+Fe nanooxides improved the content of manganese in fruits. The maximum content of zinc in fruits appeared with Fe+Mn+Zn nanooxides. These results might be due to the role of the elements in metabolic processes and penetration to the plant cell, and also, manganese function is closely related to iron [47]. Also, Roosta et al. [48] showed that the nano-Fe-chelate has a valuable result on the content of manganese and zinc in lettuce plant. The trend of obtained results is in good accordance with Schmidt et al. [38], who found that manganese is an important micronutrient with an indispensable role as a catalyst in the oxygen-evolving complex of photosystem, respiration, and nitrogen assimilation. It is necessary by plants in the second greatest quantity compared with ferric. Thus, manganese competes with the micronutrients (Fe, Zn, Cu, Mg, and Ca) for uptake by the plant.

The privilege of using such nutrients in the nanoscale is to increase its ability towards diffusion through the pores of the plant cell. In addition, the mutagenic can occur in the plant by these nanomaterials improving its growth and yield [11, 49].

4. Conclusion

Zinc, manganese, and iron nanooxides have been successfully synthesized via a green chemistry technique using a microwave-assisted hydrothermal method. The resulted nanooxides have an average particle size around 20-60 nm and small surface areas. These oxides were applied as a foliar nanofertilizer on squash plants. The use of the prepared

Table 5: Effect of nanooxides on the minerals of leaves and fruits of squash plant.

Nanooxides	N%		P%		K%		Zn (ppm)		Mn (ppm)		Fe (ppm)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
Leaves												
Control	3.48	3.48	0.12	0.13	2.40	2.45	48.00	49.00	53.00	52.67	120.00	118.33
Zn	3.45	3.45	0.23	0.22	3.00	3.07	53.00	53.33	149.00	148.00	225.00	221.67
Zn+Mn	3.77	3.77	0.45	0.43	6.40	6.30	60.00	61.00	44.00	45.00	65.00	66.00
Zn+Fe	3.46	3.46	0.13	0.14	3.80	3.80	145.00	143.33	61.00	60.33	80.00	82.33
Fe	3.54	3.54	0.15	0.16	3.44	3.46	78.00	77.33	53.00	52.33	105.00	103.33
Fe+Mn	3.64	3.63	0.15	0.15	5.80	5.73	77.00	77.67	56.00	57.00	93.00	93.00
Mn	4.62	4.62	0.32	0.31	3.80	3.80	123.00	121.00	105.00	103.33	95.00	98.00
Fe+Mn+Zn	4.03	4.03	0.31	0.32	4.28	4.23	130.00	128.67	79.00	77.67	115.00	116.33
LSD at 5%	**0.02**	**0.02**	**0.01**	**0.02**	**0.11**	**0.15**	**2.39**	**3.20**	**1.81**	**2.14**	**2.48**	**4.76**
Fruit												
Control	4.51	4.49	0.24	0.23	4.20	4.17	62.00	61.33	59.00	59.33	59.00	58.33
Zn	4.84	4.84	0.13	0.13	4.60	4.53	89.00	88.67	45.00	45.33	86.00	85.00
Zn+Mn	4.09	4.09	0.59	0.58	4.60	4.57	71.00	70.33	50.00	50.67	67.00	67.00
Zn+Fe	4.14	4.13	0.08	0.09	4.20	4.17	88.00	87.33	70.00	70.00	54.00	53.67
Fe	4.91	4.92	0.31	0.32	4.00	3.90	81.00	80.33	59.00	58.67	62.00	61.33
Fe+Mn	4.55	4.57	0.22	0.22	4.80	4.83	92.00	91.00	43.00	43.67	134.00	133.67
Mn	4.43	4.41	0.55	0.54	4.08	4.09	81.00	80.00	68.00	67.33	76.00	75.00
Fe+Mn+Zn	4.78	4.76	0.14	0.15	2.28	2.30	119.00	118.33	57.00	56.33	62.00	61.00
LSD at 5%	**0.04**	**0.05**	**0.02**	**0.02**	**0.10**	**0.11**	**1.04**	**1.62**	**0.80**	**1.07**	**1.15**	**1.66**

nanooxides as a foliar application improved the growth and the yield in comparison with untreated plants. Furthermore, the yield (kg/plant and tons/hectare) of fruit squash was significantly affected with Mn nanooxide especially when it is used individually or combined with Fe nanooxide. Also, the content of organic matter, protein, lipids, and energy recorded the higher levels in fruits of squash plants that have been sprayed with Fe nanooxide.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no competing interests.

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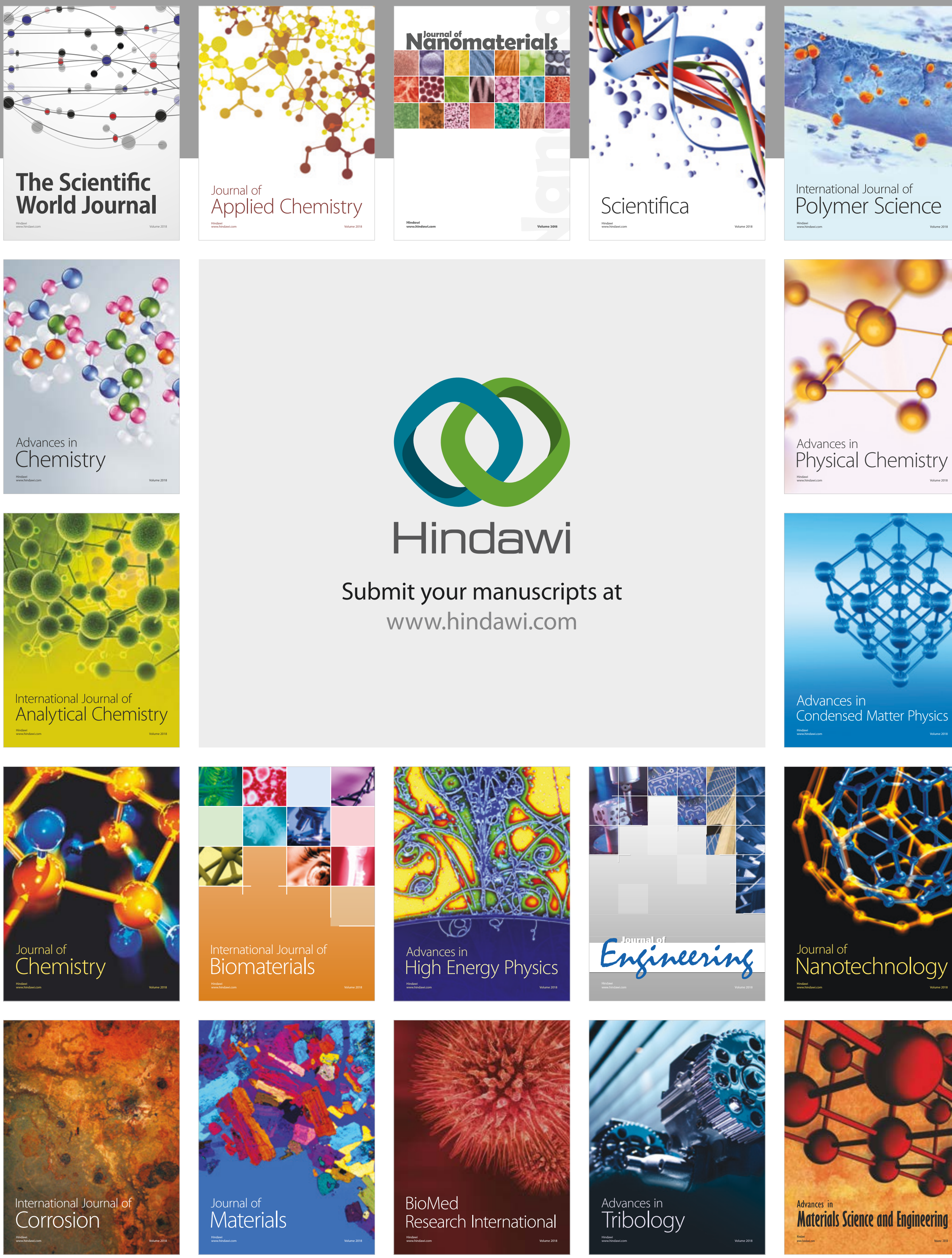

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