Iraqi Journal of Desert Studies 2024, 14 (2): 55-65 **Original Article**

The Role of NPK Nanofertilizer in Improving the Chemical Properties, Yield, and Quality of Three Oat Cultivars

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Abstract:

A field experiment was carried out during the growing seasons of 2022 and 2023 in the field of Al-Mashrooh, 37 km north Babil Governorate. to investigate effects of NPK nanofertilizer on three oats cultivars (Genzania, Carolup and Hamel) at three growth stages under split-split plot design with four replications. The main plots were three oat cultivars, the sub-plots three spraying stages (elongation, booting and flowering), and the sub-sub plots three Nano-NPK concentrations levels (0, one, and tow $g_{\ L}^{-1}$). Results showed significant difference among cultivars. In vegetative system, Carolup achieved the highest N. (1.73 and 1.78% N), P. (0.35 and 0.36 % P), and K. concentrations (2.23 and 2.28% K); whilst it has higher grain protein content (10.85% and 11.13%) and carbohydrate contents (18.76% and 20.13%) across both seasons. Highest grain yield in the first season was observed for Hamel (6.21 tons ha^{-1}) and Carolup recorded highest grain yield during 2nd year with a Averages value of 6.56 tons ha-1. The booting growth stage spraying enhanced all the traits significantly and obtained maximum N (1.75% & 1.80%) P (0.35 %& 0.32%), K (2.34 %& 2,40. %), total grain yield (6.72- and 6.89-tons ha^{-1}), protein (11.18% and 11.00%), and carbohydrate content (17.86% and 20.00%). Application of NAN0-N.P.K. at a concentration of 1 g L^{-1} significantly improved plant growth, overall yield, and grain quality. The combination of Carolup, booting stage spraying, and 1 g L^{-1} was most effective, yielding the highest nitrogen in vegetative growth (1.92% and 1.97%), total grain yield (7.61- and 8.11-tons ha^{-1}), and grain protein content (12.65% and 12.86%) for both seasons.

Keywords: Avena sativa, Nanotechnology, Chemical fertilizers, Chemical content

دور السماد NPK النانوي في تحسين الصفات الكيمائية والحاصل ونوعيته لثلاثة أصناف من الشوفان

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الملخص:

نفذت هذه التجربة في احد البيوت الزجاجية التابعة لكلية الزراعة - جامعة الانبار ،لدراسة تأثير إضافة ال NPK والرش بالسايتوكانينCPPU في النمو الخضري والجذري لنبات المطاط البراق Ficus nitida L ، تضمنت التجربة عاملين ،العامل الأول هو السماد الكيميائي NPK بأربع تراكيز وهي F0 بدون إضافة ،والتركيز الثاني F1 مزيج من الأسمدة 1غم من اليوريا +3 غم داب +2 غم كبريتات البوتاسيوم ، التركيز الثالث F2 2غم يوريا +6 غم داب +4 كبريتات البوتاسيوم ،التركيز الرابع F3 مزيج من الأسمدة 3غم يوريا +9 غم داب +8 غم كبريتات البوتاسيوم اما العامل الثاني وهو السايتوكانين CPPU بثلاث تراكيز التركيز الأول C0 بدون إضافة ،والتركيز الثاني C1 بلغ 3ملغم لتر-1 ،والتركيز الثالث C2 وكان 6ملغم لتر-1 ،صممت التجربة باستخدام تصميم القطاعات العشوائية الكاملة (RCBD) بثلاث قطاعات وثلاث اصص للوحدة التجريبية الواحدة وبلغ كل قطاع 36 معاملة وبعدد 108 وحدة تجريبية لكافة القطاعات وتلخصت النتائج بالزيادة في عدد الافرع الثانوية ومساحة الافتراش النبات ومعدل قطر الافرع الثانوية ونسبة المادة الجافة للأوراق والمحتوى النسب للأوراق من مادة الكلوروفيل الكلي ونسب النيتروجين والبوتاسيوم في الأوراق وكانت النسب 47.333 سم و0.644 سم و7.160 ملم و23.964 %و1.443 ملغم غم -1 و2.860 % و1.923 %.

الكلمات المفتاحية: Avena sativa، تقانة النانو، الأسمدة الكيميائية، المحتوى الكيميائي للنبات

Introduction

The livestock sector in Iraq faces a clear shortage of fodder crops, which is critical given the importance of this sector as a fundamental part of agriculture, comparable in significance to the plant sector. This necessitates the get for crops with high productivity such as Avena sativa. Despite the successful cultivation of oats Our country, it is still grown on a limited scale (primarily for research purposes) to produce green fodder and grains, even though it contains a high oil content and significant protein levels, with grain protein content ranging from 9% to 12% in the grains. (Addaheri and Abood, 2020).

Oats are cultivated Single or mixed with alfalfa and clover. Some cultivars, such as Hamel, Carolup, and Genzania, have proven successful in Iraq in terms of grain yield. Oats are widely used around the world as livestock feed, whether as grains or green forage, due to their high feed quality and yield (Kim *et al.*, 2006), in

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addition to their nutritional and medicinal uses. Global oat production reached about 22,571,618 tons annually, with a cultivated area estimated at 9562497 hectares, with Russia ranking first in the world (FAO 2021).

The production of the crop is a reflection of the interaction between its genetic makeup, environmental conditions, and field practices. Understanding these aspects helps specialists determine the optimal time to add nutrients at the required concentrations, using the minimum amount necessary. This is crucial for improving chemical properties, increasing yield, and enhancing its quality. When introducing or developing a new breed, it is important to know what nutrients are needed. One reason for the low yields is the low fertility of most agricultural land around the world. Thus, more effective methods of organic fertilizer application should be explored, including foliar feeding using modern technology, which plays an important role in growth characteristics and crop yields in the forward direction

Researchers look for fertilizers that are more effective than synthetic fertilizers, comparing available resources and seeking alternatives if proven effective These include nanotechnology, which has been proposed as a scientific solution replacing conventional drugs. Nanotechnology provides a unique effect on plant growth and plays a major role in the smooth running of biological processes. It can improve chemical composition, increase yield, increase quality and reduce cost when used as a foliar spray. Moreover, nanomaterials have high adsorption capacity and penetration into plant cells (Gomaa et al., 2015; Hajira et al., 2017). Based on the above, this study was conducted to determine the optimum dosage and timing of application of NPK nanofertilizer to improve oat variety quality and achieve highest yield

Materials and Methods

The field surveys were conducted during the 2021-2022 and 2022-2023 hauling seasons at a private survey site in Al-Mashrooh province (37 km north of Babylon province), located at 32.79º north latitude and 44.40º longitude East. The study aimed to investigate the role of foliar feeding with NPK nanofertilizer on chemical properties, yield, and quality of three oat varieties. The experiment used a R.C.B.D. arranged in a twice split plot. The study included three factors:

1. The first factor was three oat cultivars (Genzai, Carrolup, and Hamel).
2. The second factor was the stages of NPK nanofertilizer application, with three stages (elongation, booting, and flowering).
3. The third factor was the application of balanced NPK nanofertilizer at three concentrations (0, 1, and 2 g L^{-1}).

Field operations such as plowing, leveling, and smoothing were performed before dividing the experimental field into 81 experimental units. These units were the result of the combinations of the study factors, with three replications for each. The experimental unit covered an area of each was 4 m² (2 m × 2 m), with each unit containing 8 rows spaced 20 cm apart. The main plot treatments were separated by 1-meter-wide borders. The soil was fertilized with superphosphate (46% P_2O_5) at a rate of 0ne hundred kg ha^{-1}, mixed into the soil before planting (Jadoa, 1995). Nitrogen fertilizer in the form of urea (46%N) was applied at a rate of experimental unit kg ha^{-1} in three doses: during emergence, during tillering, and at the booting stage. The cultivars were sown in rows at a seed rate of one hundred and twenty kg ha^{-1} (Addaheri and Abood, 2020) on 12/11/2021 and 13/11/2022 for the second season. Crop management practices, including irrigation, hoeing, and weeding, were performed as needed. Plants were harvested when signs of maturity such as complete redness and dry grains had appeared.

Characteristics studied:

Amount of nitrogen in plant systems (stems and leaves):

1.Nitrogen concentrations were measured in Ministry of Science and Technology laboratories, following the method described by Bremner and Mulvaney (1982) as described by Page et al. (1982) and their results.

2.Concentrations of phosphorus in plant systems (stems and leaves):

Phosphorus levels were also measured in laboratories of the Department of Science and Technology. he concentration of phosphorus in plant growth, roots, and grain was measured by a 10:4:1 mixture of three concentrated acids ($HNO3$, $HClO4$, and $H2SO4$) to measure the concentration of phosphorus in plant growth, roots, and in rice after wet oxidation as described by Jackson (1958). Potassium in plant systems - Concentration (Stems and Leaves):

3.Potassium levels were measured in laboratories of the Department of Science and Technology. A flame photometer was used to determine potassium concentrations in plant growth, roots, and seeds after wet oxidation, as described in the Phosphorus Measurement section

4. Rice yield (sales per hectare):
5. In each experimental study, grain yield was determined by weighing the harvested grain in the middle row of the previously harvested square meters. After manual threshing and separating the straw from the grains, the yield per square meter was calculated and then converted to tons per hectare.
6. **Protein Percentage in Grains:**

- A mixture of concentrated sulfuric acid and perchloric acid was treated with 0.2 g of ground grain according to the method proposed by Greiser-Parson (1979) and then the nitrogen content (%3) was measured by the Kjeldahl method (Bremner and Mulvaney, 1982). The protein percentage **ratio** in the grains was calculated using the following formula: Protein **ratio** =Nitrogen **ratio** ×6.25\text {Protein **ratio**} = \text {Nitrogen **ratio**} \times 6.25Protein Percentage=Nitrogen Percentage×6.25

7. **Carbohydrate ratio in Grains:**

- A 0.2 g ground sample of grains was taken, and the necessary steps for measuring carbohydrate content were followed. The analysis was conducted at a wavelength of 490 nanometers using a spectrophotometer. The carbohydrate percentage was then calculated according to the method by Joslyn (1970) using the following formula:

$$\text{Carbohydrate \%} = \frac{\frac{\text{volume of extract}}{\text{Sample weight}} \text{ x Dilution } x \text{ Device reading}}{10000}$$

Result

Nitrogen Content of Shoots (%).

The results presented in Table 1 show that Carolup recorded the highest amount of nitrogen during vegetative growth, with values of 1.73% and 1.78%, respectively. In contrast, Genzania had the lowest levels of nitrogen, with values of 1.64% and 1.70% in the different seasons. These findings are consistent with those of Mali et al. (2017), who reported variability in the ability of cultivars to absorb critical nutrients in a study on maize.

The amount of nitrogen available for plant growth was significantly different depending on the irrigation water in both seasons. Booting phase had the highest nitrogen content, with values of 1.75% and 1.80% in the different seasons, while elongation phase had the lowest average, values of 1.62% and 1.67% in both periods was recorded.

Similarly, the nitrogen content of plant growth also differed significantly at different rates of NPK nanofertilizer in two seasons The highest nitrogen content was recorded as 1 g NPK per liter, with values of 1.78% and 1.83% at respectively both seasons, while control treatment had the lowest average of two This increase in nitrogen content values of 1.55% and 1.62% for seasons could be attributed to increased application of NPK nanofertilizer, which produced leaves of the proportion and chlorophyll content increased, thus increasing the nitrogen content, which is important for amino acid formation embedded, and thus accelerates the transfer of nutrients from their site of absorption to other growth zones in the plant This is due to association with transport proteins and the ability to penetrate cell walls, encouraging increased sequestration of adsorbed material from the source to sink. (2010), and Al-Masoudi (2023) studied wheat. Interactions between species and spraying phase showed that the carolup × booting phase combination produced the highest nitrogen concentration, with values of 1.80% and 1.86% for both seasons on the contrary, respectively. genzania × expansion stage combination gave the lowest average for both seasons the differences were 1.59% and 1.65%. The interaction between species and nutrient levels showed that Carolup × 1 g L-1 combination had the highest nitrogen content, with values of 1.84% and 1.88% in both seasons, respectively the combined Genzania × Control rates were 1.84% and 1.88%, 1 in both periods, and the lowest .53% and 1.61%, respectively. The interaction between spray phase and fertilizer concentration showed that the booting phase × 1 g/L combination produced the highest nitrogen concentration, with values of 1.85% and 1.90% for both seasons, respectively the elongation phase × control combination had the lowest average, 1.49% and 1.58% in both periods. Finally, a three-way interaction between species, spraying time, and fertilizer rate showed that the carolup × booting stage × 1 g/L combination produced the highest nitrogen concentration, worth 1.92% and 1.97% in both periods, respectively. On the other hand, the Genzania × Extension Degree × Control combination yielded the lowest averages, averaging 1.46% and 1.56% for the two periods, respectively.

Table 1. Cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on nitrogen concentration in vegetative growth (%) of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1}				Second season (2022-2023) Nano NPK g L^{-1}			
		0	1	2	C * S	0	1	2	C * S
Genzania	Elongation	1.46	1.68	1.63	1.59	1.56	1.72	1.67	1.65
	Booting	1.58	1.76	1.71	1.68	1.65	1.81	1.78	1.75
	Flowering	1.55	1.71	1.65	1.64	1.62	1.77	1.75	1.71
Carolup	Elongation	1.52	1.73	1.71	1.65	1.58	1.76	1.73	1.69
	Booting	1.63	1.92	1.85	1.80	1.67	1.97	1.93	1.86
	Flowering	1.57	1.88	1.79	1.75	1.68	1.92	1.81	1.80
Hamel	Elongation	1.49	1.73	1.67	1.63	1.59	1.75	1.68	1.67
	Booting	1.57	1.87	1.82	1.75	1.65	1.92	1.85	1.81
	Flowering	1.55	1.76	1.67	1.66	1.62	1.89	1.81	1.77
		N. S			**N. S**		**N.S**		**8.10**
		0.154			**0.073**		**0.137**		**0.069**
C * N	Genzania	1.53	1.72	1.66	1.64	1.61	1.77	1.73	1.70
	Carolup	1.57	1.84	1.78	1.73	1.64	1.88	1.82	1.78
	Hamel	1.54	1.79	1.72	1.68	1.62	1.85	1.78	1.75
		0.089			**0.049**		**0.079**		**0.045**
		S * N			**Averages S**		**S * N**		**Averages S**
S * N	Elongation	1.49	1.71	1.67	1.62	1.58	1.74	1.6933	1.67
	Booting	1.59	1.85	1.79	1.75	1.66	1.90	1.85	1.80
	Flowering	1.56	1.78	1.70	1.68	1.64	1.86	1.79	1.76
			0.089		**0.042**		**0.079**		**0.040**
Averages N		1.55	1.78	1.72		1.62	1.83	1.78	
			0.051				**0.046**		

Phosphorus Concentration in Vegetative Growth (%)

Table (2) shows that Carolup recorded the highest amount of phosphorus during vegetative growth, with values of 0.35% and 0.36% in both seasons in contrast to Genzania which received the lowest amount, with values of 0.28% and 0.30 % for both periods. These differences may be due to the ability of the species to develop plant systems that efficiently use, absorb and metabolize the spray, and the amount of charcoal absorbed by the roots when the recommended feed rates are applied (Hellal et al, 2020).

Phosphorus concentrations in plant growth were significantly different depending on irrigation water in both seasons. The highest concentration of phosphorus occurred during the booting stage, with values of 0.35% and 0.32% for the different periods, while the elongation phase experienced the lowest increase, amounts of 0.29% and 0.27%, respectively. at both time points These data were recorded are consistent with those reported by Ali et al. (2016), and Al-Rubai (2019).

Phosphorus concentration in plant growth was significantly different at different rates of NPK nanofertilizer in both seasons. The highest concentration of phosphorus was recorded at the rate of 1 g NPK per liter, with values of 0.34% and 0.35% for the different seasons, respectively, while the control treatment achieved the lowest, with values of 0.30% and 0.32 % in both seasons This is due to NPK fertilizers It can be attributed to nanotechnology, characterized by small sizes (ranging from 1 to 100 nanometers) and high surface areas, which provide nutrient retention and rate of absorption by the plant is higher These findings are consistent with those reported by Kumar et al. (2014), Al-Saidan (2019), and Al-Shammari (2021) investigated the addition of phosphorus nanofertilizer to wheat crops.

The interaction between species and spraying phase showed that carolup × booting phase combination produced the highest phosphorus concentration, with values of 0.40% and 0.39% in both seasons, respectively, while genzania × parallax the combined phase recorded the lowest average, 0.25 in both periods the values were % and 0.27%. The interaction between species and nutrient levels showed that Carolup × 1 g L-1 combination had the highest phosphorus content, with values of 0.37% and 0.38% in both seasons, respectively The Genzania × Control combination had the lowest average, 0 in both periods the values were .26% and 0.29%, respectively. The interaction between spray phase and fertilizer concentration showed that the combination of booting phase × 1 g L-1 resulted in the highest concentration of phosphorus, with values of 0.37% and 0.37% for both seasons, respectively a hanging phase × control. The lowest combined percentages were recorded, with values of 0.27%

and 0.29% for both periods. Three-way interactions among species, spraying time, and fertilizer rate showed that the carolup × booting stage × 1 g L-1 combination produced the highest phosphorus concentration, with values of 0.42% and 0.41% in both seasons, respectively, while Genzania × expansion phase × control combination recorded the lowest averages, with values of 0.23% and 0.26% in both seasons between.

Table 2. Cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on Phosphorus Concentration in Vegetative Growth (%) of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1}				Second season (2022-2023) Nano NPK g L^{-1}			
		0	1	2	C * S	0	1	2	C * S
Genzania	Elongation	0.23	0.27	0.26	0.25	0.26	0.28	0.27	0.27
	Booting	0.28	0.31	0.31	0.30	0.31	0.34	0.33	0.33
	Flowering	0.27	0.28	0.28	0.28	0.31	0.33	0.31	0.32
Carolup	Elongation	0.29	0.33	0.32	0.31	0.32	0.35	0.34	0.34
	Booting	0.36	0.42	0.41	0.40	0.36	0.41	0.39	0.39
	Flowering	0.34	0.37	0.35	0.35	0.34	0.38	0.36	0.36
Hamel	Elongation	0.28	0.31	0.30	0.30	0.30	0.32	0.31	0.31
	Booting	0.32	0.38	0.36	0.35	0.34	0.37	0.36	0.36
	Flowering	0.31	0.36	0.33	0.33	0.33	0.36	0.34	0.34
		N. S			**N. S**		**N.S**		**8.10**
					0.045		**0.027**		**0.042**
C * N	Genzania	0.26	0.29	0.28	0.28	0.29	0.32	0.30	0.30
	Carolup	0.33	0.37	0.36	0.35	0.34	0.38	0.36	0.36
	Hamel	0.30	0.35	0.33	0.33	0.32	0.35	0.34	0.34
		0.026			**0.011**		**0.024**		**0.011**
		S * N			**Averages S**		**S * N**		**Averages S**
S * N	Elongation	0.27	0.30	0.29	0.29	0.29	0.32	0.31	0.27
	Booting	0.32	0.37	0.36	0.35	0.34	0.37	0.36	0.32
	Flowering	0.31	0.34	0.32	0.32	0.33	0.36	0.34	0.31
			0.026		**0.016**		**0.024**		**0.014**
Averages N		0.30	0.34	0.32		0.32	0.35	0.33	
			0.015				**0.014**		

Potassium Concentration in Vegetative Growth (%):

The Carolup cultivar exhibited the highest average potassium concentration in the vegetative growth, reaching 2.23% and 2.28% for the respective seasons (Table 3). In contrast, the Genzania cultivar recorded the lowest average, of 2.14% and 2.20% for both seasons respectively.

Potassium concentration in the vegetative growth varied significantly with different spraying times over both seasons. The booting phase showed the highest potassium content of 2.34% and 2.40% in the different seasons, while the elongation phase showed 1.97% and 2.04% in both seasons This finding al- This is consistent with the results reported in studies on wheat by Jaafar (2014) and Al-Azeeli (2023).

Similarly, the concentration of potassium in plant growth also differed significantly at different concentrations of NPK nanofertilizer in the two seasons the highest concentration of potassium reached 1 g NPK per liter on average, with the value were 2.27% and 2.33% for the different periods. 04% and 2.11% respectively

The interaction between species and spray phase showed that the carolup × booting phase combination produced the highest potassium concentration, with values of 2.29% and 2.36% for the two seasons, respectively. n contrast, the Genzania × elongation phase combination yielded the lowest average of 2.07% in the first period (2021-2022), while the Hamel × elongation phase combination yielded the lowest average of 2.14% in the second period (2022-2023). Interactions between species and nutrient levels showed that the carolup × 1 g L-1 combination provided the highest potassium levels, with average values of 2.32% and 2.38%

for the two seasons, respectively overall with, genzania × control in combination in the first period (2021-2022).) was found to be the lowest 2.01%, and the Hamel × control combination resulted in the lowest 2.09% in the second year (2022-2023) The interaction between spray phase and fertilizer rate showed that booting combined phase × 1 g L-1 The highest potassium concentration, with values of 2.34% and 2.40% were obtained in the two periods, while the combination of elongation phase × control recorded the lowest concentration, 1.97% and 2.04% . on both occasions. Finally, a three-way interaction between species, spraying time, and fertilizer concentration showed that the carolup × booting stage × 1 g L-1 combination produced the highest potassium concentration, with ne values are 2.38% and 2.47% for both periods, respectively. On the other hand, the Genzania × Elongation Phase × Control combination had the lowest growth rate of 1.91% in the first year (2021-2022), while the Hamel × Extension Phase × Control combination achieved the lowest growth rate of 1.99% during the second quarter period (2022-2023).

Table 3. Cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on Potassium Concentration in Vegetative Growth (%): of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1}				Second season (2022-2023) Nano NPK g L^{-1}			
		0	1	2	C * S	0	1	2	C * S
Genzania	**Elongation**	1.91	2.18	2.13	2.07	2.06	2.22	2.17	2.15
	Booting	2.08	2.26	2.21	2.18	2.15	2.31	2.28	2.25
	Flowering	2.05	2.21	2.19	2.15	2.12	2.27	2.25	2.21
Carolup	**Elongation**	2.02	2.23	2.21	2.15	2.08	2.26	2.23	2.19
	Booting	2.13	2.38	2.35	2.29	2.17	2.47	2.43	2.36
	Flowering	2.07	2.35	2.31	2.24	2.18	2.42	2.31	2.30
Hamel	**Elongation**	1.99	2.23	2.17	2.13	1.99	2.25	2.18	2.14
	Booting	2.07	2.37	2.31	2.25	2.15	2.42	2.35	2.31
	Flowering	2.05	2.26	2.17	2.16	2.12	2.39	2.31	2.27
		0.162			**0.082**		**0.149**		**0.074**
L.S.D 0.05					**0.045**		**0.027**		**0.042**
C * N	**Genzania**	2.01	2.22	2.18	2.14	2.11	2.27	2.23	2.20
	Carolup	2.07	2.32	2.29	2.23	2.14	2.38	2.32	2.28
	Hamel	2.04	2.29	2.22	2.18	2.09	2.35	2.28	2.24
		0.094			**0.055**		**0.086**		**0.048**
	S * N				**Averages S**		**S * N**		**Averages S**
S * N	**Elongation**	1.97	2.21	2.17	2.12	2.04	2.24	2.1933	2.16
	Booting	2.09	2.34	2.29	2.24	2.16	2.40	2.35	2.30
	Flowering	2.06	2.27	2.22	2.18	2.14	2.36	2.29	2.26
			0.094		**0.047**		**0.086**		**0.043**
Averages N		2.04	2.27	2.23		2.11	2.33	2.28	
			0.054				**0.050**		

Total Grain Yield (tons ha^{-1}):

The results illustrates that the Hamel cultivar produced the highest average total grain yield of 6.21 tons per hectare in the first season (2021-2022). While Carolup cultivar achieved the highest yield in the second season (2022-2023) at 6.56 tons per hectare, the Genzania cultivar achieved the lowest average yields of 5.72 and 5.66 tons per hectare for both seasons (Table 4).

The total grain yield varied significantly depending on the spraying stage across both seasons. The booting stage had the highest yield, with 6.72 and 6.89 t ha-1 in the two seasons, respectively. In contrast, the lowest average yields were obtained in the expansion phase, at 5.32 and 5.40 t ha 1 in both seasons, respectively. This higher performance in the booting stage can be attributed to the higher number of bunches per square meter, number of grains per grain and 1,000 grain weights These data and the results of Mozam et al reported the same. (2017) and Saheed et al. (2019) no.

Total grain yield was different between the two seasons with different NPK nanofertilizer concentrations. Maximum yields were obtained at 1 g of NPK per litre, with 6.45 and 6.56 t ha 1 in the different seasons. In contrast, the treatment produced the lowest yields, at 5.33 and 5.83 t ha-1 in both seasons, respectively. This increase in yield can be attributed to the efficiency of nanofertilizer in increasing yield parameters such as number of clusters, number of grains and weight of 1,000 grains in both seasons These data are similar to those reported by other researchers, including Al-Jutheri et al. (2018) and Noeme et al. (2020).

The interaction between species and spraying phase showed that the combination of carolup × booting phase gave the highest total grain yield, of 7.10 and 7.59 t ha 1 In contrast, genzania × extension phase gave the lowest averages, for both seasons 4.84 and 5.10 t ha 1. The interaction between variety and nutrient levels showed that in the first period (2021-2022), Hamel × 1 g L-1 the combination yielded 6.68 t ha 1. Carolup × 1 g L-1 The -1-combination yielded 6.96 t ha 1 in the second year (2022-2023). In contrast, the carolupe × control combination produced the lowest yield of 5.22 t ha in the first season, and the genzania × control combination produced the lowest yield of 5.15 t ha in the second season The combination of yielded the highest average yields, being 7.20 and 7.34 t ha-1 in the two seasons, respectively, while the average was the lowest with elongation phase × control combination recorded, 4.63 and 4.96 t ha1 in both seasons. Finally, three-way interactions between species, spray and nutrient levels showed that the combination of carolup × booting stage × 1 g L-1 produced the highest total grain yield, which 7.61 and 8.11 t ha 1 in both seasons. In contrast, the Genzania × Extension Phase × Control combination produced the lowest yields, at 4.61 and 4.72 t ha 1 between the two seasons, respectively.

Table 4. Cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on Total Grain Yield (tons ha^{-1}) of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1}				Second season (2021-2022) Nano NPK g L^{-1}			
		0	**1**	**2**	**C * S**	**0**	**1**	**2**	**C * S**
Genzania	**Elongation**	1.91	2.18	2.13	2.07	2.06	2.22	2.17	2.15
	Booting	2.08	2.26	2.21	2.18	2.15	2.31	2.28	2.25
	Flowering	2.05	2.21	2.19	2.15	2.12	2.27	2.25	2.21
Carolup	**Elongation**	2.02	2.23	2.21	2.15	2.08	2.26	2.23	2.19
	Booting	2.13	2.38	2.35	2.29	2.17	2.47	2.43	2.36
	Flowering	2.07	2.35	2.31	2.24	2.18	2.42	2.31	2.30
Hamel	**Elongation**	1.99	2.23	2.17	2.13	1.99	2.25	2.18	2.14
	Booting	2.07	2.37	2.31	2.25	2.15	2.42	2.35	2.31
	Flowering	2.05	2.26	2.17	2.16	2.12	2.39	2.31	2.27
		0.162			**0.082**		**0.149**		**0.074**
					0.045		**0.027**		**0.042**
C * N	**Genzania**	2.01	2.22	2.18	2.14	2.11	2.27	2.23	2.20
	Carolup	2.07	2.32	2.29	2.23	2.14	2.38	2.32	2.28
	Hamel	2.04	2.29	2.22	2.18	2.09	2.35	2.28	2.24
		0.094			**0.055**		**0.086**		**0.048**
		S * N			**Averages S**		**S * N**		**Averages S**
S * N	**Elongation**	1.97	2.21	2.17	2.12	2.04	2.24	2.1933	2.16
	Booting	2.09	2.34	2.29	2.24	2.16	2.40	2.35	2.30
	Flowering	2.06	2.27	2.22	2.18	2.14	2.36	2.29	2.26
L.S.D 0.05			**0.094**		**0.047**		**0.086**		**0.043**
Averages N		2.04	2.27	2.23		2.11	2.33	2.28	
			0.054				**0.050**		

Protein Percentage in Grains (%)

The data in (Table 5) reveal that the Carolup cultivar achieved the highest average protein content in grains, with values of 10.85% and 11.13% across both seasons, respectively. On the other hand, the Genzania cultivar recorded the lowest averages, with 9.57% and 10.14% in the respective seasons.

Protein content varied significantly depending on the spraying stage in both seasons. For both years, the booting stage yielded significantly higher average protein percentages with 11.18 and 11.00%, while the lowest averages were reported for elongation stages of development at 9.88% and 10.02%. The difference might stem from the fact that nutrient accumulation is typically maximal at flowering; hence, it represents a very important period for nutrient uptake. Moreover, the rapid growth observed during this stage, fueled by the effective absorption of compound fertilizers, likely contributed to higher protein content.

The protein percentage also varied significantly with different concentrations of nano-fertilizer applied. The 1 g NPK L^{-1} concentration yielded the highest protein averages of 11.06% and 11.26%, while the control treatment had the lowest values, at 9.62% and 9.81% in both seasons. This suggests that the 1 g concentration may have been optimal for promoting healthy growth throughout the plant's life cycle, whereas higher concentrations might have led to nutrient toxicity, negatively affecting plant development.

The combination of Carolup × booting gave the maximum average (12.17% & 11.78%) in both seasons and the minimum average was achieved from Genzania × elongation which recorded as 9.10% & 9.25%, respectively, in both seasons (Table-4). In each season the interaction of cultivars x concentrations (Hamel × 1 g L-1) gave highest average at level of 11.58% and this was followed by that for Carolup× 1g, recorded the highest average of 11.97% in the second season (2022-2023). While the lowest significant percentage were recorded with the interaction between Genzania x control having of 8.99% and 9.45% for both seasons respectively.

The interaction of spraying stages and concentrations (booting × 1 g L^{-1}) gave the highest average of 12.08% and 11.96%, while the interaction (flowering × control) recorded the lowest average of 9.18% in the first season (2021-2022), and the interaction (elongation × control) recorded the lowest average of 9.22% in the second season (2022-2023). The three-way interaction between cultivars, spraying stages, and concentrations (Carolup × booting × 1) gave the highest average of 12.65% and 12.86% in both seasons, respectively, while the interaction (Genzania × elongation × control) recorded the lowest average of 8.77% and 8.92% in both seasons, respectively.

Table 5. cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on protein percentage in grains (%) of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1} (N)				Second season (2022-2023) Nano NPK g L^{-1} (N)			
		0	1	2	C * S	0	1	2	C * S
Genzania	Elongation	1.91	2.18	2.13	2.07	2.06	2.22	2.17	2.15
	Booting	2.08	2.26	2.21	2.18	2.15	2.31	2.28	2.25
	Flowering	2.05	2.21	2.19	2.15	2.12	2.27	2.25	2.21
Carolup	Elongation	2.02	2.23	2.21	2.15	2.08	2.26	2.23	2.19
	Booting	2.13	2.38	2.35	2.29	2.17	2.47	2.43	2.36
	Flowering	2.07	2.35	2.31	2.24	2.18	2.42	2.31	2.30
Hamel	Elongation	1.99	2.23	2.17	2.13	1.99	2.25	2.18	2.14
	Booting	2.07	2.37	2.31	2.25	2.15	2.42	2.35	2.31
	Flowering	2.05	2.26	2.17	2.16	2.12	2.39	2.31	2.27
		0.162			**0.082**		**0.149**		**0.074**
					0.045		**0.027**		**0.042**
C * N	Genzania	2.01	2.22	2.18	2.14	2.11	2.27	2.23	2.20
	Carolup	2.07	2.32	2.29	2.23	2.14	2.38	2.32	2.28
	Hamel	2.04	2.29	2.22	2.18	2.09	2.35	2.28	2.24
L.S.D 0.05		**0.094**			**0.055**		**0.086**		**0.048**
	S * N				Averages S		S * N		Averages S
S * N	Elongation	1.97	2.21	2.17	2.12	2.04	2.24	2.1933	2.16
	Booting	2.09	2.34	2.29	2.24	2.16	2.40	2.35	2.30
	Flowering	2.06	2.27	2.22	2.18	2.14	2.36	2.29	2.26
			0.094		**0.047**		**0.086**		**0.043**
Averages N		2.04	2.27	2.23		2.11	2.33	2.28	
			0.054				**0.050**		

Carbohydrate Percentage in Grains (%)

The results in the analysis of variance tables (Appendix 2 and 3) indicate a significant impact of all study factors and their interactions on the carbohydrate percentage in grains.

As shown in (Table 6), the Carolup cultivar achieved the highest average carbohydrate percentage in grains, reaching 18.76% and 20.13% in both seasons, respectively. In contrast, the Genzania cultivar recorded the lowest averages, with 15.24% and 17.11% in the respective seasons. This difference may be attributed to what Idris (2009) explained, where cultivars are considered one of the most important factors determining crop productivity. The interaction between genetics and the environment predominantly controls this, as they dictate the growth and development rates of the cultivars. Therefore, the genetic nature of the cultivars planted in a specific area directly affects the quantity and quality of the yield, in addition to the cultivars' ability to adapt to their growing environment. Selecting the appropriate cultivar for local conditions is crucial for successful cultivation. Cultivar performance varies due to genetic differences influencing their response to environmental factors. These genetic variations impact a cultivar's vulnerability or resilience to specific climatic conditions, leading to varying outcomes across seasons.

The carbohydrate percentage in grains varied significantly depending on the spraying stage in both seasons. The booting phase had the highest average, 17.86% and 20.00% in the different seasons, while the elongation phase had the lowest average, 15.52% and 16.91% in both seasons and this difference is due essential requirements of the plant It is appropriate and can be due to the need to replenish nutrients at the branching stage of the plant (extension), which is an important growth stage during this period of plant healing and nutrition to meet its growing needs It matches the vital needs of the plant and provides nutrients at critical times when the plant has exhausted its investments to meet its growing needs role (Jabouri, 2004).

The percentage of carbohydrate in grain also varied significantly with different doses of nano-fertilizer in both seasons. The 1 g NPK L^{-1} rate recorded the highest average values, reaching 17.64% and 19.68% for the different seasons, while the control treatment reached the lowest average values, which were 15.12% and 16.78, respectively % in both periods This difference is due to this fact It is possible that the optimal rate may have provided the best conditions for the growth and development of the plant, and fulfill its requirements under special test conditions

The combination of species and spray phase (Carolup × booting) yielded 20.13% and 21.91% in both seasons, respectively, on the contrary, the Genzania x flowering phase gave the lowest yield 13.98% in the first period of the season, while Genzania. and a second time for 16 in the expansion phase. 1 charcoal-based carolup, which reached a minimum of 29% showed the highest increase of 19.78% and 21.47% in both seasons, while Genzania without meal (consumed) a total were 13.25% and 15.14%, respectively, showed a lower average of 19.78% and 21.47% for both periods

The combination of spray phase and fertilizer concentration (booting × 1 g L-1) gave the highest average yield of 19.36% and 21.49%, while the combination (expansion × control) of 14.49% and 15.90% respectively both periods received relatively low averages, respectively. The three-way interaction between species, spraying time and fertilizer concentration (Carolup × booting × 1 g L-1) resulted in an average of 21.14% and 23.48% of resp contrast, if combined (Genzania × Flower × Control) in the first period (2021-2022). had the lowest concentration of 12.11%, while the combination (Genzania × length × 1 g L-1) had the lowest concentration of 14.42%. the second year (2022-2023).

Table 6. Cultivars, spraying stages, NPK nanofertilizer concentrations, and their interactions affected on Carbohydrate Percentage in Grains (%) of oats for the 2021-2022 and 2022-2023 seasons.

Cultivars (C)	Stages of application (S)	First season (2021-2022) Nano NPK g L^{-1}				Second season (2022-2023) Nano NPK g L^{-1}			
		0	1	2	C * S	0	1	2	C * S
Genzania	**Elongation**	13.74	16.65	15.44	15.28	14.42	17.42	17.03	16.29
	Booting	13.91	18.36	17.08	16.45	15.84	19.30	18.65	17.93
	Flowering	12.11	15.26	14.58	13.98	15.17	18.36	17.84	17.12
Carolup	**Elongation**	15.96	17.94	16.25	16.72	17.22	19.27	18.71	18.40
	Booting	19.17	21.14	20.08	20.13	20.20	23.48	22.04	21.91
	Flowering	18.25	20.26	19.76	19.42	18.47	21.67	20.11	20.08
Hamel	**Elongation**	13.76	15.22	14.74	14.57	16.07	16.21	15.84	16.04
	Booting	15.22	18.57	17.23	17.01	18.59	21.68	20.23	20.17
	Flowering	13.98	15.34	14.33	14.55	15.03	19.72	18.40	17.72
		3.784			**2.298**		**3.659**		**2.071**
					0.045		**0.027**		**0.042**
C * N	**Genzania**	13.25	16.76	15.70	15.24	15.14	18.36	17.84	17.11
	Carolup	17.79	19.78	18.70	18.76	18.63	21.47	20.29	20.13
	Hamel	14.32	16.38	15.43	15.38	16.56	19.20	18.16	17.97
L.S.D 0.05		**2.185**			**1.668**		**2.113**		**1.467**
	S * N				**Averages S**		**S * N**		**Averages S**
S * N	**Elongation**	14.49	16.60	15.48	15.52	15.90	17.63	17.193	16.91
	Booting	16.10	19.36	18.13	17.86	18.21	21.49	20.31	20.00
	Flowering	14.78	16.95	16.22	15.99	16.22	19.92	18.78	18.31
			2.185		**1.327**		**2.113**		**1.196**

Averages N	15.12	17.64	16.61	16.78	19.68	18.76
		1.261			**1.220**	

Conclusion

The study demonstrates that the Carolup oat cultivar, when paired with booting stage spraying and a 1 g L^{-1} concentration of NPK nanofertilizer, significantly outperforms other combinations in terms of nitrogen content, grain yield, and protein and carbohydrate levels across two growing seasons. While Hamel excelled in yield during the first season, Carolup proved superior overall. The booting stage was particularly effective for nutrient uptake. The study underscores the critical role of integrated management strategies—specifically the selection of appropriate cultivars, precise timing of nutrient application, and the use of optimal nanofertilizer concentrations—in maximizing oat yield and quality. This approach not only enhances the nutrient content in the plant but also significantly boosts the overall productivity, making it a valuable strategy for improving crop outcomes in similar agricultural settings.

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