RESEARCH ARTICLE

Enhancing Multinutrients Delivery and Seed Coating with Biodegradable Based Electrospun Nanofibre

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ABSTRACT

A field experiment was conducted at ARS, Bhavanisagar, during summer 2021, to investigate the effect of multi-nutrient-loaded electrospun PVA nanofibre on the green gram. The nanofibre developed from polyvinyl alcohol (10%) infused with macro and micronutrients. The nanofibre coated seeds recorded the higher plant height (44.97 cm); crop growth rate (1.5-18.43 g m^{-2} d^{-1}); leaf area index (0.56-1.84 m^2m^{-2}) and leaf area duration (13.29-34.77days). Further, the higher grain yield (854.2 kg ha^{-1}) and haulm yield (1100 kg ha^{-1}) were obtained from the nanofibre-coated seeds. According to the findings of this study, nanofibre technology is a novel idea for the fertilizer sector because it reduces fertilizer use and increases nutrient use efficiency.

Keywords: *Nanofibre; Multinutrients; Green gram; Electrospun*

INTRODUCTION

Mungbean [*Vigna radiata* (L.) Wilczek], often known as green gram, is a popular dietary protein supplement in many parts of the world, especially in Southeast Asia (Sing *et al*., 2017). It is primarily cultivated in tropical and sub-tropical countries of Southeast Asia, particularly India, which is the most prominent Mungbean producer with an average yield of 390 kg ha^{-1} in 2.80 million ha (Kumawat *et al*., 2009). However, global green gram cultivation is surprisingly low (390 kg ha^{-1}), and production is unlikely to expand significantly in the near future. Low fertilizer response ratio and poor nutrient management are the primary causes of lower yield.

As a result, today's agriculture's greatest issue is to increase crop productivity by using fertilizers wisely in an environmentally favorable method. However, indiscriminate application of agricultural inputs can result in a low fertilizer response ratio, unbalanced fertilization, and groundwater contamination, all of which have negative consequences (Eo and Park, 2016). Despite the direct application of agrochemicals and fertilizers, a significant amount is lost due to evaporation and runoff. For such unavoidable reasons, seed coating approach with nanofibre, may play a critical role in regulating nutrient release consistently and intelligently, as well as a nanofibre capable of encapsulating the entire set of agri inputs at desired proportions to improve germination and crop productivity (López-Valdez *et al*., 2018).

Electrospinning is a simple and easy way to make nanofibers from polymer solutions using a bias electrical source to form fibers that are a few hundred nanometers in range. Further, the nanofibre technology is already used in a wide range of applications, from electronics to medicine and protective apparel. Property of nanofibre, such as porosity and large surface area allows it to control the fertilizer release rate (Krishnamoorthy and Rajiv, 2018). This research narrated the green gram seed coating (*Vigna radiata*) with electrospun PVA nanofibre incorporating primary (N,P,K) secondary (Ca,Mg,S) and micronutrients (Fe,B,Zn). The study evaluated the physiological and yield attribute features of green gram in order to determine the strategy's efficacy. (Ks, 2019).

MATERIAL AND METHODS

Preparation of PVA electrospun nanofibre with multinutrients

The electrospun fibre was prepared using polyvinyl alcohol 10% poly vinyl alcohol (PVA) with molecular weight of 115,000 g $mole^{-1}$ purchased from Astron Chemicals (India), Ahmedabad. Multi-nutrient solution containing primary (N, P, K), secondary (Ca, Mg, S), micronutrients (Fe, Mn, Cu, Zn, B) and trace elements (Mo) was prepared using deionized water to meet the requirement of greengram. The solution was prepared in a 100X concentration and used to prepare a multinutrient solution. The details of the nutrient source and the concentration are furnished in Table 1.

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Table 1. Multinutrient mixture

Nutrients	Concentration (g/L)
KNO_3	202
$Ca(NO_3)_2$	236
Iron chelates	15
$MgSO_4$	240
NH_4NO_3	80
H_3BO_3	2.86
$MnCl_2$	1.81
$ZnSO_4$	0.22
$CuSO_4$	0.051
H_2MoO_4	0.09
Na_2MoO_4	0.12
KH_2PO_4	136

Seed coating process through electrospinning

The surface of the green gram seeds (Co-8) was coated with multinutrients loaded PVA electrospun nanofibre developed using an electrospinning machine (ESPIN Nano, Physics Instrument Corporation Ltd, Guindy, Chennai). In order to get a uniform nano-fibre, optimal solution (molecular weight, viscosity (10%) concentration) and process (tip-to-collector distance (15 cm), flow rate (0.3 mL/hr), voltage (30 kV), plate translation movement speed (60 m/min) were employed (Fig.5).

Field Experiment

To study the effect of multinutrient loaded electrospun PVA nanofibre on green gram, a field experiment was conducted with three treatments and five replications. The experiment was conducted during summer 2021 at field No-NA1, ARS Bhavanisagar. The treatments were *viz*; T_1-Absolute control, T_2- Conventional Fertilizers, T_3- Multinutrients loaded PVA electrospun nanofibre. The design followed was RBD. Biometric observations were recorded at the vegetative stage, flowering stage and maturity stage. Yield and yield attributes were recorded in the maturity stage.

Statistical analysis

The data obtained from the field experiments study was analysed statistically by assuming the procedure described by (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Characterization of electrospun nanofibre

Before loading with multinutrients SEM micrograph of electrospun nanofibre showed smooth and bead-free structure with 130 nm range. After loading with multinutrients there was some disintegration in the structure, due to the occupation of nutrients inside the nanofibre with the dimension of 268-400 nm (Fig.1). A similar kind of results was indicated by (Javazmi *et al*., 2021).

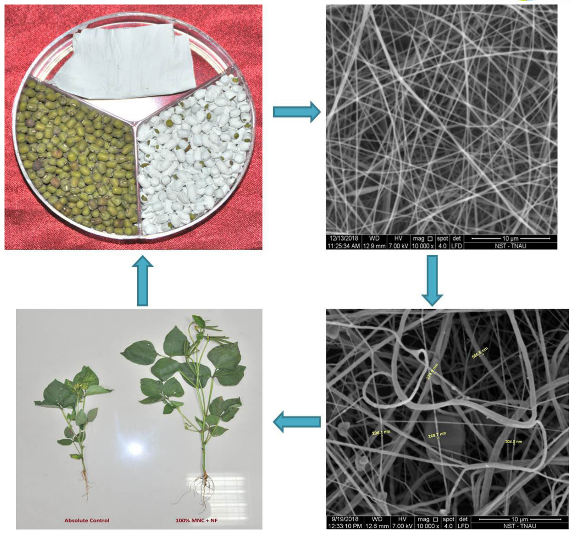


Fig 1. Effect MNC loaded electrospun nanofibre on Crop Growth

The TEM image of electrospun nanofibre before and after loading with multinutrients is given in (Fig.2). The TEM image of nanofibre showed the perfect encapsulation of nutrients into the hallow space of nanofibre without any beads. The average size of nanofibre ranges from 110 nm (with nutrients) and 45.1 nm (without nutrients). The SEM and TEM micrograph confirmed the presence of nutrients in the nanofibre. A similar result was obtained by (Nooeaid *et al*., 2021).

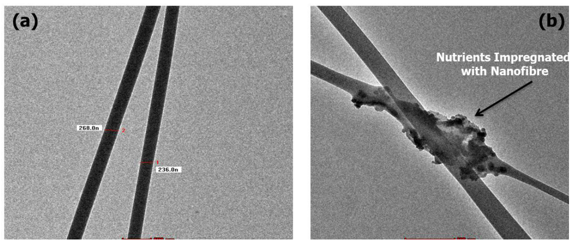
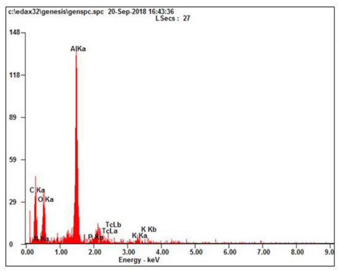


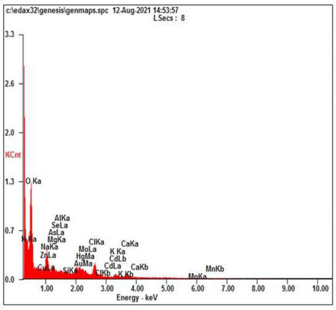
Fig 2. (a) TEM Image of Nanofibre alone; (b) Nanofibre loaded with nutrients

The EDAX graph (Fig.3) of electrospun nanofibre before loading showed the presence of carbon (31.63 %), oxygen (17.43 %), Al (41.22%) only but in the EDAX graph (Fig.4) after loading showed the presence of carbon (48.35%), nitrogen (20.92%), Zn (0.77%) and sulphur (1.60%), Mg (00.62%) and K ions loaded in the hallow core space of electrospun nanofibre. This result coincided with the author (Tan *et al*., 2021).



Element	Wt %	At %
C K	31.63	47.13
N K	02.57	03.28
O K	17.43	19.50
AlK	41.22	27.34
TcL	02.42	00.44

Fig 3. SEM- EDAX analysis of Electrospun nanofibre alone



Element	Wt%	At%
CK	48.35	57.36
NK	20.92	21.29
PK	20.43	18.20
CuL	00.00	00.00
ZnL	00.77	00.17
SK	01.60	00.99
MgK	00.62	00.36
AlK	00.13	00.07
SiK	00.00	00.00
MoL	01.18	00.17
KK	00.29	00.11
CaK	00.52	00.18
MnK	00.00	00.00
Matrix	Correction	ZAF

Fig 4. SEM-EDAX analysis of Electrospun nanofibre after loading with Multinutrients

Effect of MNC Loaded electrospun nanofibre growth parameters

The effect of electrospun nanofibre on plant height, number of branches and total leaf area were studied at vegetative, flowering and maturity stage (Table.2). The result showed that the, there was significant difference between conventional fertilizer and electrospun nanofibre. Higher plant height (44.97 cm) was observed in T_3 followed by (T_2) - conventional fertilizer treatment (41.94). It was mainly due to the seed coating with electrospun nanofibre, which released the nutrients in the rhizospheric area, that made nutrients easily available to plants.

The number of branches was higher in nanofibre-coated seeds (5.95) than conventional fertilizer applied plots (5.92) due to sustained supply of nutrients in all the growth stages. The total leaf area also followed the same pattern. The leaf area was higher in treatment T_3 followed by T_2. The absolute control recorded a very low leaf area in all growth stages. It could be because of nanofibre with multinutrients that released the required nutrients at rhizospheric region in a steady state manner. This allows the crop to easily uptake all the nutrients required for the growth of the plant without any loss (Raja *et al*., 2020).

Effect of MNC Loaded electrospun nanofibre physiological parameters

The effect of electrospun nanofibre with multinutrients on the physiological parameters was studied (Table.3) at all growth stages. The result showed that the crop growth rate increased from vegetative to flowering stage and it decreased at maturity stage. Among the treatments (T_3) nanofibre with multinutrients recorded higher Crop growth rate (CGR) of (3.13, 18.43 and 9.14 gm^{-2} d^{-1}) followed by conventional fertilizer (3.05; 15.50; 7.81 gm^{-2} d^{-1}) and absolute control (2.79; 13.48; 6.79 gm^{-2} d^{-1}) in vegetative, flowering and maturity stage respectively.

Table 2. Effect MNC loaded electrospun nanofibre on Growth parameters

Treatments	Plant height (cm)			Number of branches			Total leaf area (cm^2)		
	30 DAS	Flowering Stage	Maturity Stage	30 DAS	Flowering Stage	Maturity Stage	30 DAS	Flowering Stage	Maturity Stage
T_0-Abolute control	13.73	29.16	33.25	2.91	4.76	5.64	172.22	950.15	556.67
T_1-RDF	14.31	31.65	41.94	3.32	5.06	5.92	202.06	1011.51	641.04
T_1-MNC+NF	15.19	35.80	44.97	3.53	5.19	5.95	210.64	1036.54	684.82
CD	0.235	0.158	0.747	0.017	0.026	0.049	0.969	4.682	3.296
SE(d)	0.094	0.063	0.300	0.007	0.011	0.020	0.388	1.877	1.321

Likewise, the leaf area index (LAI) is higher in treatment T_3 compared to other treatments. The LAI was also higher in the vegetative and flowering stage and lower at maturity stages. It may be because electrospun nanofibre loaded with the complete set of all the primary (N,P,K), secondary (Ca,Mg,S) and micronutrients (Fe,Zn,B) are integrated to encourages the plant growth restorative properties under field conditions (Guo *et al*., 2018). In this connection multinutrients delivery through the nanofibre it also enhances the chlorophyll and nutrients uptake in plants (Mohanraj, 2013).

Table 3. Effect MNC loaded electrospun nanofibre on Physiological parameters

Treatments	Crop growth rate (g m^{-2} d^{-1})				Leaf area index			Leaf area duration (days)		
	15-30 DAS	30-45 DAS	45-60 DAS	60-75 DAS	30 DAS	Flowering Stage	Maturity Stage	30 DAS	Flowering Stage	Maturity Stage
T_0-Abolute control	1.11	2.79	13.48	6.79	0.45	2.23	1.31	10.53	20.44	29.63
T_1-RDF	1.29	3.05	15.50	7.81	0.54	2.67	1.82	11.51	22.27	34.11
T_1-MNC+NF	1.51	3.13	18.43	9.14	0.56	2.76	1.84	13.29	24.76	34.77
CD	0.027	0.11	0.42	0.27	0.016	0.043	0.016	0.042	0.375	0.059
SE(d)	0.011	0.04	0.17	0.11	0.006	0.017	0.006	0.017	0.150	0.024

The nanofibre infused with multinutrients recorded the higher leaf area duration (LAD) at all growth stages (13.29, 24.76 and 34.77 days) which is due to for the targeted supply of nutrients at the root zone.

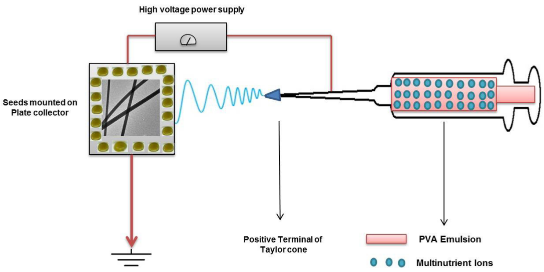


Fig 5. Schematic Representation of Process of nanofibre formation

Number of nodules per plant

The results showed that the nanofibre with multinutrient-coated seeds significantly influenced the nodule formation in green gram at flowering stage. The nanofibre infused with multinutrients recorded higher number of nodule per plant (19.5 plant^{-1}) followed by conventional fertilizer (17.5 plant^{-1}). The absolute control plot recorded the lowest nodules count (14.5 plant^{-1}) at flowering stage. It could be because nanofibre infused with micronutrient increased the nitrogenous enzyme activity in plant, the similar trend of results were reported by (Sahai *et al*., 2019)

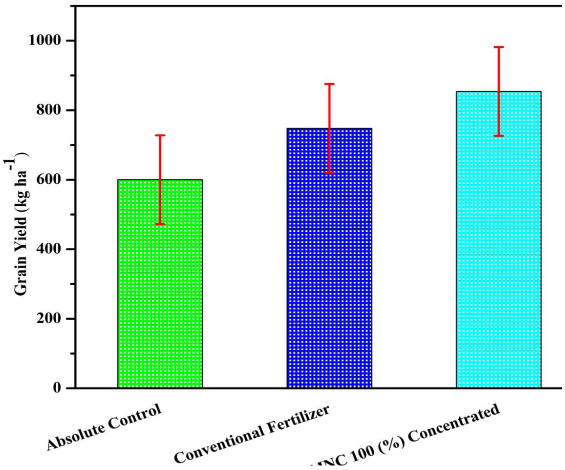


Fig 6. Effect MNC loaded electrospun nanofibre on Grain yield

Effect of MNC Loaded electrospun nanofibre on yield

Grain yield

Grain yield of green gram was significantly influenced by nanofibre loaded with multinutrient-coated seeds. The results revealed that, the plots that received the seeds coated with nanofibre multinutrients, recorded higher yield (854.42 kg ha^{-1}) followed by conventional fertilizer application (748.42 Kg ha^{-1}). The absolute control recorded a very low yield of (600 Kg ha^{-1}). A similar trend of yield was observed by the author (Subbaiya *et al*., 2012).

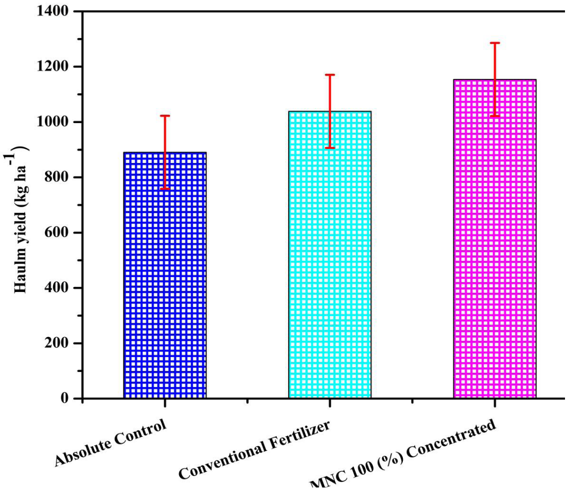


Fig 7. Effect MNC loaded electrospun nanofibre on Haulm yield

Haulm yield

Regarding haulm yield, the electrospun nanofibre coated seeds recorded 41% higher haulm yield when compared to absolute control. The conventional fertilizer treatment recorded the haulm yield of 890.54 kg ha^{-1}. This might be due to regulated supply of nutrients at rhizospheric zone, which is controlled by hydrophilicity of polymer. A similar observation of nanofibre coated seed increasing haulm yield was observed by (Palchoudhury *et al*., 2018).

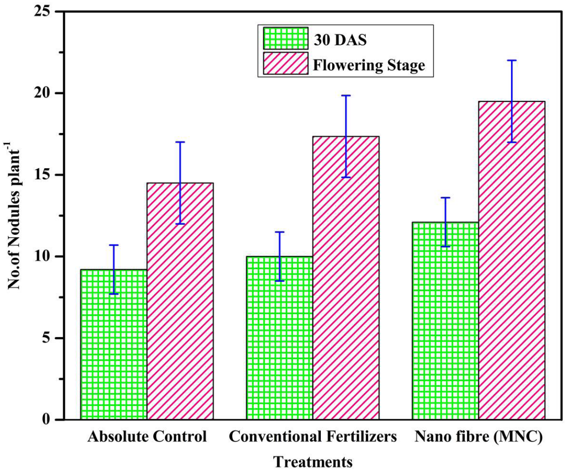


Fig 8. Effect MNC loaded electrospun nanofibre on No.of nodule plant^{-1}

CONCLUSION

The application of nanofibre technology in agriculture is an essential requirement due to the prevailing fertilizer shortage. However, the present research demonstrates the scope of nanofibres' performance in pulse productivity. This study concluded that the nanofibres are capable of releasing the complete set of nutrients at the surface of the seed coat during the time of germination. This pattern of fertilizer application through nanofibre technology solves the growth defect occurring during the early germination period and eventually improves germination percentage, plant height, grain yield and haulm yield. Moving forward, additional studies are needed to investigate the mechanisms responsible for the improvement of crop growth with a different plant species and different climatic conditions.

Conflict of interest

The authors here by declare no conflict of interest.

Ethics statement

No specific permits were required for the described field studies because no human or animal subjects were involved in this research.

Consent for publication

All the authors agreed to publish the content.

Competing interests

There were no conflict of interest in the publication of this content.

Author contribution

The manuscript was written through contributions of all authors.All authors have given approval to the final version of manuscript.

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