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Synthesis, characterization and on field evaluation of pesticide loaded sodium alginate nanoparticles

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ABSTRACT

The pesticide formulations in use these days have their own burdens on farming systems in terms of their accumulation in soil and ecosystems which can have serious effects on mankind and living organisms. With the help of nanotechnology, controlled release of agrochemicals, site targeted delivery of various macromolecules desired for improved plant disease resistance, enhanced plant growth and efficient nutrition utilization can be easily done. Nanoencapsulation has an advantage of safer handling and more efficient use of pesticides with less exposure to environment that guarantees ecoprotection. In plant entomology, nanotechnology targets specific agricultural problems in plant pests interaction and provide new ways for crop protection. The present investigation involves the delivery of imidacloprid (admire) pesticide in the form of nanoformulation to plants and investigation of their ultimate effects which can provide some insight for the safe use of this novel technology for the improvement of crop yield and safety.

1. Introduction

Pesticides play an important role in agriculture, as they help in preventing crop loss caused by pests. There is always a tendency to maximize agricultural yields because plants constitute the primary food source. It has been achieved now with the use of modified high yield crops and synthetic fertilizers but still the productivity is negatively hindered by plant pests that throw in significantly to the total crops losses. One third of world's potential food supplies are estimated to be lost due to pre and post harvest pests and diseases (Raileanu et al., 2010). In order to reduce these losses, pesticides are used. Use of pesticides has greatly influenced the quality and quantity of food available for the growing world population. However, conventional application of pesticides results in contamination of air, ground water and surface water and these (pesticides) degrade through processes like biodegradation, photo degradation and hydrolysis (Le Roy Boehm, Zerrouk, & Fessi, 2000; Muro-Sune, Gani, Bell & Shirley, 2005), due to which less than 0.1% of the applied pesticides actually reach the target pests and remaining adversely affects non-target organisms.

The swiftly rising demand for food and energy is a main challenge for growing population of the world. Control of pests is a crucial task to achieve the goals for food and energy. The excessive application of pesticides increase the pollution potential which leads to groundwater contamination, spreading of toxic substances in the environment by leaching or in runoff by rainfall and volatilization which becomes a serious issue (Dailey, 2004; Fernandez-Perez, Villafranca-Sanchez, Gonzalez-Pradas, & Flores-Cespedes, 1999; Yun-Tiao et al., 1984). The increasing use of pesticides is also affecting our economy. The people are also facing lot of health related problems because of pesticides (Choudhary, Kumar, Walia, Parsad, & Parmar, 2006; Sancho, Villarroel, Fernandez, Andreu, & Ferrando, 2010; Sarmento, Ferreira, Veiga, & Ribeiro, 2006; Zhu, An, Li, & Yu, 2009). Thus, there is a strong need to identify and investigate new means of use of pesticides so that their use can be minimized if cannot be stopped. One way is to use biopesticides/natural pesticide and the other is to use new formulations with small amount of pesticide in them (Liu, Laks, & Heiden, 2002; Mir, Finkelstein, & Tulipano, 2010; Riyajan & Sakdapipanich, 2009; Tsuji, 2001). Much effort has been focused on the design of targeted, tailored and well-defined carriers loaded with catalysts, drugs or enzymes. The regulation of the release is a best alternate to avoid many limitations. Polymers offer variety of properties which are appropriate for controlled release of encapsulated material. Now a day's polymers have achieved enormous attention because of their wide spectrum applications in diverse fields especially in healthcare and agriculture due to their interesting properties, easy handling, biodegradable and biocompatible nature. Nanocapsules are solid hollow particles with diameter in nanometer range and great potential for encapsulation of large quantities and large sized guest molecules into their empty core domains (Heuskin et al., 2012; Qian, Guo, & He, 2012;

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Sirianni, Jang, Miller, & Saltzman, 2010; Touloupakis, Margelou, & Ghanotakis, 2011). There are several reports of applications of polymers nanoformulations in human medicine but very less is reported on controlled release of pesticides using polymer nanocapsules. Nanoparticles containing pesticides can be used very effectively against pests. Moreover, the dose of pesticide used is very less in nanoformulation and, hence minimizes potential negative effect (if any) associated with overdose. The pesticide becomes eco-friendly after encapsulation of agrochemicals in nanoparticle. Controlled release technology has several advantages over conventional formulations as these formulations result in use of smaller dose and hence reduces the loss by limiting leaching, volatilization and degradation (Otto, Vosloo, Liebenberg, & De Villiers, 2008). These formulations are also economical as less active material is needed in them. The encapsulation of toxic material such as pesticide in the polymers makes them less toxic and also these remain available to the target organisms for longer duration. Further phytotoxicity is reduced by lowering the mobility of the active agent in soil and also these can be transported easily with the reduction of inflammability (Cao et al., 2005; Roy, Bajpai, & Bajpai, 2009; Zhao, Zhang, Gao, & Shen, 2006). Considering these parameters, present work has been focused on synthesis, optimization and characterization of admire pesticide (active ingredient imidacloprid) loaded polymer (sodium alginate) nanoformulation and its effect on sucking pests (leafhopper) of Okra (bhindi) crop. The nanoformulations using natural polymers are valuable in applications to encapsulate pesticides/drugs and to serve as functional carriers. The polysaccharide sodium alginate, an anionic agent has been used as nanocarrier for various drugs because of its bicompatability and non-toxicity. Moreover, sodium alginate is useful in extending the shelf life of manufactured products. In alginate delivery systems, the main mechanism governing active compound release in physiologic fluids is the sodium–calcium exchange. When calcium alginate is introduced in environment rich in monovalent salts, insoluble calcium alginate is converted into soluble alginate, resulting in solubilization of the nanoformulation and subsequent pesticide/active compound release.

2. Materials and methods

2.1. Chemicals

Sodium alginate, dicholoromethane, poly vinyl alcohol (PVA) and calcium chloride were purchased from SD Fine Chem. Limited, dioctyl sodium sulphosucinate (AOT) and D-mannitol were procured from Central Drug House Pvt. Ltd., imidacloprid was taken (Admire pesticide) from Bayer India Ltd.

Seeds of crops:

- Crops-Bhindi (OKRA, Abelmoschus esculentus)
- Variety-Sarika (Nunhems Company)

2.2. Preparation of sodium alginate nanoparticles

Nanoparticles were formulated by emulsion cross linking technology (Chavanpatil et al., 2007). Sodium alginate solution in water (0.1–1.0%, w/v; 10 mL) was emulsified into dioctyl sodium sulfosuccinate (AOT) solution in methylene chloride (0.05–20%, w/v; 30 mL) by sonication for 1 min over ice bath. The primary emulsion was further emulsified into 150 mL of aqueous PVA solution (5%, w/v) by sonication for 1 min over ice bath to form a secondary water-in-oil-in-water emulsion. The emulsion was stirred using a magnetic stirrer, and 50 mL of aqueous calcium chloride solution (60%, w/v) was added gradually to the above emulsion. The emulsion was stirred further at ambient conditions for 18 h and then under vacuum for 1 h to evaporate methylene chloride. For preparing pesticide-loaded nanoparticles, pesticide (150 mg) was dissolved in the aqueous alginate solution by sonication, which was then processed as above. Nanoparticles formed were recovered by ultracentrifugation at 15,000 r.p.m., washed two times with deionized water to remove PVA and unentrapped pesticide and resuspended in water. D-Mannitol (5%, w/v) was added as cryoprotectant and lyophilized at −90 °C and 0.0010 mbar pressure for 24 h.

2.3. Experimental design

The preparation of pesticide-loaded sodium alginate nanoparticles was carried out using systematic design of experiments employing Design Expert Software (Version 7.1.6, Stat-Ease Inc., Minneapolis, MN). A central composite design (CCD) with $\alpha = 1$ was employed as per the standard protocol. In the present study, three levels two-factor CCD design was employed for optimization of nanoformulation. The concentration of sodium alginate and concentration of dioctyl sodium sulphosuccinate (AOT) were selected as independent variables based on preliminary studies. Entrapment efficiency percentage and particle size were taken as response variables. All other processing variables were kept invariant throughout the study. In all, 13 experimental runs were carried out as shown in Table 1. The central point (0, 0) was studied in pentet. The statistical analysis of data was done using the Design Expert Software.

2.4. Determination of pesticide loading and encapsulation efficiency

Pesticide loading in nanoparticles was determined with the help of UV–vis spectrophotometer. Pesticide loading is defined as the amount of pesticide encapsulated in 100 mg of nanoparticles, and is represented as % (w/w). Pesticide encapsulation efficiency is expressed as the percent of the total pesticide added that is encapsulated in nanoparticles. The amount of pesticide in nanoparticles was calculated by the difference between the total amount of pesticide added and the amount of unbound pesticide remaining in the aqueous supernatant. The later can be determined following the separation of pesticide-loaded nanoparticles from the aqueous medium by centrifugation. The supernatant was collected, measured and analyzed for free pesticide content using UV–vis spectrophotometer with unloaded sodium alginate nanoparticles taken as blank. With the help of absorbance of supernatant, unknown concentration was calculated by putting in Eq. (1) obtained by absorbance versus known concentration of pesticide.

$$y = 1.571x + 0.123 \tag{1}$$

Encapsulation efficiency was then calculated as follows:

$$\%\text{Encapsulation efficiency(EE)} = \frac{\text{total amount of pesticide added} - \text{unbound pesticide}}{\text{total amount of pesticide}} \times 100$$

$$\%\text{Pesticide loading} = \frac{\text{total amount of pesticide added} - \text{unbound pesticide}}{\text{total weight of nanoparticles}} \times 100$$

2.5. Characterization of nanoparticles

Surface morphology, topology and size of pesticide loaded sodium alginate nanoparticles were characterized by Transmission

Table 1
Central composite design used to study effect of formulation variables on % encapsulation efficiency (Y_1) and particle size (Y_2).

Exp. no.	Amount of sodium alginate (g) (X_1)	Amount of AOT (g) (X_2)	Encapsulation efficiency (%) (Y_1)	Particle size (nm) (Y_2)
1	1.00	10.03	99	300
2	0.55	10.03	80	200
3	0.55	10.03	78	225
4	0.10	20.00	80	300
5	0.55	10.03	85	190
6	1.00	20.00	99	350
7	0.55	10.03	80	200
8	1.00	0.05	20	70
9	0.10	10.03	70	250
10	0.10	0.05	20	50
11	0.55	0.05	30	100
12	0.55	20.00	70	200
13	0.55	10.03	65	150

Electron Microscope (Hitachi-H-7501SSP/N-817-0520). Size at preliminary level was taken by Zeta sizer (Malvern). Drug/pesticide loading in sodium alginate nanoparticles was confirmed by UV-Visible and FTIR (Shimadzu).

2.6. *In vitro cytotoxicity of imidacloprid loaded sodium alginate nanoparticles*

Vero cell lines at a density of 1×10^4 per well were cultured in a 100-μL volume of cell culture medium (EMEM supplemented with 10% fetal bovine serum and antibiotics) in a 96-well cell culture plate. After 24 h, cultured cells were treated with pesticide loaded sodium alginate nanoparticles, dummy nanoparticles and original pesticide in a concentration of 10 μg/mL and 5 μg/mL well dispersed in 100 μL of deionised water with sonication and incubated for 24 h. Untreated cells were also taken as reference. Media without cells was also taken in three wells to correct the background coloration. After incubation, the cultures were removed from incubator into laminar flow hood and 10 μL of resazurin solution prepared in EMEM media (1 mg/mL of media and placed at 4° C for 20 min) was added in all wells and incubated for 24 h. After 4 h, the pink colored resorufin is formed and absorbance was observed by spectrophotometer (ELISA plate reader) at wavelength 573 nm. Cytotoxicity percentage was calculated with reference to untreated cells after normalizing the background coloration of media

$$\%\text{Cytotoxicity} = \frac{\text{OD of unstimulated samples} - \text{OD of stimulated samples}}{\text{OD of unstimulated samples}} \times 100$$

2.7. *On field study on crop pests (jassids/leafhoppers)*

Four different plots of equal dimensions (1 m^2, with 1 m separation) were considered for the on filed study. Each plot contained almost ten healthy plants of age one month. One plot was considered as the reference or control. Second plot was treated with dummy nanoparticles, third one with normal plane pesticide and the fourth plot was treated with nanoformulation containing pesticide. A concentration of 0.145 mg/L was considered for the present study. 150 mL of aqueous solution of these different formulations were sprayed on the plants of respective plots. After the spray, numbers of sucking pests (leafhopper) were examined from time to time at regular interval. For evaluation, three leaves of one plant i.e. from top, middle and bottom were randomly selected from each plot.

3. Results and discussion

3.1. *Optimization results*

The trial experiments revealed that the concentrations of sodium alginate and AOT influenced the particle size of the sodium alginate nanoparticles. Thus, concentrations of sodium alginate (X_1) and AOT (X_2) were selected as the formulation variables to optimize the preparation of sodium alginate nanoparticles. The effect of sodium alginate concentrations was studied at 3 levels i.e., −1 level (0.1%, w/v), 0 level (0.55%, w/v) and +1 level (1%, w/v) and that of AOT at −1 level (0.05%, w/v), 0 level (10.03%, w/v) and +1 level (20%, w/v). Table 1 shows the results of 13 experimental runs carried out using the design protocol. The data obtained was analyzed and fitted into various polynomial models. It was observed that the response Y_1 (% encapsulation efficiency) fitted best into the quadratic response surface model with backward elimination after natural logarithmic transformations of the data. On the other hand response Y_2 (particle size) fitted best into the quadratic response surface model after square root transformation of the data. The polynomial models showing the relationship between the independent variables and the responses Y_1 and Y_2 can be expressed by the following Equations:

$$Ln(Y_1) = 4.37 + 0.093X_1 + 0.64X_2 + 0.053X_1X_2 - 1.517E - 003X_1^2 - 0.60X_2^2$$

$$Sqrt(Y_2) = 14.13 + 0.70X_1 + 4.12X_2 + 0.023X_1X_2 + 1.78X_1^2 - 2.71X_2^2$$

Table 2 summarizes the various factor effects and their associated p-values. It can be observed that the response Y_1 and Y_2 were influenced significantly and synergistically by the linear contribution of X_1, X_2, quadratic contribution of X_1, X_2 and the interaction effects of X_1 and X_2.

The polynomial models were further analyzed by ANOVA analysis (Table 3) to estimate the significance of response surface models. The results reveal that the models were significant with $R^2 \geq 0.9$

Table 2
Summary of each factor effect and its *p*-Value.

Factor	Y_1		Y_2	
	Factor effect	*p*-Value	Factor effect	*p*-Value
A-Polymer	1.69	0.2351	1.07	0.3358
B-Surfactant	79.13	<0.0001	37.16	0.0005
AB	0.37	0.5638	7.754E−004	0.9786
A^2	2.055E−004	0.9890	3.20	0.1169
B^2	31.97	0.0008	7.41	0.0297

Table 3
Statistical summary of the quadratic response surface model.

Response factor	Model								Lack-of-fit	
	F-Value	Prob > *F*	R^2	Adjus. R^2	Pred. R^2	Adeq. Prec.	C.V.	Std. dev.	*F*-Value	Prob > *F*
Y_1	23.73	0.0003	0.9443	0.9045	0.5406	12.253	4.30	0.18	5.63	0.0642
Y_2	9.26	0.0054	0.8687	0.7749	−0.0370	9.552	12.09	1.66	4.97	0.0778

and without significant 'lack-of-fit'. Moreover, the adjusted R^2 were found to be in reasonable agreement with predicted R^2. The lower values of coefficient of variance (C.V.) indicate the reliability of experiments carried out. Further, adequate precision which measures the signal to noise ratio was observed to be adequate (>4) indicating that the models can be used to navigate the design space. Fig. 1(a) portrays a 3-dimensional response surface plot which was constructed by using the model Y_2. It shows the combined effect of concentration of sodium alginate (X_1) and concentration of AOT (X_2) on particle size. It can be inferred that concentration of AOT is having more pronounced effect than sodium alginate concentration on particle size. Increasing the concentration of AOT was found to increase the particle size of the nanoparticles, which can be attributed to formation of micelles/emulsion at CMC (critical micellization concentration).

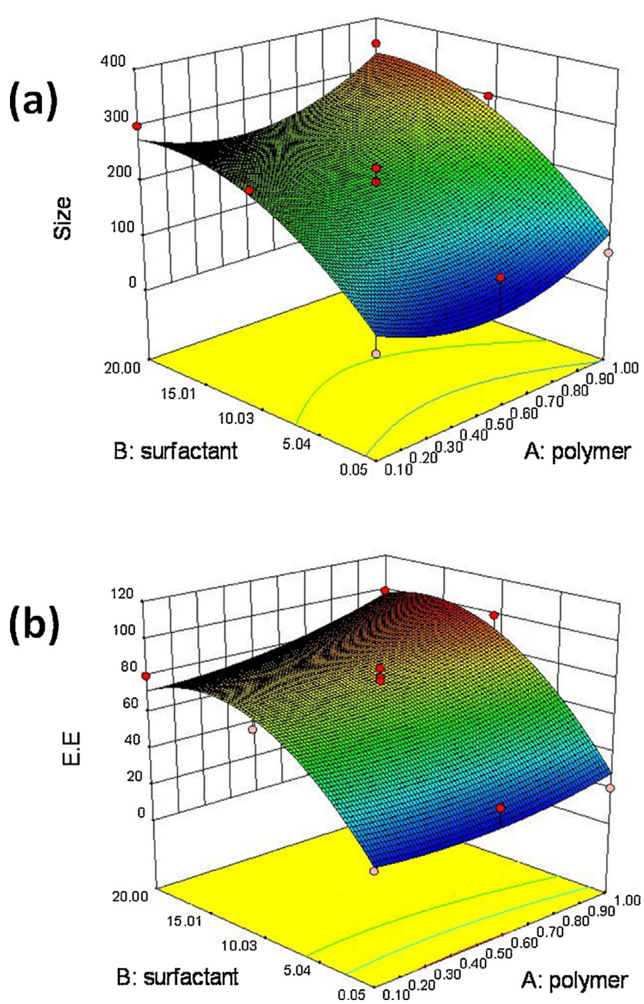

Fig. 1. (a) Response surface plot showing combined effect of concentrations of sodium alginate (X_1) and AOT (X_2) on particle size of nanoparticles, (b) response surface plot showing combined effect of concentrations of sodium alginate (X_1) and AOT (X_2) on encapsulation efficiency (E.E.) of drug within nanoparticles.

Fig. 1(b) depicts a combined effect of concentration of sodium alginate and surfactant (AOT) on % encapsulation efficiency. At lower values of polymer concentration, increasing the surfactant concentration resulted in increased entrapment of the drug which can be attributed to higher degree of micelle formation at higher surfactant concentrations. Further, it can be observed that increasing the polymer concentration also resulted in increase in % encapsulation, which was more pronounced at higher surfactant concentrations. In addition, at higher values of polymer concentration increasing the surfactant concentration did not result in more significant change in % encapsulation. These results may be attributed to the inadequate interaction between the polymer and surfactant in solution due to increase in viscosity by increasing polymer concentration. A numerical optimization technique using the desirability approach was used to develop pesticide loaded sodium alginate nanoparticulate formulation with the desired responses. The optimization was done to locate the optimal concentrations of polymer and surfactant under the constraints of minimizing the particle size and maximizing the % encapsulation. The numerical optimization tool provided us with different sets of optimal solutions. Using these solutions, an optimal batch of pesticide loaded sodium alginate nanoparticulate formulation was prepared and analyzed for particle size and % encapsulation efficiency. The optimal calculated parameters were concentrations of sodium alginate- 1% (w/v) and AOT- 15% (w/v). The optimized batch of pesticide loaded sodium alginate nanoparticulate formulation was found to have the % encapsulation efficiency (Y_1) of 98.66%, and particle size (Y_2) of 150 nm.

3.2. Characterization of pesticide loaded sodium alginate nanoparticles

The characterization of pesticide loaded nanoformulation was done with the help of TEM, zeta sizer and FTIR as reflected in Fig. 2.

3.2.1. Particle size analyzer result

Particle size was determined with the help of zetasizer. It works on the principle of dynamic light scattering (DLS). The particle size obtained from zetasizer was in the range of 150 nm and is reflected in Fig. 2(c). A broad range of size appears due to aggregation of nanoparticles (which was later confirmed by the TEM). It is difficult to maintain the nanoparticles in segregated form because with the passage of time particles aggregate and their size increase.

3.2.2. TEM images

TEM images were taken with the help of Hitachi TEM system (Hitachi-H-7501SSP/N-817-0520). TEM results reflect particle sizes in the range of range of 50–100 nm. Fig. 2(a) and (b) show the low magnification and high magnification images of nanoparticles. As the time of sonication increase, the particle size decreases. The variation in size may be due to aggregation of the nanoparticles which occurs due to improper sonication or by the time lag between sonication and time of imaging the sample.

3.2.3. FTIR results

Fig. 2(d) represents the FTIR spectrum of pesticide, sodium alginate and pesticide loaded sodium alginate nanoformulation. In FTIR

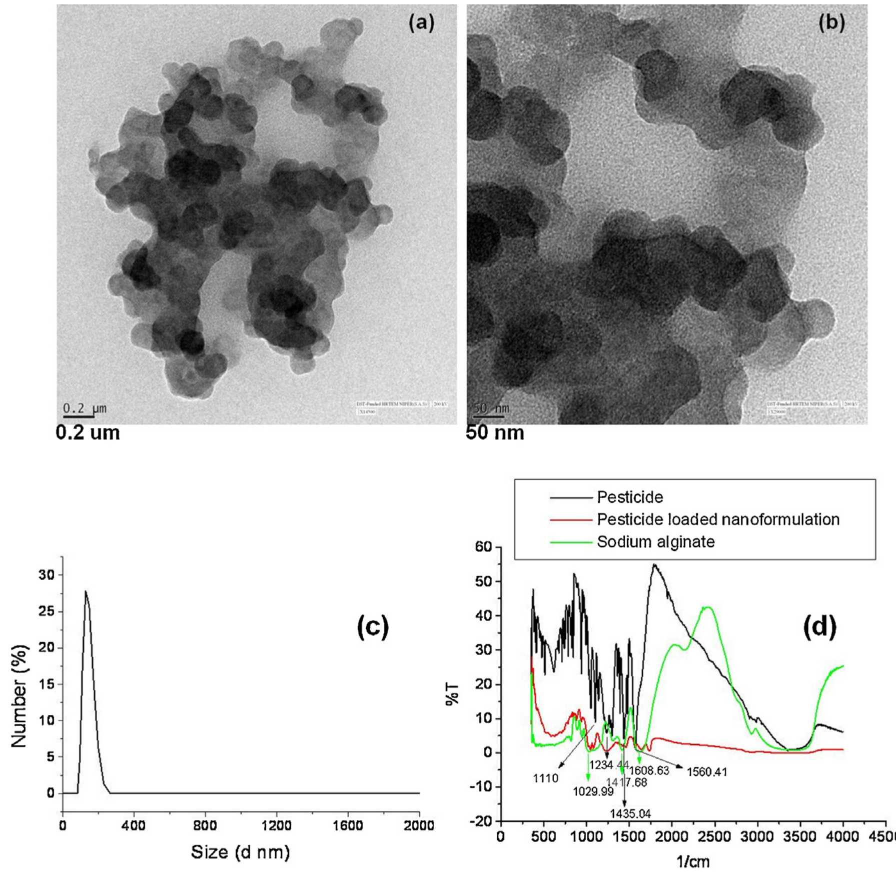

Fig. 2. (a and b) TEM micrographs of pesticide loaded sodium alginate nanoparticles, (c) particle size analysis (d) FTIR of pesticide loaded sodium alginate nanoparticles.

spectra of imidacloprid (admire) the band at 1560.41 cm^{-1} is due to the =CH— stretching of the pyridine group, the $—NO_2$ symmetric stretching band located at 1234.44 cm^{-1}, while the bands at 1435.04 cm^{-1}, and that at 1110 cm^{-1},are probably due to the aromatic =CH— and to the aryl —Cl stretching, respectively. Other bands and peaks are due to the presence of other additives or excipients presents in admire pesticide. In spectra of sodium alginate the band around 1029.99 cm^{-1} (C—O—C stretching) is attributed to its saccharide structure. In addition, the bands at 1608.63 and 1417.68 cm^{-1} are assigned to asymmetric and symmetric stretching peaks of carboxylate salt groups. However, nonappearance of broad peak at around 3500–3300 cm^{-1} in the IR spectrum of nanoformulation establish/confirms the absence of intermolecular hydrogen bonded —OH groups. Moreover, the nanoformulation was lyophilized (i.e. freeze dried under vacuum) and after that IR spectrum was recorded. Thus, the presence of any weak intermolecular hydrogen bonding of —OH groups will not be detectable by IR spectrometer. With the help of FTIR, it can be confirmed that the pesticide is present in pesticide loaded sodium alginate nanoformulation. It can also be confirmed that there is no chemical interaction between sodium alginate and pesticide; hence actual properties of each are maintained as such.

3.3. Determination of pesticide loading and encapsulation efficiency

Pesticide loading and pesticide encapsulation efficiency was found to be 2.46% and 98.66% respectively. These were calculated by considering the total weight of nanoformulation obtained

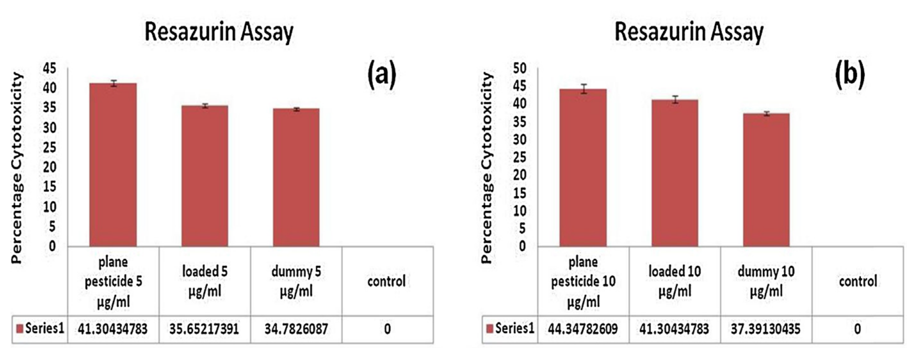

Fig. 3. Cytotoxicity of imidacloprid, imidacloprid loaded nanoparticles, dummy nanoparticles at concentration of (a) 5 µg/mL and (b) 10 µg/mL.

Table 4
Effects of different insecticidal treatment on sucking pest (leafhopper) at different time of observations.

Date of observation	Control treatment and mean pest population	Dummy treatment and mean pest population	Normal treatment and mean pest population	Nano encapsulated treatment and mean pest population
1st day	10 ± 0.50	7 ± 1.09	2 ± 1.22	7 ± 2.16
3rd day	12 ± 0.70	5 ± 1.11	2 ± 1.87	5 ± 1.42
5th day	13 ± 0.92	8 ± 1.53	2 ± 1.50	5 ± 1.42
7th day	13 ± 1.00	10 ± 1.87	2 ± 1.26	4 ± 2.00
9th day	14 ± 0.92	12 ± 2.78	2 ± 1.74	2 ± 0.86
11th day	14 ± 0.92	14 ± 1.05	3 ± 1.42	1 ± 0.70
13th day	15 ± 1.20	15 ± 1.73	4 ± 1.01	1 ± 0.86
15th day	15 ± 1.64	15 ± 1.73	5 ± 1.66	1 ± 0.92

(6000 mg), total amount of bound pesticide (148 mg) and total pesticide taken initially (150 mg).

3.4. *In vitro cytotoxicity results of imidacloprid loaded sodium alginate nanoparticles*

The pesticide loaded nanoparticles were taken at concentrations of 5 μg/mL and 10 μg/mL. Pesticide-loaded nanoparticles contain 2.46% of imidacloprid pesticide only. The absorbance was taken at 573 nm and corresponding % cytotoxicity with standard deviation and error bars are shown in Fig. 3. These experiments clearly reveal that at this conc. loaded-pesticide nanoformulation is very less toxic than original pesticide. The experiment was repeated in triplicate.

3.5. *On field evaluation of different treatments on crop pests (jassids/leafhoppers)*

A perusal of the data presented in Table 4 revealed that all insecticidal treatments were superior as compared to control check in sucking pest (leafhopper) management. The significant difference for leafhopper infestation in different insecticidal treatment was noticed. After 2 days of spray, the population of leafhopper was found to be maximum10 per 3 leaves in control check as compared to other insecticidal treatment viz. dummy, normal and encapsulated. The leaf hopper population in this insecticidal treatment was recorded to be 7, 2 and 7 per 3 leaves respectively. The effect of nanoencapsulated insecticidal treatment was found to be effective up to 15th day in which the leafhopper population was found to be in range of 7–1 per 3 leaves while in

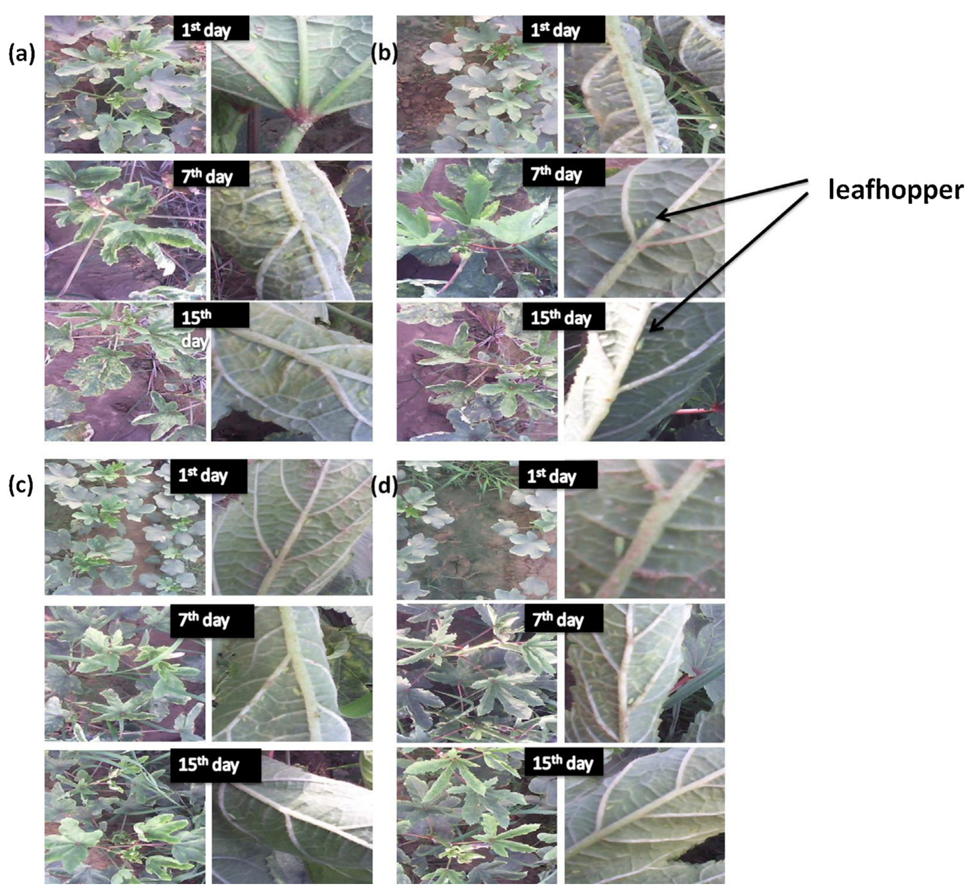

Fig. 4. Leaf infestation in (a) control, (b) dummy, (c) pesticide encapsulated nanoformulation and (d) plain/normal plot at different (1st, 7th & 15th day) time of observation.

other insecticidal treatment the leafhopper population recorded to be above threshold level which has harmful effect in crop. In control check the leafhopper population was recorded in the range of (10–15 per 3 leaves) up to 15th day, in dummy insecticidal treatment the leafhopper population was recorded in the range of (7–15 per 3 leaves) and in normal insecticidal treatment the population was recorded in the range of (2–5 per 3 leaves) up to 15th day which is above threshold level. The other insecticidal treatments were not so effective up to more days as the insecticidal effect of other treatments was found to be decreasing with increasing no. of days as shown in Table 4. Moreover, the data was analyzed statistically with one-way analysis of variance (ANOVA). The results represented that the nanoencapsulted treatment is significant as compared to control and dummy treatment with $p < 0.001$ and dummy treatment is non significant as compared to control treatment with $p > 0.05$ value. The pictures of different plots at different intervals of time are depicted in Fig. 4. Thus, it was found that nanoencapsulated insecticidal treatment shows more superior effect in efficacy (as nanoformulation contains only 2.46% of pesticide as compared to plane/normal pesticide), control measure and long lasting as compared to other treatments.

4. Conclusion

The environmental problems caused by overuse of the pesticides have attracted a lot of attention of scientists in recent years who are engaged in research in this area. The present work deals with the synthesis and characterization of pesticide (imidacloprid) loaded sodium alginate nanoparticles. Synthesized pesticide-loaded sodium alginate nanoparticles were characterized by particle size analyzer, FTIR and TEM. FTIR confirms the presence and nature of pesticide in loaded nanoformulation. Transmission electron micrographs (TEM) confirmed the size of pesticide-loaded nanoparticles in the range of 50–100 nm. Entrapment efficiency and pesticide loading was estimated to be 98.66% and 2.46% respectively. Sodium alginate nanoparticles because of their biodegradability, biocompatibility, better stability, low toxicity, simple and mild preparation methods, offer a valuable tool to pesticide delivery systems. The prepared nanoformulation was tested for its efficacy on the crop- OKRA (bhindi). Four different formulations i.e. control, dummy, plain and encapsulated (loaded) were evaluated on four different plots which were of same dimensions. The observations were recorded after different intervals of time i.e. 1st day, 3rd day, 5th day, 7th, 9th, 11th, 13th, and 15th day. The pest population of leafhoppers was calculated using standard procedure. The results reflected that encapsulated (pesticide loaded nanoformulation) formulation is more effective than even plane pesticide. Further, the toxicity analysis of dummy, loaded and plane formulations were also carried out. The results reflected that encapsulated pesticide has lower toxicity than plane pesticide. Hence, the proposed work can be explored in future for its use in commercial purposes. The development of such nanoformulations of pesticide will provide increased efficacy, reduced amount of pesticide, decreased amount of residue of pesticide in food, decrease in the risk of environment pollution, decrease in non target effects, good for economy and increased safety for the farmer or pesticide applicator.

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