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Larvicidal bioefficacy, antioxidant activity and cytotoxicity assessment of lemongrass oil nanoemulsion for controlling dengue vector, *Aedes aegypti*

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Abstract
Present study highlights the use of lemongrass essential oil in developing kinetically stable nanoemulsion for larvicidal application with major focus on addressing safety concerns. Various oil and surfactant ratios were evaluated for preparing stable oil in water nanoemulsion of lemongrass oil and 1:1 ratio exhibited great thermodynamic stability as recorded through dynamic light scattering study. Fourier-transform infrared spectroscopy (FTIR) analysis depicted the characteristic peaks at 1737.62 cm^{-1} and 1638.50 cm^{-1} of α, β- unsaturated esters (C-O), and conjugated alkene (C=C). Transmission electron microscopy (TEM) analysis revealed spherical droplets with smooth surface and the size was estimated as 38.1nm. Lemongrass nanoemulsion exhibited higher antioxidant activity as evident from the DPPH (85.17% at) and NO (72.4%) free radical scavenging activity. The enhanced larvicidal activity was observed at 24h, 48h and 72h of exposure against *Aedes aegypti* larvae and the LC_{50} value was calculated as 2.07ppm after 24h of exposure. Cytotoxicity assay against normal human renal cells revealed higher cell viabilities at lower concentrations after 24h and 48h did not show any apparent cytotoxicity impact at different concentrations. Current research validated the safer development from lemongrass essential oil with promising larvicidal application which may be further utilized as wider therapeutic agents.

Keywords: *Aedes aegypti*, lemongrass oil nanoemulsion, larvicidal activity, cytotoxicity, antioxidant activity

Introduction
Mosquito borne diseases like malaria, Zika virus, dengue and chikungunya have become a major problem across the globe and warrant immediate attention for their control. Among these diseases, dengue is a deadly one and given much consideration owing to its quick transmission behaviour [1]. *Aedes aegypti* is a primary vector to transmit dengue infection in tropical and subtropical regions. Recently, several dengue cases have been documented and reported from India and other countries [2, 3]. According to the World Health Organization report, approximately 50–100 million dengue cases per year were reported all over the world. Till date, no concrete drug or treatment is available to prevent from dengue infection. Vector control is a major problem in developing countries and to target the mosquito breeding sites is one of the most essential approach for efficient mosquito vector control [4].
Enormous efforts have been made to develop effective herbal larvicides against mosquitos because synthetic larvicides has raised major concerns of environmental and human health. However, plant based nanoemulsions can be used as an alternative to synthetic larvicides. Nanoemulsions are derived from natural essential oils which are found to be eco-friendly, healthier, safer and cost-effective [5, 6]. Essential oils consist of chemical constituents which are volatile in nature. Nanoemulsions are colloidal solutions which are kinetically stable, with small droplet size, increased surface area [7]. Lemongrass oil shows various biological activities such as antioxidant, antimicrobial and pesticide activity. Therefore, in the present study, main focus was on the biosynthesis of nanoemulsions from lemongrass essential oil with enhanced larvicidal activity and least toxic impact on non-target species.

Materials and Methods
Chemicals
Polyoxyethylene sorbitan monooleate (Tween 80), 2-diphenyl-1-piceryl-hydrazyl-hydrate (DPPH), Ascorbic acid, Sodium nitroprusside, Sulphanilamide, Phosphoric acid, Napthylethylene diamine dihydrochloride, 3-(4,5-Dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT). These chemicals were procured from local authorized sellers.

GC-MS/MS characterization of lemongrass essential oil
GC-MS/MS analysis was carried out using GC-MS/MS Shimadzu TQ-8030 to achieve the speed, accuracy and ease-of-operation. This instrument provides high sensitivity analysis of wide range of molecules through variety of measurements modes and temperature was programmed from 100°C to 300°C at the rate of 3°C cm^{-1}. GCMS injector temperature was set at 250°C and interface temperature was maintained up to 300°C. In mass spectrometer multiple ions of sample were generated and analyzed according to their specific mass-to-charge ratio (m/z). GC-MS/MS study of lemongrass essential oil was conducted to determine the volatile molecules present in the sample and separate accordingly.

Preparation of nanoemulsion
For the biosynthesis of lemongrass nanoemulsion, a practically new approach has been adopted using a high energy process *i.e.* ultrasonication. For standardizing the protocol and to attain the nanodroplet size of nanoemulsions, lemongrass essential oil was mixed with

different ratios (1:0.25, 1:0.50, 1:1, 1:2, and 1:3) of polyoxyethylene sorbitan monooleate (Tween 80) and Milli Q water. Most important aspect is the surfactant or emulsifier used is non-toxic, hydrophilic, stable against pH variation, and shows ionic strength and compatibility with other components. Hence, lemongrass oil nanoemulsion was sonicated under cold conditions for an hour with pulse 10:03 second and amplitude 25% using the ultrasonicator (Sonics vibra^{TM} cell).

Physicochemical Characterization of Nanoemulsion

Dynamic Light Scattering (DLS)

Dynamic Light Scattering (DLS) analysis was conducted to evaluate the droplet size and hydrodynamic distribution of nanoemulsions. This technique is based on photon correlation spectroscopy, which detect the droplet size of nanoemulsions using Malvern Zetasizer Nano ZS. To calculate the droplet size of nanoemulsion samples were diluted (1:9 ratio) prior to size analysis. Zeta potential analysis was performed to evaluate the stability of nanoemulsions.

Transmission Electron Microscopy (TEM)

TEM study was carried out to analyze the atomic structure *i.e.* size and shape or morphology of biosynthesized nanoemulsions using TECNAI G20 HR-TEM. Few drops of samples diluted in MilliQ water (1:9 ratio) and stained with uranyl acetate dye were taken and coated on a copper grid and left for few hours for drying. After this, sample was scanned under the microscope.

Fourier transform infrared spectroscopy (FTIR)

FTIR analysis was recorded for the identification of various functional groups present in nanoemulsion. For this study, sample was prepared by ultrasonication process and was further diluted up to the desired concentration. Then sample was scanned in FTIR between the moderate scanning range of 41000- 400 cm^{-1} using FT-IR Spectrum 2 (Perkin Elmer).

Stability analysis

Stability analysis exhibit assessment of the physical stability of nanoemulsions under different environmental conditions like temperature, humidity, and light for 3 months. Readings were recorded through spectrophotometer at different time intervals. Thermodynamic stability of nanoemulsions was evaluated at different temperature such as 20℃, 4℃ and centrifuge at 8000rpm for 30 minutes. This study was monitored through DLS to observe any change in viscosity and the droplet size.

Larvicidal bioassay of lemongrass oil nanoemulsion

Bioassay study was evaluated using the standard procedure of World Health Organization [8]. For this study, immature aquatic stages *Aedes aegypti* mosquito were collected from the natural breeding sites from the local areas of Agra city and maintained in the enamel tray in the laboratory with a mixture of dog biscuit and yeast (3:1). From this pool, III instar larval stages were screened for evaluating the insecticidal activity of lemongrass oil nanoemulsion. Test concentrations were ranged from 0.05, 0.1, 0.5, 1, 5 and 10 ppm and the percent mortality was recorded after 24 h, 48 h and 72 h of treatments. For each test concentration 20 mosquito larvae with 200mL of distilled water were added in a glass beaker (250mL) and larval food were provided to the larvae up to three days of exposure. Control setup was conducted in parallel of experiment with distilled water served as negative control whereas, permethrin served as positive control. All test concentrations with five replicates were monitored during the experimental setup.

Free radical scavenging activity of nanoemulsion

In order to assess the scavenging activity of the nanoemulsions, 2, 2-diphenyl-1-piceryl-hydrazyl-hydrate (DPPH) scavenging assay was performed using previously established protocol [9]. For this assay, 1.5 ml of different concentrations (10-100ppm) of nanoemulsions were added to 1.5 ml of 0.25 mM DPPH solution. Test concentrations were incubated for 30 min at room temperature and colour change was observed. Samples absorbance was monitored at 517 nm through uv-vis spectrophotometer. Ascorbic acid was used as standard.

Nitric Oxide antioxidant activity assay (NO): This assay was performed to evaluate scavenging activity of free radicals using the protocol of Kang *et al*. [10]. Briefly, 1.0 ml of 5.0 mM sodium nitroprusside mixed with 1.0 ml of different concentration of nanoemulsions (25-500ppm) and mixture was incubated for 60 min at room temperature. After this, an equal amount of Griess reagent (1% sulphanilamide, 2% phosphoric acid, and 0.1% napthylethylene diamine dihydrochloride) was prepared and added to the reaction mixture. Absorbance was recorded at 546nm using uv-vis spectrophotometer.

Cytotoxicity assessment on HEK 293 cell lines

Assessment of any potential cytotoxic effect of nanoemulsions, 3-(4, 5-Dimethylthiazol-2-yl)-2, 5-diphenyltetrazolium bromide (MTT) assay was conducted using Mossman protocol [11] on HEK293 cell lines. Briefly, 96-well plates were seeded with 5×10^3 cells/well along with culture medium (DMEM, 10% FBS and 1% penicillin streptomycin) and incubated overnight at 37℃. These cells were treated with different concentrations of nanoemulsion for 24 and 48h. After that 10 µL of MTT was added to each well and the plates were incubated for 3 h in a dark condition. Supernatant was removed and 200 µL of DMSO was added to each well for dissolving the formazan crystals. With the help of ELISA plate reader the absorbance was recorded at 570 nm and percent cell viability was calculated through the formula:

% Cell Viability = (Absorbance of treated cells/Absorbance of untreated cell) x100.

Statistical analysis

Results are shown as Mean ± Standard Deviation (SD) values calculated using Graph Pad Prism software. For evaluation of larvicidal susceptibility, Probit analysis [12] method was used to calculate LC_{50}, LC_{90}, values at 95% fiducial limits. Abbott's formula [13] was used to determine the control mortality as T-C/100-CX100, where, T = % mortality of test organism, C = % mortality of control.

Results

Nanoemulsion preparation and characterization

In the present study, a novel procedure has been adopted for the preparation and characterization of nanoemulsions. Lemongrass essential oil extracted through steam distillation process was used. GC-MS analysis results with identification of chemical constituents in lemongrass

essential oil are presented in the characteristic spectra (Fig. 1). Lemon Grass essential oil produces terpenoidal hydrocarbons which are medicinally and industrially important. These chemical constituents are listed in Table 1 indicating the presence of a total 12 chemical constituents. Some major constituents of lemongrass essential oil are trimethylsilane (42.19%), Octadecanoic acid (32.54%), trans-3(10)-Caren-2-ol (8.09%), and 2, 6-Octadienal, 3, 7-dimethyl (6.64%).

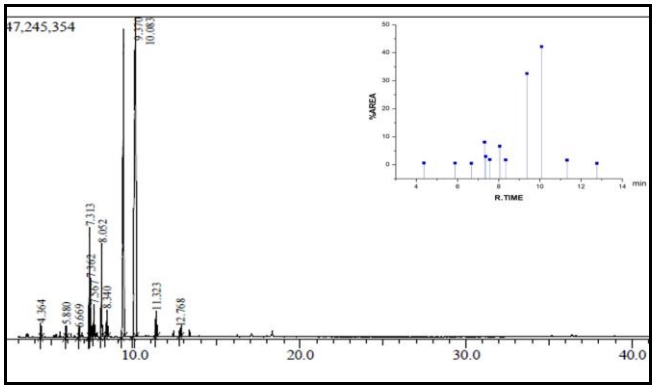

Fig 1: GC-MS analysis showing chemical constituents of lemongrass essential oil.

Table 1: Phytochemical screening of lemongrass essential oil.

Peak	RTllll	Area	Area%	Name
1	4.364	3852638	0.63	1,6-0ctadien-3-ol,3,7-dllllthyl-
2	5.88	3763061	0.61	Octahydro-1-oxa-cyclopropa[c]ii
3	6.669	3175904	0.52	Bicyclo[2.2.l]heptan-2-ore,4-lxotm-1,7.7-trimethyl-
4	7.313	49739118	8.09	trans-3(10)-Caren-2-ol
5	7.362	18299573	2.98	Cydopeutaii, 1-nrthyl-2-acetyl-3-(l-lllthylethenyO-
6	7.567	11353396	1.85	2,6-0ctadien-1-ol,3,7-dllllthvl-, (Z).
7	8.052	40859086	6.64	2,6-0ctadienal 3,7-dinlthyl-,(E).
8	8.34	10880201	1.77	6-kopropen -3-nrthoX)'nrthoxy-3-nrthyl<yclohexei
9	9.37	200112685	32.54	Octadecamic acid,9,10-epoxy-18-{trimethy iloxy)-.nrthyl ester,c-
10	10.083	259397288	42.19	[1{3,3-Dllrtthyloxiran-2-yllltl1y0-3,7-dllllthylocta-2,6-<iienyl]trimethylsilrul
11	11.323	10307001	1.68	4-Hexen-l-0!, 5-nrthyl-2{1-methylethenvO-, acetate
12	12.768	3160167	0.51	Bicyclo[5.2.0]oomir,2-meth rn!-4,8,8-trimeth -4-vinyl-
		614900118	100	

Different ratios of nanoemulsion such as 1:0.25, 1:0.50, 1:1, 1:2, 1:3, 1:4 and 1:5 (oil: surfactant) were prepared. The best ratio was obtained with 1:1 ratio of nanoemulsion with the major feature of great thermal stability (Fig. 2).

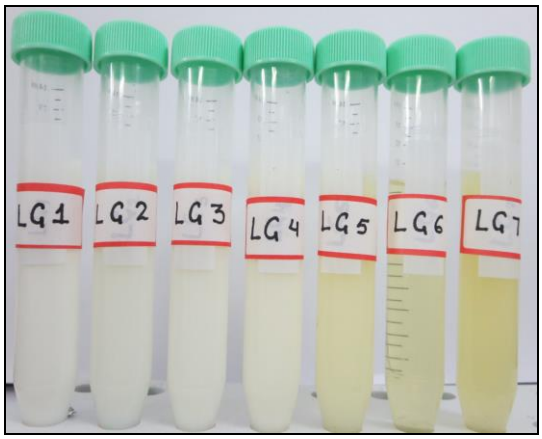

Fig 2

DLS analysis was performed to evaluate the droplet size, polydispersity index and zeta potential of lemongrass oil nanoemulsions. Fig. 3 shows the size distribution of lemongrass oil nanoemulsions as 98.41nm whereas, zeta potential of lemongrass oil nanoemulsions as -4.22mV. Polydispersity index (PDI) determines the broadness of the size distribution and homogenous dispersion in nanoemulsions (Table 2).

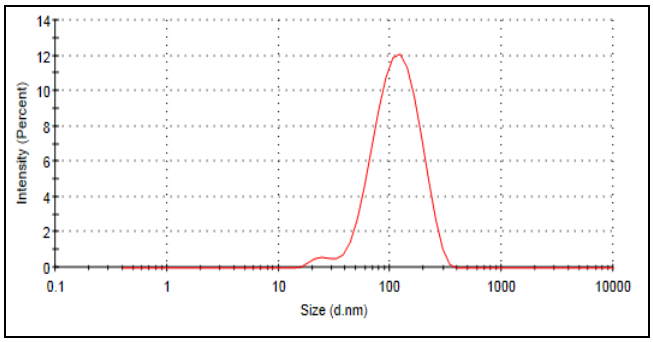

Fig 3: DLS analysis shows the size distribution of lemongrass oil nanoemulsions.

Table 2: Droplet size, polydispersity index and zeta potential of lemongrass essential oil nanoemulsions

Oil: Surfactant Ratios	Droplet size (nm)	Polydispersity index (PDI)	Zeta Potential (mV)
1:0.25	101.2	0.201	-8.10
1:0.5	72.67	0.232	-7.22
1:1	221.2	0.205	-4.22
1:1.5	227.3	0.193	-3.31
1:2	415.4	1.0	-2.06
1:2.5	488.9	1.0	-1.98
1:3	689.2	1.0	-1.80

TEM analysis was done to determine the size and size distribution of nanoemulsions. Fig. 4. depicts that lemongrass oil nanoemulsion droplets were spherical in shape with smooth surface and the size was recoded as 38.1nm.

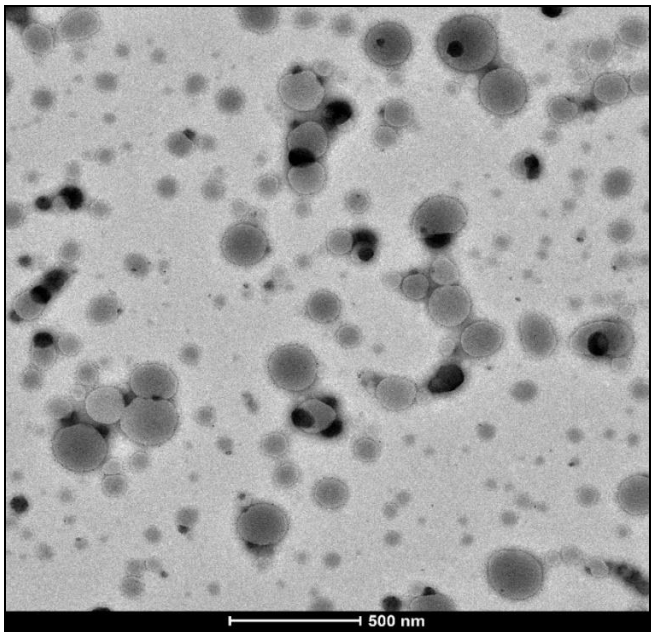

Fig 4: TEM analysis of lemongrass oil nanoemulsion (1:1 ratio).

FTIR spectral analysis was conducted to examine the characteristic peaks of lemongrass oil nanoemulsions as 1737.62 cm^{-1} and 1638.50 cm^{-1} of α, β- unsaturated esters (C-O), and conjugated alkene (C=C), given in Fig. 5. Another prominent peak was reported at 535.14 $cm^{-1}$and 537.71 cm^{-1} of halo compound (C-Br) while different peaks are shown here.

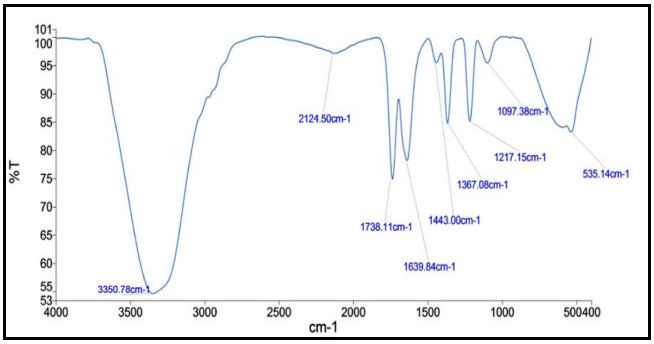

Fig 5: FTIR spectral analysis of lemongrass oil nanoemulsions (1:1 ratio).

Free radical scavenging activity of nanoemulsion

The scavenging activity of lemongrass oil nanoemulsion was examined through DPPH assay and NO assay. It was observed that the maximum percent radical scavenging activity was recorded at 10ppm concentration as 85.17%. Detailed DPPH scavenging activity has been presented in Fig. 6a. As concentration increases (1-100ppm) the percent radical scavenging was decreased. The NO scavenging assay showed a concentration-dependent increase in radical scavenging activity. Maximum NO scavenging activity at 25ppm concentration as 72.4% and the least scavenging activity was calculated as 70.13% at 500ppm concentration (Fig. 6b). Standard ascorbic acid depicted relatively higher antioxidant activity that ranged between 95 and 97 % with DPPH assay and 80% with NO assay. Overall higher scavenging activity of lemongrass nanoemulsion was noticed with DPPH assay.

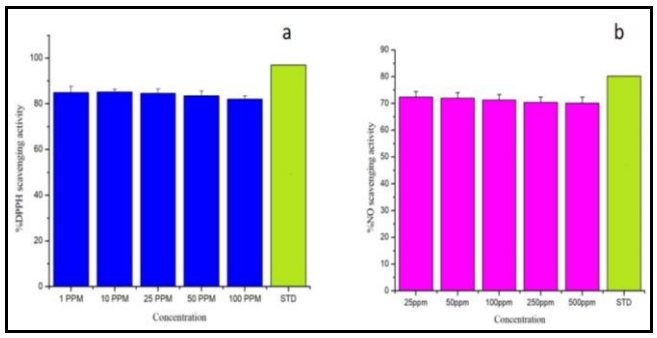

Fig: 6 Graphical representation of a) DPPH scavenging activity and b) NO scavenging activity of lemongrass oil nanoemulsions

Larvicidal activity of nanoemulsion

Fig. 7. depicts the insecticidal mortality rate of the third instar larvae with varying concentration of lemongrass oil nanoemulsion after 24h, 48 and 72h of exposure. It was observed that insecticidal activity of nanoemulsion has potential to control mosquito population. Negative control showed 100% survivability as compared to positive control. The probit analysis depicted the mean percent mortality as 5% at lower concentration (0.05ppm) and 80% at higher concentration (10ppm) after 24h which increased up to 96% after 72h of exposure. Hence, it was noticed that mortality rate is concentration and time dependent with significant relationship between the mortality rates after 24h and 48h.

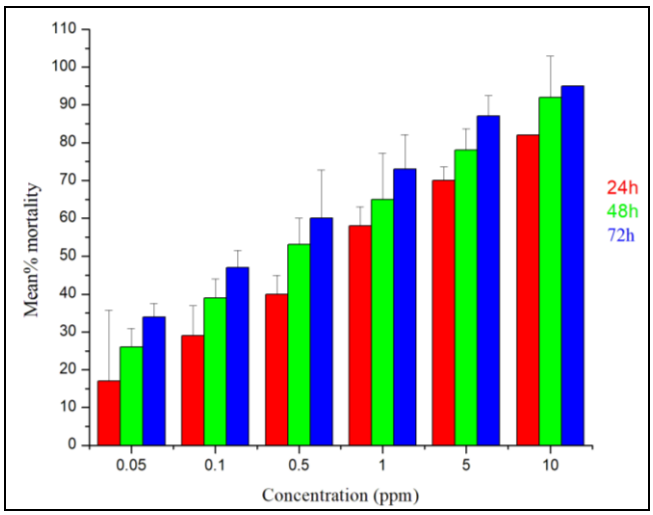

Fig: 7 Graphical representation of larvicidal activity of lemongrass oil nanoemulsions after 24h, 48 and 72h of exposure

Table 3 revealed the enhanced larvicidal activity as evidenced from the LC_{50} value as 2.07ppm and the LC_{90} value was 37.09ppm after 24h of exposure. Whereas, after 48h of treatment the LC_{50} value was estimated as 1.41ppm and the LC_{90} value was calculated as 28.46ppm and after 72h of exposure the LC_{50} value was evaluated as 0.50ppm and the LC_{90} value was recorded as 8.29ppm. The insecticidal activity of nanoemulsions was associated with the droplet size however, presence of bioactive compounds in lemongrass oil nanoemulsion enhanced their insecticidal effect against immature stage of *Aedes aegypti*.

Table 3: Larvicidal activity of lemongrass oil nanoemulsions after 24h, 48 and 72h of exposure.

Hours	LC_{50} (LFL-UFL)	LC_{90} (LFL-UFL)	χ^2	Equation
24	2.07 (1.59-2.78)	37.09 (22.073.93)	5.75	Y=1.023X+4.676
48	1.41 (1.08-1.88)	28.46 (17.03-55.93)	5.35	Y=0.982X+4.853
72	0.50 (0.39-0.64)	8.29 (5.52-13.95)	5.815	Y=1.051X+5.316

Cytotoxicity assessment in HEK 293 cell lines

This study was conducted to examine the toxic impact of nanoemulsions if any, on non-target living organisms through studying their impact on a mammalian cell line model HEK 293. Varying concentrations (0.1, 1, 10 and 100ppm) of lemongrass oil nanoemulsions were selected to determine the percent cell viability on HEK 293 cells. After 24h of exposure the maximum percent cell survivability was obtained as 92.8% at 0.1ppm whereas, the slightly lower percent cell survivability was calculated as 88.1% at 1ppm concentration (Fig. 8a). After 48h, the maximum percent survivability was recorded as 99.2% at 1ppm concentration (Fig. 8b) which reached at 61% at the highest, 100ppm concentration after 48h.

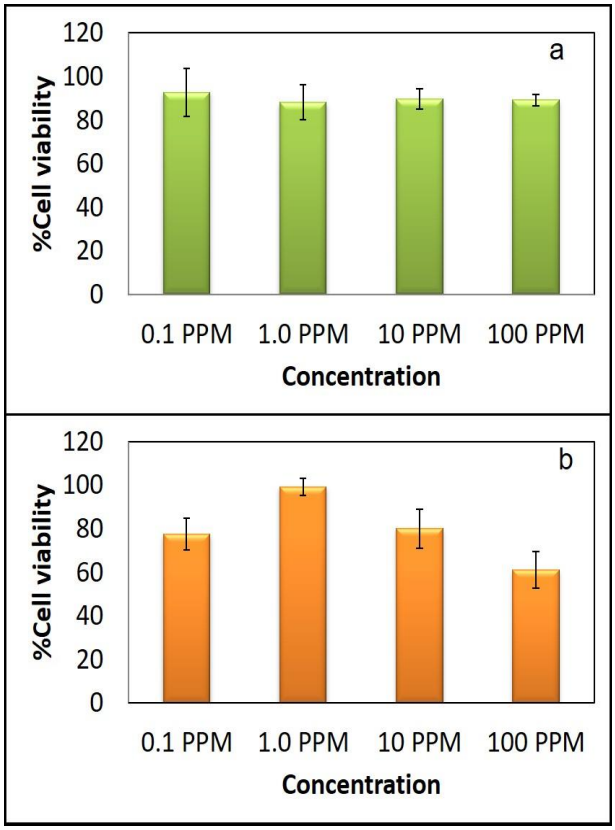

Fig 8: Percent cell viability on HEK 293 cells following exposure with various concentrations of lemongrass oil nanoemulsion a) after 24h b) after 48h.

Morphological characterization of HEK 293 mammalian cells following 24h post treatment with nanoemulsion is shown in Fig. 9. These treated cells did not show any apparent cytotoxicity impact at different concentrations in spite of a gradual decrease in percent cell viability which was observed on HEK 293 cells along with increasing concentration after 48 h of treatment with lemongrass oil nanoemulsion (Fig. 10). This confirmed that this nanoemulsion was safer to use in the aquatic environment as no distinct risk could be noticed under laboratory conditions.

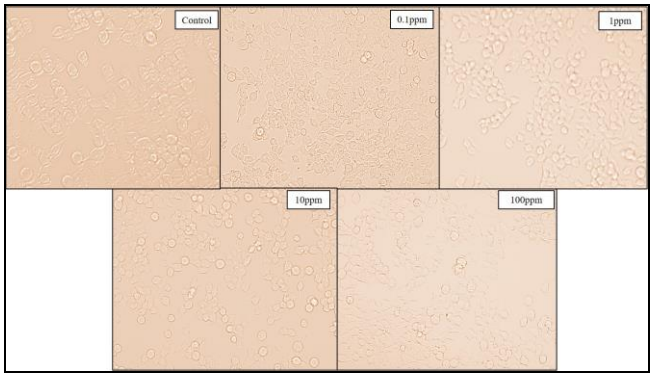

Fig 9: Cytomorphological characterization of HEK 293 cells following exposure with various concentrations of lemongrass oil nanoemulsion after 24h.

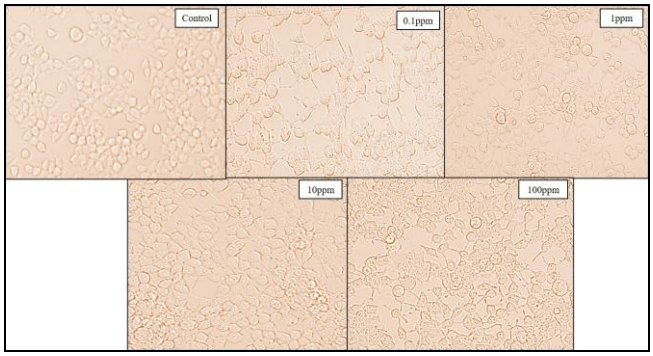

Fig 10: Cytomorphological characterization of HEK 293 cells following exposure with concentrations of lemongrass oil nanoemulsion after 48h.

Discussion

Mosquito borne diseases are of great public concern worldwide owing to higher morbidity and mortalities and inadequate conventional vector control strategies. Leading to the upsurge of resistant strains of mosquitoes moreover, *Aedes* borne arboviral diseases are likely to sustain in the future too as a result of growing human population and international travel leading to their geographical spread [14]. Several researches have been conducted on mosquito vector control through botanicals but these were not effective as compared to the commercialized and widely used chemical methods. Hence, we need to develop an alternative approach which has great bioefficacy and environmentally friendly nature at the same time. To combat this mosquito menace, now-a-days, plant essential oils are gaining attention and in the present study nanotechnology approach has been utilized for exploiting their potential in managing mosquito vectors. Previously, researches have been conducted on phytochemical investigation of plants as larvicides and repellents against mosquito vector [4, 15, 16]. Lemongrass essential oil is being used as a mosquito repellent [17, 18].

In the present study, phytochemical screening of lemongrass essential oil was done through GC-MS analysis revealed that this oil is a mixture of various functional groups and the major component of trimethylsilane (42.19%) than Octadecanoic acid (32.54%). Scientific literature clearly indicates the presence of these two major constituents in the essential oil of lemongrass although there was slight variation in the percent of these compounds. In one study [19], conducted by Neral -38.49%, Geranial- 50.51% in lemongrass essential oil were reported however, another study [20] reported Citral (34.8%), Neral (30.72%), and

Geraniol (5.54%) compound and these differences were quantitative which may be attributed to a number of environmental factors for instance, collection time, rainfall, solar radiation, season, soil profile and temperature.

In the present study, for the synthesis of nanoemulsions, lemongrass oil (LG) was used with varying ratios of oil and surfactant such as1:0.25, 1:0.50, 1:1, 1:2, 1:3, 1:4 and 1:5. The best ratio was obtained with 1:1 and surfactant (Tween 80) was used for the stabilization of nanoemulsions. Tween 80 was used as a surfactant as it has a high hydrophilic-lipophilic balance (HLB-15) and favourable for the oil-in-water emulsion. A characteristic peaks of lemongrass oil nanoemulsions was observed at 1737.62 cm^{-1} and 1638.50 cm^{-1} of α, β- unsaturated esters (C-O), and conjugated alkene (C=C). Many studies were conducted on the GC-MS analysis and FTIR analysis of biosynthesized essential oils with their larvicidal activity [20, 21, 22]. Recently, lemongrass oil extracted with Soxhlet extraction apparatus has been characterized through GC-FID and FTIR analysis [23]. FTIR spectra confirmed seven functional groups. The FTIR spectra depicted peaks values were 803 cm^{-1} (halo compound), 1387 cm^{-1} (sulphate), 1860 cm^{-1} (aromatic compound), 2059 cm^{-1} (isothiocynate), 2554 cm^{-1} (thiol), 3291 cm^{-1} (carboxylic acid) and 3430cm^{-1} (alcohols). These results were found to be the same as in our study and the same functional groups were present in this study.

For this purpose, investigation of lemongrass oil bioactive compounds has been done and found that it has high DPPH and nitric oxide (NO) scavenging activity ranging from 70% to 85% at different concentrations which is less than the standard ascorbic acid scavenging activity. Few studies also state that lemongrass oil has natural antioxidants and their scavenging activity was highest evaluated up to 70% [24, 25]. Another study evaluated the antioxidant activity of lemongrass essential oil (*Cymbopogon citratus*) grown in north Indian plains through DPPH and nitric oxide (NO) assay [26]. The results clearly indicate that lemongrass essential oil has effective free radical scavenging and has the potential to be a powerful antioxidant.

In this study, lemongrass nanoemulsion showed promising larvicidal activity against third instar larvae of *Aedes aegypti*. Larvicidal bioassay of lemongrass nanoemulsion was evaluated as LC_{50} value 2.07ppm after 24h of exposure whereas, after 48h the LC_{50} value was estimated as 1.41ppm. In the previous literature survey, many researches were conducted on larvicidal activity of essential oils [27, 28, 29, 30] and the mean percent mortality ranged from 5% to 80%. It is evident from published reports that some essential oils and nanoemulsions were also prepared as fast acting larvicides against mosquito vectors. There are no reports were available on the larvicidal activity of lemongrass nanoemulsion.

In recent decades, dengue fever is most rapidly expanding as mosquito-borne diseases which increase worldwide. Hence, lemongrass nanoemulsion was used as an effective alternative. However, the use of nanoemulsion goes beyond the target species and reaching towards non-target organism. Thus, need to evaluate the potential toxicity of lemongrass nanoemulsion to ensure that it may not cause any harmful impacts on ecosystem. It was noticed that bioactive component lemongrass oil nanoemulsion has high free radical scavenging potential which fight against oxidative stress and prevent the cell damage in the system. To evaluate the cytotoxicity of lemongrass nanoemulsion MTT assay was performed which reveals that nanoemulsion does not shows any toxic effects on HEK 293 mammalian cell lines. Hence, lemongrass oil nanoemulsion is safe and ecofriendly in nature with no toxic impact on non-target organisms. In our study, the maximum percent cell survivability was estimated as 92.8% at 0.1ppm and at higher concentrations also cells are viable after 24h and 48h of exposure. Lowest cell viability was calculated as 61% at 100ppm concentration after 48h of treatment. A gradual increase in concentrations was observed with decrease in percent cell viability was observed on HEK 293 cells which does not shows significant toxicity on system. Several researches have been conducted on cytotoxicity assessment of plant based essential oil which reveals that essential oils are safe and environment friendly [19, 31, 32, 33] but there is no literature available on the lemongrass nanoemulsion against mammalian cell lines.

Conclusion

Hence, a systematic study was performed for fabricating novel mosquito larvicides using the green nano biotechnology approach with the key finding of the study as lemongrass nanoemulsion is safe with no cytotoxic effects hence, biocompatible, eco-friendly and cost-effective towards the management of dengue vectors and transmission of the disease. Therefore, we found that lemongrass nanoemulsion is effective alternative of insecticides against mosquito-borne vectors with enhanced antioxidant potential and cytotoxicity. However, no reports were available on lemongrass oil nanoemulsion with insecticidal activity.

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Conflict of Interest

Authors declare no competing interest.

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