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Formulation Development and Characterization of Nanoparticulate Drug Delivery System for Selected Drug and Its Kinetic Profile.

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Abstract- Nanoparticulate drug delivery systems have gained considerable attention for improving the therapeutic efficacy of poorly soluble anticancer drugs through controlled and targeted delivery. The present study aimed to formulate and characterize Docetaxel-loaded nanoparticles using Poly(lactic-co-glycolic acid) (PLGA) as a biodegradable carrier polymer. Nanoparticles were prepared by nanoprecipitation using optimized drug-to-polymer ratio and stabilizer concentration. The formulations were evaluated for particle size, zeta potential, entrapment efficiency, drug loading, and in-vitro drug release. FT-IR spectroscopy confirmed compatibility between drug and polymer, while zeta potential analysis indicated good colloidal stability. In-vitro release studies demonstrated sustained release of Docetaxel over an extended period. Kinetic analysis using zero-order, first-order, Higuchi, and Korsmeyer–Peppas models suggested a controlled drug release pattern predominantly governed by diffusion. The findings indicate that PLGA-based Docetaxel nanoparticles are a promising approach for targeted anticancer drug delivery with potential to enhance therapeutic efficacy and reduce systemic toxicity. Further in-vivo studies are recommended to confirm clinical applicability.

Keywords: Nanoparticles; Docetaxel; PLGA; targeted drug delivery; nanoprecipitation; controlled release; zeta potential; drug entrapment efficiency; anticancer therapy.

I. INTRODUCTION

Nanoparticulate drug delivery systems have emerged as an advanced pharmaceutical approach for improving the therapeutic performance of poorly soluble drugs through controlled and targeted drug release. Conventional drug delivery methods often produce fluctuations in plasma drug concentration, leading to reduced therapeutic efficacy and increased adverse effects. Nanoparticles, typically ranging from 1–1000 nm, provide several advantages including enhanced bioavailability, improved cellular uptake, prolonged circulation time, and site-specific drug delivery. Among various biodegradable polymers, Poly(lactic-co-glycolic acid) (PLGA) has gained significant importance due to its excellent biocompatibility, biodegradability, and ability to provide sustained drug release. Docetaxel is a potent anticancer drug widely used in the treatment of breast, lung, prostate, and gastric cancers; however, its poor aqueous solubility and systemic toxicity limit its therapeutic effectiveness. Encapsulation of Docetaxel into PLGA nanoparticles offers a promising strategy to enhance drug stability, improve entrapment efficiency, and reduce toxicity through controlled release. Nanoprecipitation is considered a simple and effective technique for preparing polymeric nanoparticles with desirable physicochemical properties. The present study focuses on the formulation and characterization of Docetaxel-loaded PLGA nanoparticles and evaluation of their drug release kinetics. This approach is expected to improve therapeutic efficacy, minimize adverse effects, and contribute to the development of effective targeted anticancer drug delivery systems.

II. MATERIALS AND METHODS

2.1. Materials

Docetaxel was procured from Scion Pharma, Taiwan, and used as the model anticancer drug for nanoparticle formulation. Poly(lactic-co-glycolic acid) (PLGA), used as the biodegradable polymeric carrier, was obtained from Lactel, Durect Corporation Birmingham

Division, Mumbai. D-α-Tocopheryl polyethylene glycol succinate (TPGS), employed as a stabilizer and surfactant during nanoparticle preparation, was procured from Eastman Company, United Kingdom. Acetone, used as the organic solvent for polymer dissolution and nanoparticle preparation, was purchased from SRL, Mumbai. The dialysis membrane used for in-vitro drug release studies and separation procedures was obtained from Himedia, Mumbai. All chemicals and reagents used during the study were of analytical grade and utilized without further purification.

2.2. Equipments

The formulation and characterization of the developed system were carried out using various standard laboratory and analytical instruments to ensure accuracy, reproducibility, and reliability of results. A high-shear homogenizer (Kinematica AG, Polytron PT 2100) was used for primary emulsification and size reduction of the formulation. Rotary evaporation (Buchi, Switzerland) was employed for solvent removal under reduced pressure. Probe sonication (Hielscher Ultrasonics, Germany) was utilized to further reduce particle size and achieve uniform dispersion. Magnetic stirrer with hot plate (Remi Equipment, India) was used for continuous mixing and controlled heating during preparation steps.

Analytical measurements were performed using a UV-Visible spectrophotometer (Shimadzu, Japan) for absorbance studies, while pH was measured using a digital pH meter (Eutech Instruments, Singapore). The precise weighing of materials was carried out using an analytical balance (Mettler Toledo, Switzerland). Centrifugation studies were performed using a laboratory centrifuge (Remi, India) for separation and stability analysis. Low-temperature storage conditions were maintained using a deep freezer (-20°C) (Blue Star, India), and freeze-drying of samples was carried out using a lyophilizer (Labconco, USA).

Further characterization studies included particle size analysis using a Malvern Panalytical particle size analyzer (UK) to determine size distribution and uniformity. Structural and functional group analysis of the formulation components was performed using FTIR spectroscopy (Bruker, Germany). All instruments were used in accordance with the respective manufacturer's operating protocols to ensure standardization and reliability of experimental outcomes.

IR spectroscopic study of Docetaxel

Compatibility study (IR spectroscopy)

The drug-polymer compatibility was ascertained by subjecting the drug and homogenates of drug and polymer to Infrared spectrophotometric study.

2.3. Method Of Preparation Of Docetaxel Loaded Nanoparticles:

Nano precipitation

The nanoparticles are prepared by dissolving the drug in the organic phase along with the polymer (PLGA) and then added to the aqueous phase containing TPGS, which acts as an emulsifier and stabilizing agent. The organic phase solution was introduced dropwise into the aqueous phase under high-speed homogenization at 11,000 rpm to facilitate the formation of a fine emulsion. The resulting dispersion was further maintained under continuous magnetic stirring for 4 hours at room temperature to ensure complete solvent diffusion and nanoparticle formation. Subsequently, the formulation was subjected to reduced pressure conditions for 2–3 minutes to remove residual solvent and improve particle stability. This process results in the formation of uniform drug-loaded nanoparticles with enhanced encapsulation efficiency. The composition of the eight batches of Docetaxel nanoparticles is presented in Table 3.

Ingredients	Formulation Codes							
	F1	F2	F3	F4	F5	F6	F7	F8
Docetaxel (mg)	5	5	5	5	5	5	5	5
TPGS (%g/ml)	0.012	0.02	0.025	0.03	0.04	0.05	0.06	0.08
PLGA (mg)	10	15	25	30	40	50	60	80
Acetone (ml)	3	3	3	3	3	3	3	3
Water (ml)	10	10	10	10	10	10	10	10

Table 1: Composition of the Nanoparticles by Nano precipitation Method

2.4. Evaluation Of Docetaxel Loaded Nanoparticles:

1. Drug Loading
2. Particle size
3. Zeta potential
4. Entrapment efficiency
5. In vitro drug release

Particle Size:
Particle size was determined by using MALVERN instrument.

Zeta Potential:
Zeta potentialwas determined by using MALVERN instrument UK.

Lyophilization:
The obtained centrifuged samples were lyophilized and stored at 2-8^{0}C. The samples are lyophilized to attain stability. The obtained lyophilized powder is utilized for determination of entrapment efficiency and in-vitro drug release parameters.

Entrapment Efficiency:
Lyophilized nanoparticles 5mg were dissolved in 1ml of diluents and the drug amount was determined by HPLC analysis. The encapsulation efficiency was determined as the mass ratio of entrapped Docetaxel in nanoparticles to the theoretical amount of the drug used in the preparation. The entrapment of the Docetaxel PLGA nanoparticles was expressed as loading capacity.

$$\text{Entrapment Efficiency (\%)} = \frac{\text{Amount entrapped}}{\text{Total drug loaded}} \times 100$$

HPLC METHOD:
Application : Reverse phase
Method : Isocratic
Mobile phase :Acetonitrile:water:Methanol :: 45 : 30 : 25
Column: Zorbax-SB-C18, 250 x 4.6 mm, 5µ-particl size
Flow rate: 1.0mL/min
Detection: 230nm
Column temperature: Ambient
Injection Volume: 10µL
Linear Regression coefficient in the range of 0.25-0.75 mg/ml of R^2 =0.9998(n=5)

IN-VITRO DOCETAXEL RELEASE:
5 mg drug equivalent freeze-dried Docetaxel loaded nanoparticles were dispersed in 3 ml pH 7.4 phosphate buffer solution which is transferred in dialysis bag and suspended in 100 ml of isotonic pH 7.4 Phosphate buffer solution (PBS). The bag was placed under magnetic stirring in a water bath maintained at 37 ± 0.5° C. At fixed time intervals 5ml of samples were taken out and fresh buffer was replaced. The obtained solution was analyzed by HPLC to determine the drug content.

Mathematical Modeling of Drug Release
Mathematical modeling of drug release is a fundamental and essential tool in the field of controlled drug delivery. It involves the application of mathematical equations to describe and predict the rate and mechanism of a drug's release from a delivery system (e.g., a polymeric matrix, nanoparticle, or hydrogel) over time. By fitting experimental in-vitro release data to these models, researchers can gain valuable insights into the physicochemical processes governing the release, such as diffusion, erosion, or a combination of both. This knowledge is critical for optimizing the formulation, ensuring a predictable release profile, and predicting the in-vivo performance of the drug delivery system.

III. RESULTS AND DISCUSION

Hplc Method
Samples collected in diffusion studies were analyzed by HPLC technique. For this purpose, a standard plot was plotted in HPLC by using reference standard of Docetaxel.

Table 2: Standard Curve of Docetaxel by HPLC

S.No	Concentration (mg/ml)	Peak area
1	0	0
2	0.2	2889000
3	0.3	4391000
4	0.5	5795000
5	0.6	7298000
6	0.7	8657000

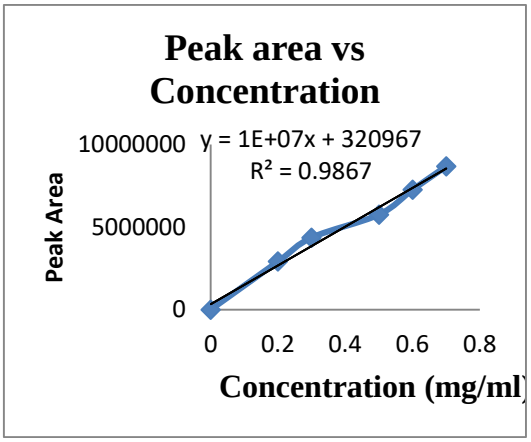


Figure 1: Standard plot of Docetaxel by using HPLC

3.1. Evaluation Parameters

The prepared nanoparticles were comprehensively evaluated to ensure their quality, stability, and performance. The assessment focused on the following key parameters:

- Drug Loading and Entrapment Efficiency
- Particle Size
- Zeta Potential
- In-vitro Release Study

Table 3: Nanoparticles were evaluated by determining their entrapment efficiency, particle size, zeta potential, and drug loading.

Batch No	Drug Loaded (mg)	Entrapment Efficiency (%)	Zeta Potential (Mv)	Particle Size (nm)
F1	0.21	4.2	-0.280	252.3
F2	0.22	4.8	-0.505	153.7
F3	0.20	4.3	-1.88	543.1
F4	1.08	20.8	-12.1	229.2
F5	1.92	37.6	-24.4	108.5
F6	3.29	64.5	-24.6	133.2
F7	4.12	81.5	-25.8	154.6
F8	4.88	97.3	-27.5	123.6

Optimization of Formulations:

The initial phase of the work plan focused on optimizing the surfactant concentration for nanoparticle formulation. To accomplish this, three preliminary formulations were prepared using varying concentrations of TPGS (0.015%, 0.03%, and 0.06%). The most effective concentration was determined based on the resulting nanoparticles' particle size and entrapment efficiency.

The optimum drug polymer ratio was selected on the basis of entrapment efficiency and drug loading capacity of the formulations.

Based on the entrapment efficiency data and drug loading capacity of all the batches formulations F6 to F8 was considered for evaluation of Diffusion study by invitro method and the batch results was shown in Table-8

Table 4: in-vitro diffusion study was conducted on the formulations

Ingredients (mg)	F6	F7	F8
PLGA	78	98	128
TPGS%(g/ml)	0.031	0.032	0.029
Docetaxel (mg)	5	5	5
Acetone (ml)	3	3	3
Water (ml)	10	10	10

***In- vitro* drug release of Docetaxel loaded Nanoparticles:**

Drug	Docetaxel
Total no. of time points including zero	11
Diffusion medium (pH)	7.4 PBS
RPM	200
Vol. of diffusion medium (mL)	100
Vol. of sample removed (mL)	5
Formulations	F6, F7, F8

Table 5: Cumulative % drug diffusion

Time (Hr)	Cumulative % drug diffusion		
	F6	F7	F8
0	0	0	0
24	34.5	31.8	26.2
48	41.4	38.6	32.4
72	47.2	41.4	38.5
96	55.6	50.5	45.6
120	63.2	55.6	50.2
144	68.9	63.4	54.6
168	74.8	70.0	63.7
192	80.7	76.2	68.8
216	87.9	82.4	73.9
240	**96.2**	90.9	85.6

The in-vitro diffusion studies were conducted in a pH 7.4 buffer using a dialysis membrane over a period of 240 hours. Initially, all three batches exhibited a rapid drug release of approximately 25-35% within the first 24 hours, which is attributed to the release of drug adsorbed on the nanoparticle surface. Following this initial burst, a slow and constant release profile was maintained for the remainder of the 240-hour study. The drug diffusion for F6, F7 and F8 formulations was found to be approximately 96.2%, 90.9% and 85.6% respectively after 240Hrs. Therefore, F8 formulation will be considered as best possible formulation among the other formulations due to better drug diffusion through membrane dialysis and concentration of PLGA plays an important role for drug diffusion as well as dissolution.

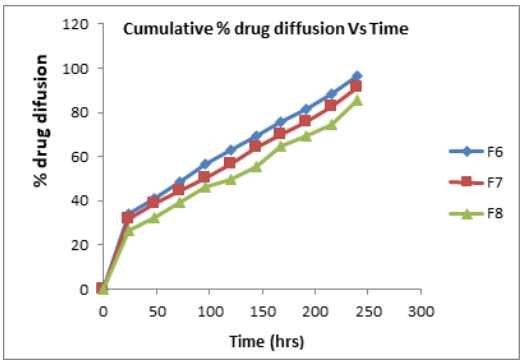


Fig 2: Diffusion study profile Curve of formulations F6 to F8

Zero order plot for F8 formulation

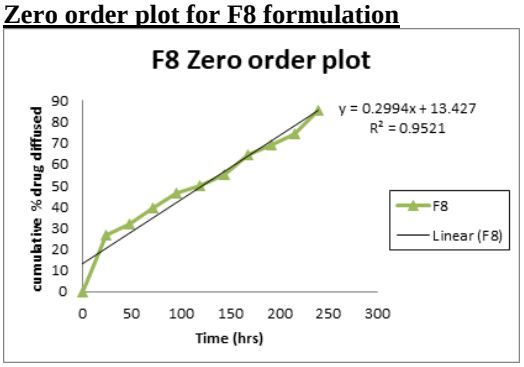


Fig 3: F8 Formulation plot (Zero order)

F8 formulation (First order plot)

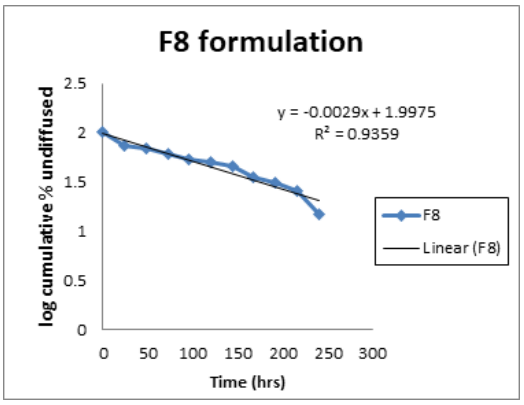


Fig 4: F8 Formulation plot (First order)

Higuchi plot for F8 formulation

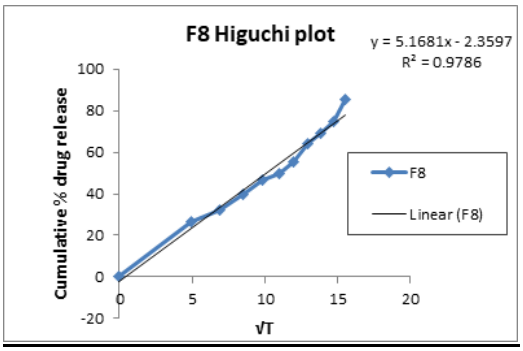


Fig 5: Higuchi plot For F8 Formulation

DRUG RELEASE KINETICS

Table 6: Drug diffusion kinetics for formulations F6, F7 and F8

Difusion kinetics		Formulations		
		F6	F7	F8
Zero order	R^2 value	0.878	0.934	0.954
	K_0	0.281	0.326	0.289
First order	R^2 value	0.887	0.917	0.946
	K_1	0.008	0.006	0.004
Higuchi	R^2 value	0.989	0.986	0.988
	K_H	5.987	5.536	5.176
Peppa's	R^2 value	0.955	0.957	0.979
	n value	0.797	0.789	0.776

Based on the in-vitro diffusion study, the drug release from formulation F8 best fit the Higuchi model, as indicated by the highest R^2 value of 0.979. Further analysis using the Korsmeyer-Peppas equation revealed an "n" value of 0.776, suggesting an anomalous diffusion mechanism where drug release is controlled by a combination of both diffusion and matrix erosion.

IR studies:

Infrared (IR) spectroscopy confirmed the absence of any significant drug-polymer interactions. The IR spectrum of the pure drug and the 1:1 drug-polymer mixture exhibited characteristic peaks within the range of 3386.95 cm^{-1} to 709.35 cm^{-1}, which indicates that the drug's molecular structure remained undisturbed. This evidence confirms that the drug is compatible with the polymer used in the formulation, allowing the Docetaxel formula to be reproduced on an industrial scale without concerns of potential drug-polymer incompatibility.

Table 7: DATA FOR IR SPECTRA OF DOCETAXEL

FUNCTIONAL GROUPS	FREQUENCY(cm^{-1})
(--O—H) Stretching in alcohols	3386.95
(--C—H) Stretching in alkanes	2928.19&2860.73
(>C=O) stretching	1709.49
(–NH) Stretching(2^0 Amine)	1504.64
(–C–H) bending	1453.26
(–C–O) stretching 3^0 Alcohols	1168.16
(–C–O) stretching 2^0 Alcohols	1103.28
(–Phenyl) stretching	709.35

Table 8: DATA FOR IR SPECTRA OF MIXTURE OF DOCETAXEL AND PLGA:

FUNCTIONAL GROUPS	FREQUENCY(cm^{-1})
(--O—H) Stretching in alcohols	3388.21
(--C—H) Stretching in alkanes	2979.22 & 2934.29
(>C=O) stretching	1710.28
(–NH) Stretching (2^0 Amine)	1503.07
(–C–H) bending	1448.8
(–O–) stretching	1257.98
(–C–O) stretching 3^0 Alcohols	1169.61
(–C–O) stretching 2^0 Alcohols	1098.59
(–Phenyl) stretching	709.32

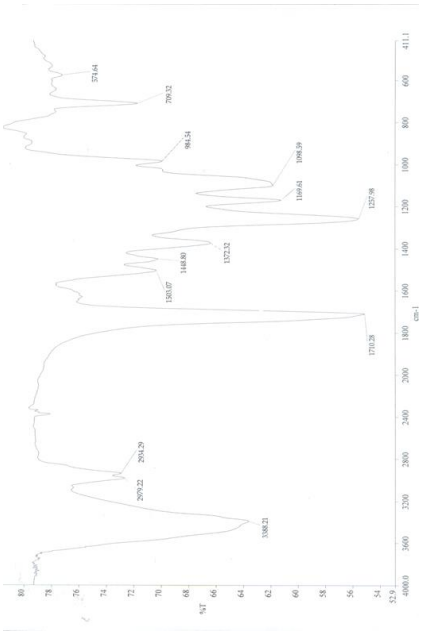


Fig-6: FT-IR Spectrum of Docetaxel

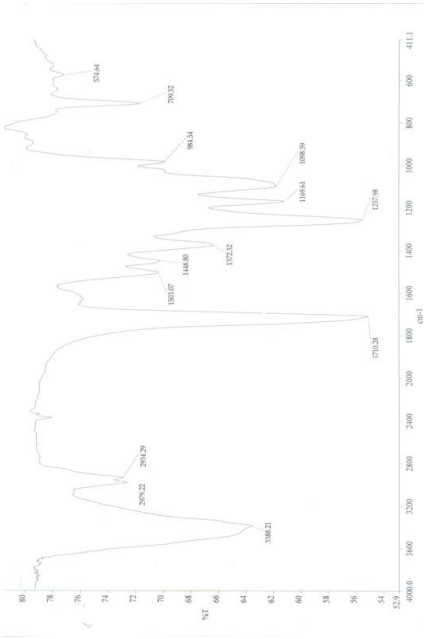
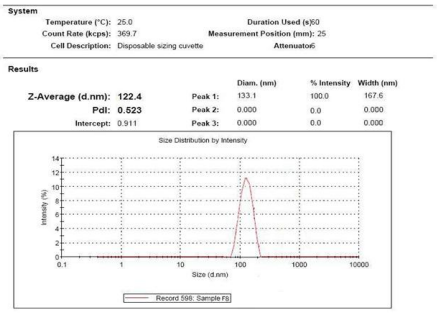


Fig-7: FT-IR SPECTRA OF FORMULATION F8

Zeta Potential studies:



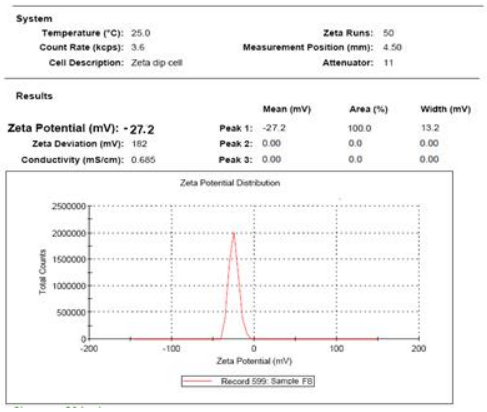


Fig-17:Size Distribution and Zeta Potential Reports of F8

IV. CONCLUSION

This research successfully developed novel polymeric nanoparticles for Docetaxel using the nanoprecipitation technique with TPGS as an emulsifier. We optimized various formulations by adjusting the drug, polymer, and surfactant ratios. Our findings show that TPGS is an effective emulsifier, significantly improving the nanoparticles' drug entrapment efficiency, particle size distribution, and zeta potential, as well as their in-vitro drug diffusion.

After 240 hours, the drug diffusion rates for formulations F6, F7, and F8 were 96.4%, 91.5%, and 85.4%, respectively. However, formulation F8 stood out with a high drug entrapment efficiency of 98%, making it the optimal formulation with a drug-to-polymer ratio of 1:40. Our results also confirmed that both particle size and zeta potential are highly dependent on the amount of TPGS used in the preparation.

Furthermore, drug release kinetics were best explained by the Higuchi model, which showed the highest linearity with an R^2 value of 0.978. The release mechanism was identified as an anomalous diffusion mechanism, based on a Korsmeyer-Peppas exponent (n) of 0.774.

REFERENCE

1. Martindale, 34th edition, the complete drug reference, Pitavastatin, 2005; pg no: 997-1000.
2. Ahad, A., Al-Jenoobi, F. I., & Al-Suwayeh, S. A. (2014). An updated review on polymeric nanoparticles for oral drug delivery. J. Drug Deliv. Sci. Technol., 24(1), 1-13.
3. Desai, M. P., Labhasetwar, V., Amidon, G. L., & Levy, R. J. (1997). In vitro and in vivo studies with microparticles and nanoparticles for intestinal delivery of proteins. Pharm. Res., 14(11), 1568-1574.
4. Fonseca, C., Simoes, S., & Gaspar, R. (2022). Paclitaxel-loaded polymeric nanoparticles: formulation, physicochemical characterization, and in vitro evaluation. J. Control. Release, 83(1), 1-11.
5. Gref, R., Minamitake, Y., Peracchia, M. T., Trubetskoy, V., Torchilin, V. P., & Langer, R. (1994). Biodegradable long-circulating polymeric nanospheres. Science, 263(5154), 1600-1603.
6. Hanes, M. D., Charest, L. A., Nielson, G. S., Parenteau, M. I., & S. P. S. (1997). Preparation and characterization of poly(lactic-co-glycolic acid) nanoparticles for controlled release of doxorubicin. Biomaterials, 18(10), 839-847.
7. Higuchi, T. (1961). Mechanism of sustained-action medication. Theoretical analysis of rate of release of solid drugs dispersed in solid matrices. J. Pharm. Sci., 50(12), 1018-1022.
8. Klibanov, A. L., Maruyama, K., Torchilin, V. P., & Huang, L. (1991). Lipid-coated polymeric nanoparticles: a new class of long-circulating drug carriers. Pharm. Res., 8(3), 403-407.
9. Korsmeyer, R. W., Peppas, N. A. (1983). Effect of the morphology of polymers on the kinetics of controlled drug release. J. Control. Release, 2(1), 89-98.
10. Kreuter, J. (1983). Nanoparticles as a novel drug delivery system: drug loading and encapsulation efficiency. J. Microencapsul., 2(1), 1-10.
11. Lanza, G. M., & Wickline, S. A. (2001). Nanotechnology in medicine. Circulation, 104(16), 2005-2008.
12. Langer, R., & Peppas, N. A. (2000). Present and future of biomaterials for drug delivery: an overview. Adv. Drug Deliv. Rev., 45(1), 1-7.
13. Mohanraj, V. J., & Chen, Y. (2006). Nanoparticles - a review. Trop. J. Pharm. Res., 5(2), 561-573.
14. Panyam, J., & Labhasetwar, V. (2003). Biodegradable nanoparticles for drug and gene delivery to cells and tissue. Adv. Drug Deliv. Rev., 55(3), 329-347.
15. Rawat, M., Singh, D., Saraf, S., & Saraf, S. (2008). Nanoparticles: A novel approach for targeted drug delivery. Int. J. Pharm. Sci. Nanotechnol., 1(1), 10-18.
16. Reis, C. P., Neufeld, R. J., Ribeiro, A. J., & Veiga, F. (2006). Nanoencapsulation I. Methods for preparation of drug-loaded polymeric nanoparticles. Nanomedicine: Nanotechnology, Biology and Medicine, 2(1), 8-21.
17. Soppimath, K. S., Aminabhavi, T. M., Kulkarni, A. R., & Rudzinski, W. E. (2001).

Biodegradable polymeric nanoparticles as drug delivery devices. J. Control. Release, 70(1-2), 1-20.
18. Siepmann, J., & Siepmann, F. (2008). Mathematical modeling of drug release. Int. J. Pharm., 364(2), 328-340.
19. Torchilin, V. P. (2003). Polymer-drug conjugates for targeted delivery. Adv. Drug Deliv. Rev., 55(3), 373-407.
20. Torchilin, V. P. (2007). Targeted polymeric micelles for drug delivery. J. Drug Target., 15(1), 1-11.
21. Yadav, V., & Pandey, J. P. (2018). Nanoparticles: A review on preparation, characterization and applications. J. Drug Deliv. Ther., 8(6), 332-339.
22. Wang, Y., Zhu, X., & Li, R. (2010). Formulation and in-vitro characterization of docetaxel-loaded PLGA nanoparticles. AAPS PharmSciTech, 11(2), 856-863.
23. Lee, H. B., L., N. S. J. C. W. (1999). Drug release from nanospheres made of poly(d,l-lactide-co-glycolide). J. Pharm. Sci., 88(3), 320-327.
24. Ganesan, P., & P. M. S. (2013). Nanoparticulate drug delivery system: an overview. J. Pharm. Res., 7(4), 160-167.
25. Jain, R. K., & Stylianopoulos, T. (2010). The role of the tumor stroma in the EPR effect. J. Control. Release, 147(1), 1-8.
26. Singh, R., & Lillard, J. W. (2009). Nanoparticle-based drug delivery systems: an overview. Exp. Mol. Pathol., 86(3), 205-214.
27. S. A. J. S., & P. G. (2007). Nanoparticles as drug delivery system: A review. Int. J. Pharm. Res. Dev., 3(2), 1-8.
28. S. J. A. (2010). Formulation and characterization of sustained release nanoparticles of an anticancer drug. J. Appl. Pharm. Sci., 1(1), 1-7.