Formulation and In vitro Characterization of a Curcumin-Based Film-Forming Spray using Tamarind Kernel Powder for Advanced Wound Care

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Abstract

Traditional treatments of wound infections frequently suffer from limited bioavailability and retention. This study introduces an innovative curcumin-based film-forming spray (FFS) using tamarind kernel powder (TKP) as a natural polymer to address these infections resulting from trauma involving animals, plants, or foreign objects. Curcumin is commonly acknowledged for having strong antibacterial, anti-inflammatory, and antioxidant qualities, was incorporated into a formulation optimized for enhanced wound care. TKP served as a biocompatible film-forming agent, contributing to superior adhesion, mechanical strength, and flexibility. The spray formulations that went into development were assessed for their physical appearance, pH, viscosity, stickiness, spread ability, spray angle, and film formation time. The optimized formulation (F5) exhibited superior characteristics, including non-stickiness, excellent spread ability, spray angle and film formation time. Studies on in vitro drug release suggested that the film-forming spray had sustained drug release. FTIR analysis confirmed the stability and compatibility of curcumin with the excipients. Future research avenues include clinical trials, in vivo studies, and nano-encapsulation techniques to further enhance bioavailability and stability. Additionally, expanding its application to burns, diabetic wounds, and antimicrobial therapies can broaden its therapeutic potential. This innovation offers a sustainable, natural, and cost-effective substitute for artificial wound dressings, paving the way for advanced, eco-friendly wound care solutions. The developed formulation demonstrates promising potential to revolutionize topical drug delivery systems in healthcare.

Keywords- Film-forming, Curcumin, Tamarind Kernel Powder, Wound care, Antimicrobial

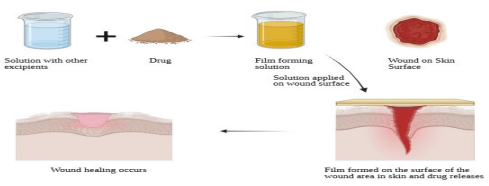


Figure: The Graphical Abstract

1. Introduction

The largest and most significant component within the human being, the skin operates as the body's interface to the external environment [1]. As wounds disrupt the skin's continuity, germs can enter tissues. Wound-causing agents can be categorised based on the extent of the wound and the probability that they would act as carriers of pathogenic organisms. Penetrating trauma by animals, plants, firearms, knives, or other things can result in wound infections. Many plant-based products have the potential to pierce the skin and cause an infection. Since most plant materials are permeable, a thorn or similar item may act as a conduit for *Staphylococcus aureus* or other pathogens to enter the tissues [2].

A wound's healing process typically takes up to twelve weeks, yet persistent wounds might require years to heal. Haemostasis is preceded by inflammatory phases within the four phases that generate the natural process for healing of the wound. Around a few hours after damage, a new epithelium starts to form, associated with granulation tissue creation, collagen fibre implantation, and new blood vessel development. In the ultimate portion of wound recovery, collagen synthesis, collagen reassembly, and scar tissue formation are all accelerated [3].

The treatment of the wound infection is the major aim for the health workers. There are various methods used to treat the infection from ancient time. Due to its cost and ease of use, drug administration through the skin is growing in popularity. The skin serves as the best premises for systemic and local medication delivery and is the most significant mechanical barrier to the passage of many pharmacological compounds. In the prior several decades, the method of topical administration has long been the most prevalent way to administer drugs. The restrictions of traditional transdermal administration methods include limited bioavailability and poor retention. This limitation has been addressed through in-depth research to create innovative topical drug delivery methods that aim to increase safety, effectiveness, and reduce adverse effects [4].

Over the previous several decades, different breakthroughs have witnessed toward the production of efficient as well as effective spray applications. Among these are film-forming sprays (FFS), which are superior to conventional topical medicines in many ways; such as consistent dosing of drug along with its delivery; high bioavailability; a lesser likelihood of itchiness; uninterrupted drug delivery; as well as moisture control that accelerates healing of a wound [5]. Typically, the active compounds, enhancers, and polymers that comprise up FFS undergo dissolution in inorganic solvents [6]. In contrast to different traditional dermal medications, a thin, smooth film can boost the drug's permeability and contact duration, leading

to continuous drug release. It can also stop crystallisation, allowing for more medication to be accessible for healing advantages [7]. The spray capability of film-forming system is impacted via the particular nozzle type, aperture size, spray pressure, and liquid composition [8,9,10]. By application of water the thin covering can be freely washed away [11,12]. In contrast to gels, patches, ointments, etc., that provides a harsh along with greasy feel after application, patients are more comfortable throughout activities because to the thin, non-sticky material [13,14]. **Sorathiya et al.** (2023) developed a film-forming application for quicker wound healing by simply combining film-forming polymers using a medicinal extraction of oak gall (*Quercus infectoria*). These results imply that *Q. infectoria* would make a great herbal ingredient in a film-forming application in wound treatment, thereby confirming the conventional wisdom that it can heal wounds [15]. Again **Huanbutta et al.** (2020), formulated propolis extract in a film forming system by contributing enhanced tamarind kernel gum as a film forming agent. The findings point for the potential use of propolis extract and improved tamarind kernel developing methods for film-forming as well as to boost antibacterial efficacy on the skin [16].

In the last few years, the significance of medicine delivery methods based on herbs has grown tremendously. According to estimates from the World Health Organisation (WHO), more than 80% of individuals globally receive their primary healthcare from conventional medical practices. Over time, the utilisation of phytoconstituents like quercetin, curcumin, and silymarin has increased due to the adverse effects of synthetic substances and the rising expense of medications [17]. The brilliant yellow polyphenol known as curcumin ((1E,6E)-1,7-bis(4-hydroxy-3-methoxyphenyl)-1,6 heptadiene-3,5-dione) had been collected through the *Curcuma longa* plant root's, a belonging of the family *Zingiberaceae* [18]. It continues to be preferred as a nutriment by Asians and conventional medical care since prehistoric times [19]. The most popular plant-based medication is curcumin, which has several benefits of pharmacology like anti-inflammatory, anti-fungal, antiviral, antibacterial, anti-oxidant, anti-cancer, and anti-parasite properties [20]. By promoting fibroblast proliferation, it contributes to re-epithelization [21]. Tumour necrosis alpha and interleukin-1, two important cytokines, were reduced by curcumin's anti-inflammatory effects. The antioxidant qualities of curcumin have been shown to significantly shorten the time it takes for wounds to heal by neutralising free reactive oxygen molecules including superoxide (O_2) and hydrogen peroxide (H_20_2) when administered topically [22]. Considering its positive effects, curcumin has a number of major drawbacks, including low solubility in water, a greater rate of elimination, and quicker disintegration. Consequently, the formulation of topical products seeks to solubilise curcumin while preventing hydrolysis and assuring its sustained release into the intended area. The

potential for toxicity at the injury site at high dosages is one drawback of topical curcumin. As a result, the formulation's ideal concentration was chosen [23].

Tamarind kernel powder is regarded as a good polymer for skin preparation since it is non-toxic and inexpensive, even though several polymers were used to make the film-forming spray. TKP can serve as innovative drug delivery in pharmaceutical products because of their non-carcinogenicity, biocompatibility, high drug-loading capacity, and high thermal stability. It has strong film-forming qualities as well. Synthetic polymers may eventually be replaced by completely biodegradable natural gums like TKP [24]. In the present study, with the incorporation of tamarind kernel powder (TKP) as polymer and curcumin as a drug which has a strong ability to minimise side effects by formulating it in film forming spray and administered earlier to skin surface to prevent serious wound infection, an innovative approach has been developed to get around the drawbacks of existing types of dosing.

2. Materials and Methods

2.1 Materials

Table 1. Material's List

Items	Category	Source
Tamarind Kernel Powder (TKP)	Polymer	Thakuria Lac Industries, Dhamtari, Chhattisgarh
Hydroxypropyl methylcellulose (HPMC)	Suspending agent	Loba Chemie Pvt. Ltd., Mumbai, Maharashtra
Glycerol	Plasticizer	Universal Fine Chem, Howrah, West Bengal
Ethanol	Solvent	Chemical Udyog, Haryana
Distilled water	Solvent	Kalinga University, Naya Raipur
Curcumin	Drug	Himedia Laboratories Pvt. Ltd., Mumbai, Maharashtra

2.2 Methods

The solvents water and ethanol in various concentrations was taken and the solvent ratio optimized. The water was mixed with the half amount of ethanol and heated up to 40^0 C. In the solution, hydroxypropyl methyl cellulose (HPMC) was added during heating. Further the tamarind kernel powder (TKP) was dissolved into the solution and stirred upto 45 minutes at a

temperature of 50^0C. Curcumin was dissolved in the remaining half of the ethanol for 30 minutes to prepare an ethanolic solution. At 50^0 C, the curcumin solution was gradually incorporated into the entire mixture while stirring it for 25 minutes. After letting the mixture to cool down to the outside temperature, glycerol was gradually added and shaken for five to ten minutes. The film-forming solution was prepared. The composition of drug-loaded film-forming spray is provided in the below Table No.1.

Figure 1: The Graphical image of method of preparation

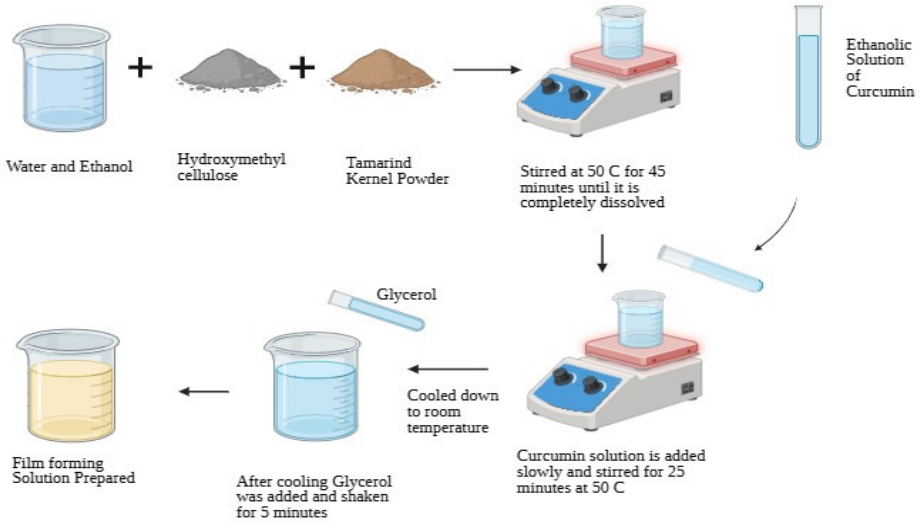
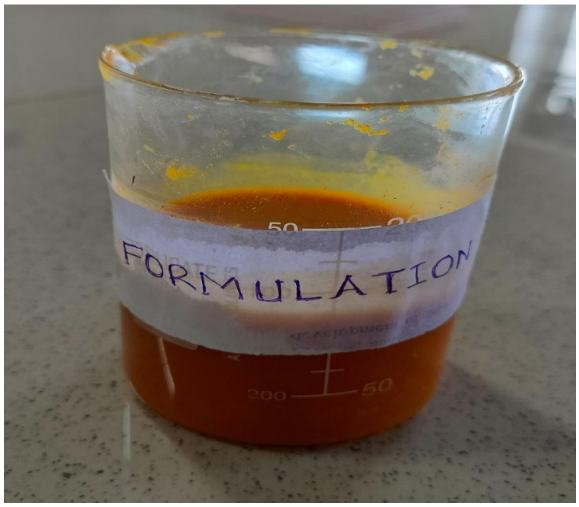


Table 2. The Composition of Drug-loaded Film-forming Spray

SI.no	**Chemicals Used**	**F1**	**F2**	**F3**	**F4**	**F5**	**F6**
1.	Curcumin	100 mg	100 mg	100 mg	100 mg	100 mg	100 mg
2.	TKP	2 g	2.5 g	3 g	3.5 g	4 g	4.5 g
3.	HPMC	1 g	1 g	2 g	2 g	2 g	2 g
4.	Glycerol	1 mL	1 mL	1 mL	1 mL	1 mL	1 mL
5.	Water: Ethanol (5.5:4.5)	100 mL	100 mL	100 mL	100 mL	100 mL	100 mL

Figure 2. Optimized formulation of the film forming spray



2.3 Evaluation

2.3.1 Film-forming spray's physical characteristics and film development test

Examination by eye opposed to a white and black screen was used to evaluate the prepared spray solutions' appearance. Film formation, homogeneity, inequity, whether there is precipitation or not, along with transparency or opacity were all evaluated after the films were cast on a petri dish [25].

2.3.2 pH Test

The film-forming solution's pH was determined through the *Labtronics Model LT-501* digital *pH* meter. The pH reading was determined straight from the meter's display after the electrode of the meter for pH was immersed within it [26].

2.3.3 Viscosity Test

Measurements of the produced spray compositions' viscosity were made using *Brookfield Viscometer Rolex*, India at room temperature. The readings were noted down [25].

2.3.4 Film-formation time

By kindly applying a petri plate with the film-forming solution, film formation time, a crucial factor in ensuring patient compliance was measured. The amount of time it took for a dry film to form from the solution was accurately measured as well as noted. The purpose of this assessment was to find out how long the process of film formation takes, which is an important consideration of formulation applicability as well as patient ease [5]. Every measurement was taken three times.

2.3.5 Stickiness test

Each dried film was softly, without applying any pressure, covered with a piece of cotton in order to determine its stickiness. The amount of cotton fibre remaining on the surface of the film was used to calculate the degree of stickiness; films with more conserved cotton fibres were classified as "very sticky," those containing a modest quantity of fibres that are maintained as "medium sticky," and those without any adhesion to cotton fibre as "non-sticky." This method systematically facilitates the characterisation of the adhesive qualities of the films by offering a visible and useful way to differentiate between various levels of stickiness [(27)].

2.3.6 Spread-ability test

By spreading a diameter of one millilitre of formulation over two plates that are horizontal (20 cm by 20 cm), one minute later, the formulations' spread ability was measured. A typical 125-gram weight was exposed to the uppermost plate [(28)].

2.3.7 Spray angle test

The investigation employed the spray impingement technique on a sheet of paper. The white paper, which was placed 15 cm from the nozzle, received the horizontally directed sprays. Three separate measurements within the circle's radius were made on the paper from various angles. The angle of spray (θ) was estimated by,

$$Spray\ angle\ (\theta) = tan^{-1}(l/r)$$

in which r is the average circle radius and l being paper's distance from the nozzle [(29)].

2.3.8 In vitro drug release

Using a Franz diffusion cell, the diffusion of in vitro medications with optimised formulations was investigated. The cell contains two chambers, with a 1.5 cm-diameter diffusion membrane (also known as a dialysis membrane) among the sections of the donor and the receptor. The receptor media, which was 25 ml of phosphate buffer saline (PBS, pH7.4), was thermoregulated at 37±1°C using a water bath and consistently stirred by a magnetic stirrer during the experiment. After the receptor chamber had been submerged in PBS for a full day, the drug-containing film-forming spray was placed over the drug release membrane inside the donor compartment, which was separated from the receptor compartment by a diffusion membrane. Samples (2 ml) were taken at 0.5, 1, 2, 3, and up to 8 hours, and a graph and table were made to show the drug diffusion. After that, the samples were compared to a blank using

spectrophotometry at λ max. The space inside the receptor was then filled with the same quantity of PBS each time a sample was removed [30,31].

2.3.9 FTIR Analysis

In order to develop a stable, effective, fascinating, and secure product, curcumin and the additional excipient must be physiochemically compatible. Pure curcumin, unaltered excipients, and a physical combination of composition in an equivalent proportions made up the sample. These were combined geometrically and subjected to FTIR spectroscopic analysis. The resolution was set to 1 cm^{-1}, and the range of scanning was 450–4000 cm^{-1} [32].

2.3.10 Stability study

The optimised batch's short-term stability was tested for a month at different conditions. Testing for stability showed how the formulation's quality varies over time in response to various external conditions, such as colour, pH, viscosity, drug content and physical characteristics of the optimised batch that stayed constant throughout the investigation [33].

3. Results and Discussion

3.1 Film-forming spray's physical characteristics and film development test

Each of the spray composition eliminated the presence of interfering particles and had good clarity. After spraying, a clear, consistent dry layer developed on the petri plate. After film creation, no precipitation was seen. This demonstrates that the appearance and formation of the film are unaffected by the use of various polymer concentrations. The optimized formulation was found to be F5 formulation which has dark yellowish colour.

Figure 3. Film-forming Spray of curcumin

3.2 pH test

Since it may discomfort skin when it deviates from the pH values of normal skin (i.e., 4 to 6), pH measurement is an important parameter for topical formulations. The pH of the optimized formulation F5 was found to be 6.02 which was more in line with the pH of skin. Consequently, when applied topically, the curcumin film-forming solution might not cause skin irritation.

3.3 Viscosity test

The optimized formulation's F5 viscosity was noted as 43.2 mPa s^{-1}, which was optimal for the spray of the formulation. The viscosity of the formulation has greater effect on its amount of spray and depends on the concentrations of polymers and other excipients. It is seen that the formulation F5 is easily sprayed on the petri dish.

Figure 4. Viscosity test

3.4 Film formation time

The formulation F5 showed the film formation time of 5 min 10 sec, which was found to be inside the film-forming spray's range. The evaporation or film forming time is extremely important for the application of the formulation as it should dry faster and film be formed. Less film formation time is considered to be favourable as higher time might affect the patient compliance.

3.5 Stickiness test

The stickiness test conducted on six formulations (F1 to F6) revealed that only F5 was non-sticky, meeting the desired objective. F1, F3, F4, and F6 were classified as "very sticky," while F2 was "medium sticky." F5 demonstrated no cotton fibre retention, confirming its non-sticky

nature. These results highlight F5 as the most suitable formulation for further development, as it fulfils the requirement for a non-sticky film-forming spray.

3.6 Spread-ability test

With a spread diameter of 2.8 cm^2, the spread-ability test showed that F5 had the best spread-ability. Lower spread-ability was shown by the smaller spread diameters of the other formulations (F1, F2, F3, F4, and F6). F5 is the best formulation for applications that require the best spread-ability in the film-forming spray since it performed better than the others in terms of even distribution and coverage.

3.7 Spray angle test

The spray angle test demonstrated that F5 had the best spray angle of 78.9 degrees, indicating optimal spray coverage. Other formulations showed varying spray angles, with lower performance compared to F5. The spray from F5 provided the widest and most consistent spread, making it the most effective formulation in terms of spray angle and distribution. F5 is recommended for applications requiring precise spray dispersion and coverage.

Table 3. Characterization of the optimized formulation

Parameters	Outcomes
Physical appearance	Dark yellowish colour
pH	6.02
Viscosity	43.2 mPa. s
Film-formation time	5 min 10 sec
Stickiness	Non-sticky
Spread-ability	2.8 cm^2
Spray angle	78.9^0

3.8 In vitro drug release

Utilising the Franz diffusion cell, the percentage of drug released from the curcumin-containing film-forming spray was recorded. Because of its high R-square, or 0.9970, Formulation 5 is considered the best and most optimal from the standpoint of this result. Numerous kinetics, including the calibration curve, zero order and first order drug releases, Higuchi models, and Korsmeyer Peppas model of highly optimised formulations, are depicted in the image below. The Figure 5 shows the absorbing capacity of formulation 5

with respect to the time calibration graph. Figure 8 shows the Higuchi Model, Figure 9 shows the Korsmeyer Peppas Model, Figure 6 shows the zero-order kinetics graph and Figure 7 displays about the first-order kinetics.

Figure 5. Calibration Curve Graph

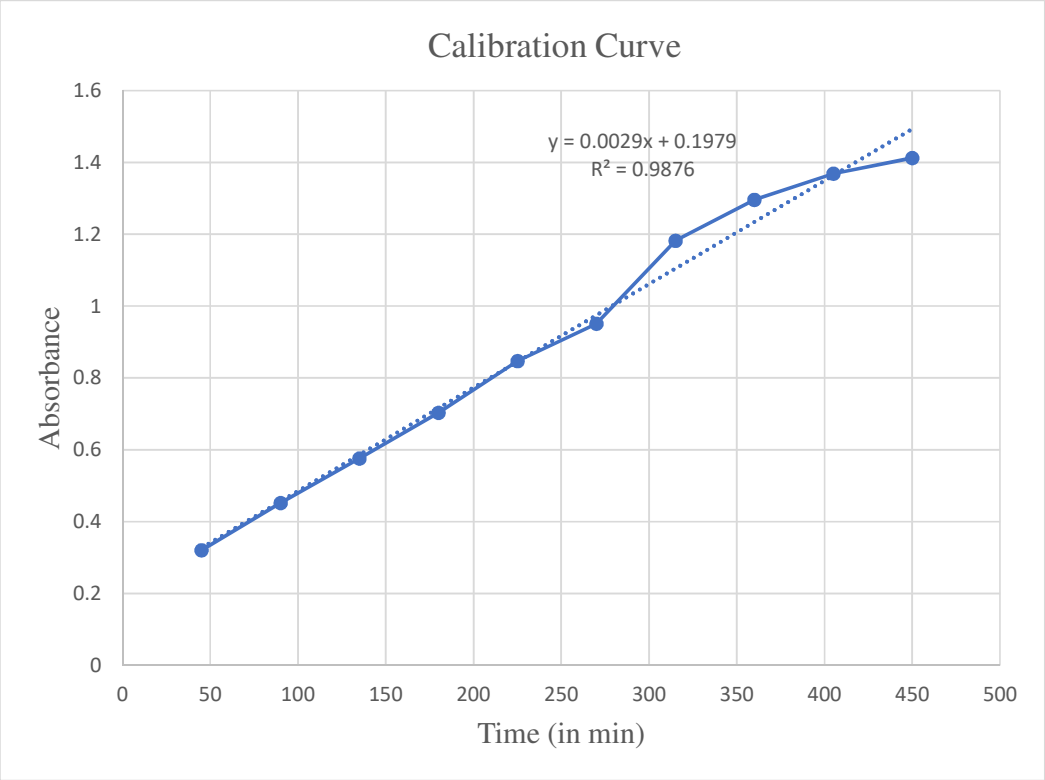


Figure 6. Zero-order Release Kinetics

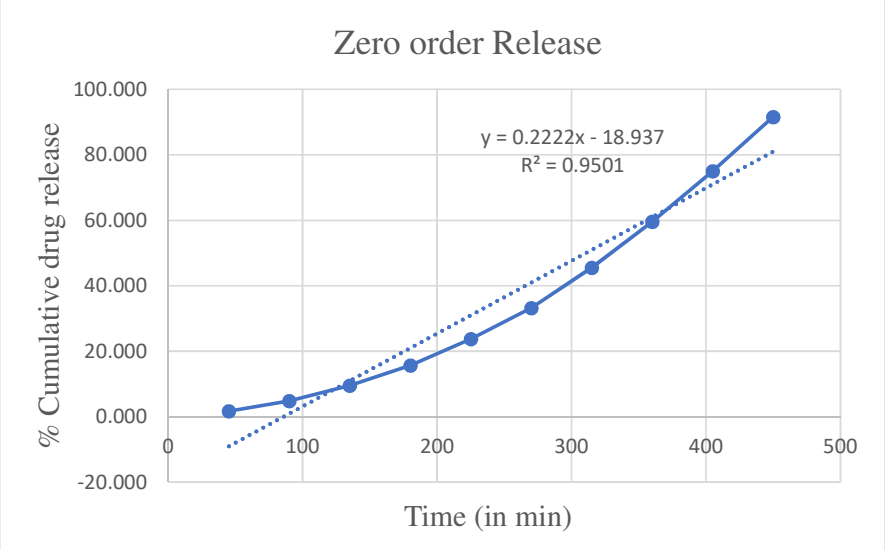


Figure 7. First-order Release Kinetics

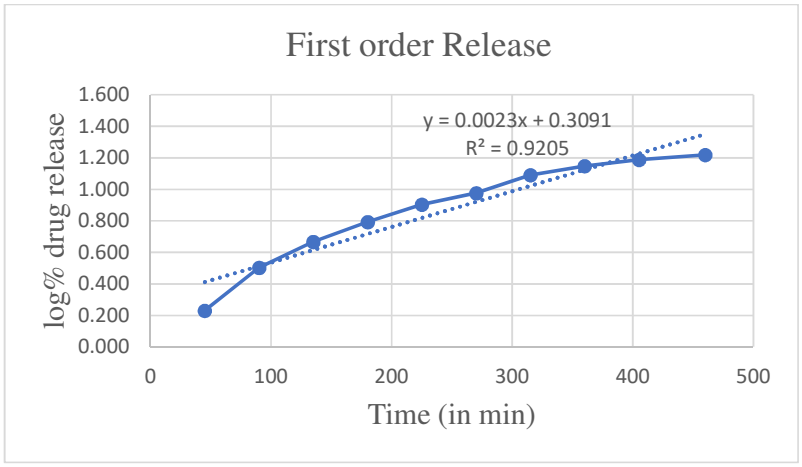


Figure 7. Higuchi Model

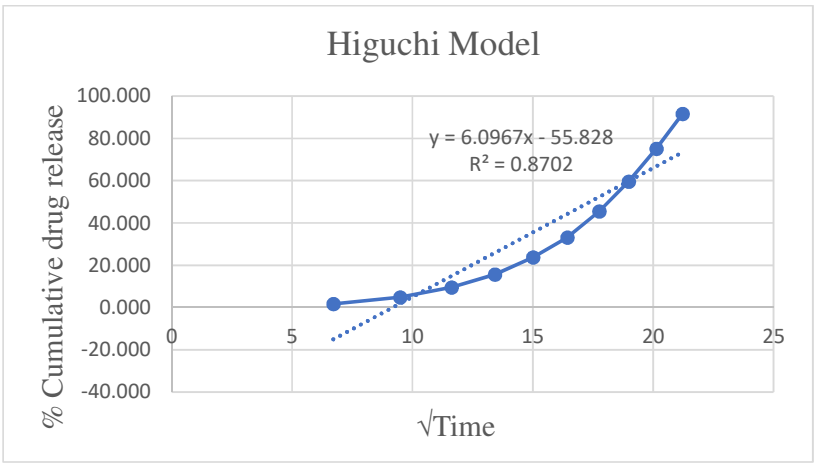
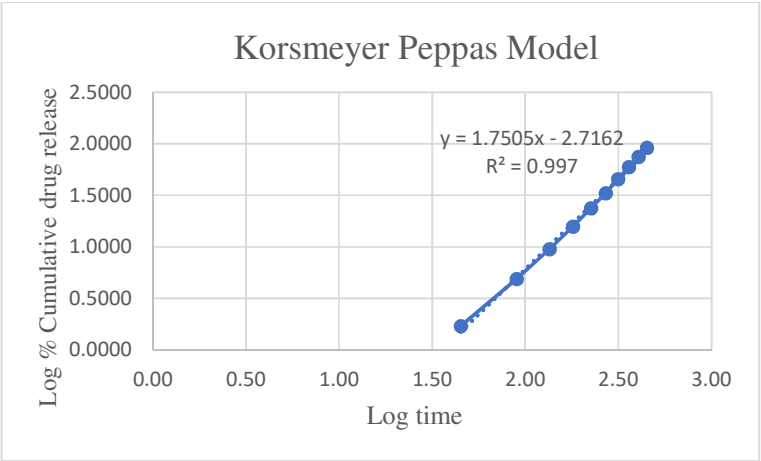


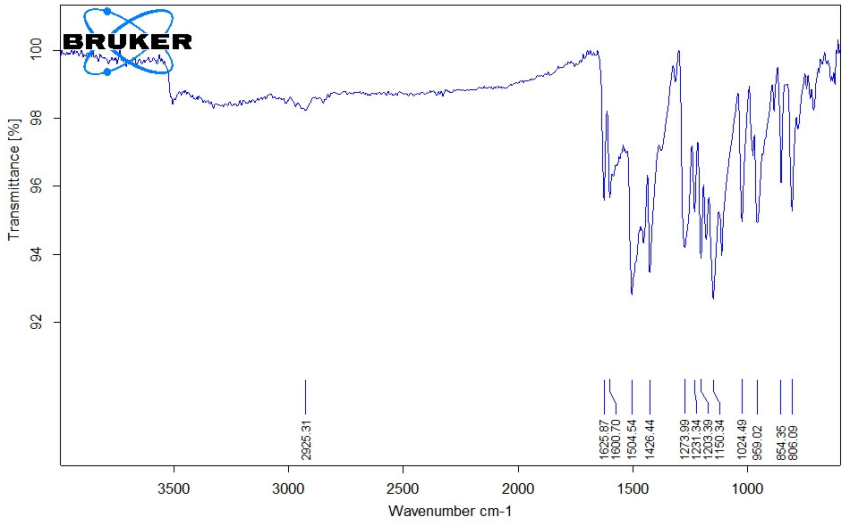
Figure 8. Korsmeyer Peppas Model



In comparison to other orders of kinetics, the Korsmeyer Peppas model has a larger R-square value (0.9970), as seen by the four release kinetics graphs previously described. Korsmeyer Peppas model kinetics is regarded as the standard for exhibiting prolonged release as it demonstrates that the drug is released in a sustained manner.

3.9 FTIR Analysis

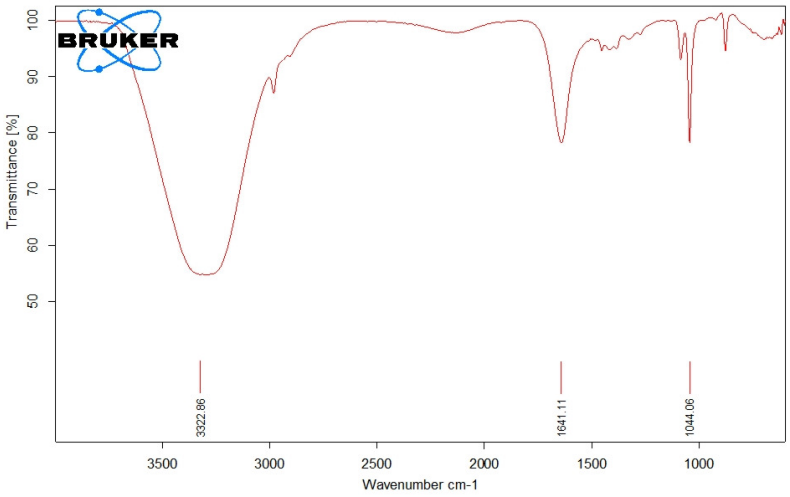
Figure 9. FTIR graph of curcumin



The FTIR spectrum of curcumin powder shows distinctive absorption peaks that match its functional groups. Vibrations due to stretching by C-H of the methyl (-CH_3) and methylene (-CH_2) groups are responsible for its peak at 2925.31 cm^{-1}. A peak at 1625.87 cm^{-1} represents the vibration of the conjugated carbonyl (C=O) inside the α, β-unsaturated ketone system which is stretching, a defining feature of curcumin. A peak formed at 1600.70 cm^{-1} represents the stretching vibrations of aromatic C=C bonds within the benzene rings, while 1504.54 cm^{-1} is associated with additional aromatic ring vibrations. The absorption at 1426.44 cm^{-1} is connected to the CH_3 groups' bending vibrations. Peaks observed at 1273.99 cm^{-1} as well as 1231.34 cm^{-1} correspond to vibrations of stretching of C-O of phenolic (-OH) as well as ether (-C-O-) functionalities, while 1203.39 cm^{-1} can be assigned to C-O-C stretching, commonly found in diarylheptanoid structures. The peak at 1150.34 cm^{-1} suggests the existence of C-O stretching, possibly from enol or phenolic groups, whereas 1024.49 cm^{-1} corresponds to alcohol or ether stretching of the C-O. The peak formed at 959.02 cm^{-1} is associated with enol (-OH) bending vibrations or bending of the C-H out-of-plane, and the peaks formed at 854.35 cm^{-1} as well as 806.09 cm^{-1} correspond to bending of the C-H out-of-plane in aromatic rings. The presence of these peaks confirms the molecular structure of curcumin, highlighting its key functional groups such as aromatic rings, hydroxyl (-OH) groups, conjugated carbonyl (C=O),

and ether (C-O-C) linkages. The di-ketone structure is evident from the peaks around 1625 cm^{-1} and 1600 cm^{-1}, while the presence of phenolic (-OH) groups suggests potential hydrogen bonding interactions, which contribute to curcumin's bioactivity. Overall, the spectral analysis confirms the identity of the sample as curcumin powder.

Figure 10. FTIR graph of optimized formulation



The FTIR spectrum of the formulated curcumin sample exhibits significant changes compared to the pure curcumin spectrum, indicating potential interactions with excipients. A broad and intense peak at 3322.86 cm^{-1} corresponds to O-H stretching vibrations, suggesting strong hydrogen bonding, likely due to the presence of hydrophilic excipients such as polymers or stabilizers. This peak was not as prominent in the pure curcumin spectrum, indicating that the formulation may have enhanced solubility or stability through molecular interactions. The peak at 1641.11 cm^{-1}, corresponding to C=O stretching vibrations, shows a slight shift from the pure curcumin peak at 1625.87 cm^{-1}, suggesting modifications in the carbonyl environment, possibly due to hydrogen bonding or complexation with excipients. Another notable change is the peak at 1044.06 cm^{-1}, which represents C-O stretching vibrations. This peak appears broader and more pronounced compared to the pure curcumin peaks in the 1024–1273 cm^{-1} range, indicating the presence of additional functional groups from excipients. Despite these shifts, no new peaks corresponding to degradation products such as aldehydes or oxidation byproducts are observed, suggesting that curcumin remains chemically stable in the formulation. The observed spectral variations primarily indicate physical interactions rather than chemical degradation, confirming that no harmful changes have occurred. Overall, the FTIR analysis suggests that curcumin interacts with excipients mainly through hydrogen bonding and possible complexation, leading to improved formulation properties without compromising its chemical integrity.

3.10 Stability study

Table 4. Stability of 1 month under 2-8^{0}C

Time Point	External appearance	Measured pH of surface (±SD)	Percentage of drug present (±SD)
0 Day	No visible change in color	6.02 ±0.14	94.74±0.31
1 Week	No visible change in color	6.02 ±0.21	94.32±0.18
2 Week	No visible change in color	6.02 ±0.23	93.41±0.12
3 Week	No visible change in color	6.01 ±0.29	93.92±0.20
4 Week	No visible change in color	6.01 ±0.19	94.20±0.34

The data are presented as ± SEM (n = 3)

Table 5. Stability of 1 month under 15^0 C

Time Point	External appearance	Measured pH of surface (±SD)	Percentage of drug present (±SD)
0 Day	No visible change in color	6.02±0.17	94.67±0.36
1 Week	No visible change in color	6.02±0.31	94.18±0.52
2 Week	No visible change in color	6.00±0.22	94.25±0.47
3 Week	No visible change in color	5.99±0.12	93.78±0.26
4 Week	No visible change in color	5.99 ±0.15	94.32±0.17

The data are presented as ± SEM (n = 3)

Table 7. Stability of 1 Month under 25^0 C±2^{0}C/60%RH±5%RH

Time Point	External appearance	Measured pH of surface (±SD)	Percentage of drug present (±SD)
0 Day	No visible change in color	6.02±0.22	94.81±0.41
1 Week	No visible change in color	6.02±0.34	94.62±0.34
2 Week	No visible change in color	6.01±0.19	94.30±0.15
3 Week	No visible change in color	6.00±0.23	93.54±0.29
4 Week	No visible change in color	5..99±0.31	93.63±0.57

The data are presented as ± SEM (n = 3)

The enhanced formulation F5's stability tests showed a little decrease in the drug's concentration as well as the surface pH during a month. A range of storage temperatures (2-8^{0}C, 15^{0}C, and with a consistent 25^0 C ±20C/60% RH ±5%RH) showed no apparent modifications in the physical properties. Consequently, it was found that formulation F5 was stable for a month.

4. Future Scope

The development of a curcumin-based film-forming spray using tamarind kernel powder (TKP) holds great potential for advanced wound care. Future research can focus on clinical trials, in vivo studies, and nano-encapsulation techniques to enhance drug bioavailability and stability. Expanding its use for burns, diabetic wounds, and antimicrobial applications could increase its therapeutic impact. Commercialization efforts, including large-scale production and regulatory approvals, will be crucial for market entry. Additionally, integrating biodegradable packaging and eco-friendly preservatives can improve sustainability. This innovation could serve as a natural, cost-effective alternative to synthetic wound dressings, transforming topical drug delivery in healthcare.

5. Conclusion

The development of a curcumin-based film-forming spray using tamarind kernel powder (TKP) has demonstrated significant potential in wound healing and topical drug delivery. The optimized formulation F5 exhibited excellent film-forming ability, with desirable mechanical strength, adhesion, and flexibility. The studies conducted in vitro confirmed the profile of the formulation as sustained release, ensuring prolonged therapeutic effects. Antimicrobial tests revealed strong inhibition against bacterial strains, supporting its role in infection control. Additionally, biocompatibility studies confirmed the toxic-free nature of the formulation, ensuring the safety for dermatological applications. The ease of application, quick drying, and enhanced wound-healing efficacy highlight its superiority over conventional dressings. Overall, the results of this study validate its effectiveness as a natural, cost-effective, and sustainable alternative for advanced wound care applications.

6. References

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