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FORMULATION AND EVALUATION OF LINAGLIPTIN MUCOADHESIVE BUCCAL PATCH

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Keywords:

Type II diabetes mellitus, Linagliptin, Mucoadhesive buccal patch, Sustained release, DPP-4 inhibitor, and solvent casting

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ABSTRACT: Diabetes mellitus is a chronic metabolic disorder characterized by elevated blood glucose levels, with type II diabetes mellitus being the most prevalent form, primarily resulting from insulin resistance and/or insufficient insulin secretion. Mucoadhesive buccal patches, which are designed to adhere to the buccal mucosa for systemic effectiveness, offer a more effective option for oral administration because they bypass the first pass metabolism. Linagliptin, a dipeptidyl peptidase-4 (DPP-4) Inhibitor, is commonly used for the management of type II diabetes but suffers from limitations related to oral bioavailability and patient adherence. The present study aims to formulate and evaluate a Mucoadhesive buccal patch of linagliptin to provide sustained drug release and improve therapeutic effects. The primary objective Includes assessing the Mucoadhesive strength to ensure prolonged adhesion to the buccal mucosa, evaluating the formulation for pharmaceutical Suitability, and creating an ideal patch with desired physicochemical properties. The buccal patches were successfully developed with polyvinylpyrrolidone K30 (PVP K30) and hydroxypropyl methylcellulose (HPMC) as polymers using the solvent casting method, and the selected polymers and excipients ensured good flexibility, mucoadhesive property, and compatibility with the buccal environment. Evaluation parameters like physical properties, drug content uniformity, swelling index, and In-vitro drug release profiles confirmed uniformity, sustained drug release, and effective adhesion, all of which are essential for a reliable buccal delivery system. This study highlights the potential of buccal patches as an innovative alternative to conventional oral dosage forms, offering benefits such as enhanced bioavailability, and improved patient compliance.

INTRODUCTION: One of the most chronic disorders of metabolism and an increasing worldwide health concern is diabetes mellitus (DM). This disorder is caused by an imbalance in the body's ability to regulate blood sugar levels, which leads to persistently high blood glucose levels.

There are two primary forms of diabetes mellitus: type 1 and type 2: (Type 1 diabetes) is the autoimmune destruction of the pancreatic beta cells that produce insulin, because their bodies are unable to produce enough insulin. T1DM can strike at any age. The more prevalent kind of diabetes, known as type 2 diabetes (T2DM), typically appears in adulthood ¹.

Insulin resistance, which occurs when the body's cells are unable to react to insulin signals efficiently, is its main characteristic. T2DM is frequently linked with increased hepatic glucose synthesis and decreased pancreatic insulin secretion. Poor diet and physical inactivity are two

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lifestyle variables that contribute significantly to the development of type 2 diabetes. Yet the development of it is also influenced by genetic predisposition. The goals of diabetes mellitus treatment are to control blood sugar levels and lower the chance of complications. Lifestyle changes are one of these strategies. As a result, diabetes mellitus is linked to a higher risk of consequences, such as renal failure, cardiovascular disease, neuropathy, and vision impairment. Oral and injectable treatments are among the various pharmacological groups available for the treatment of type 2 diabetes^{1, 2}. Sulfonylurea, SGLT2 inhibitors, and metformin are examples of oral drugs that assist control blood sugar levels. Insulin is also used to treat type 2 diabetes, as are injectable drugs such as pramlintide and GLP-1 receptor agonists.

A mucoadhesive buccal drug delivery system (MBDDS) is a pharmaceutical formulation that adheres to the mucosal lining of the cheek for controlled drug release and absorption, bypassing first-pass metabolism, enhancing drugs bioavailability, potentially eliminating the need for frequent dosing are some benefits of these systems. Buccal patches are a novel and promising drug delivery method that offers numerous benefits². These thin, flexible films are a popular option in the pharmaceutical industry because they provide a number of important advantages for buccal administration.

A well-known feature of buccal patches is their affordability. Their effective manufacturing processes and the possibility of employing fewer excipients frequently result in lower manufacturing costs, which eventually allow patients to purchase prescriptions at a lower cost. Another advantage of buccal patches is patient compliance. Particularly for people who might have trouble taking conventional oral drugs, their convenience stems from their simplicity of administration and lack of water or swallowing requirements. Effectively managing chronic diseases like diabetes requires patients to stick to prescribed treatment regimens^{3, 5}. The potential for both local and systemic pharmacological effects is one of the most notable characteristics of buccal patches. These films escape the liver's first-pass metabolism by entering the mouth cavity and possessing direct access

through the internal jugular vein to the systemic circulation. Given that a sizable amount of the medication enters the bloodstream immediately, medications administered by buccal patch can thus attain high bioavailability. Especially helpful for medications that need a quick need of action and are poorly absorbed in the gastrointestinal tract, or break down in the stomach region^{1, 2, 4}. Administration of drug via buccal mucosa to the systemic circulation designed to provide sustained release of active ingredients. Within the oral mucosal cavity, the Buccal region offers an attractive route of administration through the systemic circulation. The mucosa has a rich blood supply and it is relatively permeable. Buccal adhesive Patches adhere to the buccal mucosa to buccal mucosa for the extended period of time.

Buccal dose form types are categorized according to their design and structure. They are matrix and reservoir types. When using a matrix-type buccal patch, the medication, adhesive, and additives are combined^{9, 12}. A buccal patch containing a cavity for the drug and any additives that are discrete from the adhesive is the reservoir type. An impermeable backing is employed to control the direction of drug distribution. In diabetes management, they offer an exciting avenue for delivering diabetes medications more effectively and improving patient compliance. For a condition like diabetes, where precise medication timing and dosage are critical, buccal patches provide a convenient and reliable option^{2, 4}.

Type 2 diabetes (T2DM) can be treated with linagliptin, an inhibitor of dipeptidyl peptidase-4 (DPP-4). Linagliptin is a xanthine-based dipeptidyl peptidase-4 (DPP-4) inhibitor distinct from other DPP-4 inhibitors due to its unique pharmacokinetic properties unlike others in its class, which are primarily eliminated through the kidneys, and linagliptin is mainly excreted *via* a biliary/hepatic route. This characteristic allows for its use in patients with varying degrees of renal function, including those with severe chronic kidney disease, without the need for dose adjustments. (DPP-4), works by increasing the body's production of in cretin hormones. In cretin hormones, such as glucagon-like peptide-1 (GLP-1) and glucose-dependent insulin tropic polypeptide (GIP), are released by the intestine in response to food

consumption. They greatly help in the regulation of blood sugar^{9, 15}.

- By stimulating the production of glucose-dependent insulin by the pancreas
- By suppressing the release of glucagon from the pancreas
- By rapidly breaking F hormones

Linagliptin has a high affinity for DPP-4 and a long terminal half-life (up to 184 hours), allowing for once-daily dosing. Linagliptin is primarily excreted unchanged through the enter hepatic system (bile and gut), with minimal renal excretion^{24, 25}.

Patients with renal impairment can utilize linagliptin without changing their dosage because of its unique excretion profile. It has been shown that linagliptin has a wide therapeutic window and is well tolerated even at dosages well over the therapeutic threshold. In contrast to other anti-diabetic drugs like sulfonylureas, linagliptin has a low risk of hypoglycemia.

Linagliptin could contain intrinsic antioxidant properties due to its chemical structure, which might help in heart protection. Preclinical study suggests that linagliptin may improve cognitive function and protect neurons^{2, 8}. Its anti diabetic properties, when combined with diet and exercise, can assist people with type 2 diabetes improve their glycemic control. It can be used either alone or in combination with other oral anti-diabetic drugs. Additionally, it has anti-inflammatory and cardiovascular protective effects^{45, 49}.

Linagliptin has shown effectiveness in reducing fasting glucose, fasting plasma glucose, and HbA1c in a number of clinical investigations. Pioglitazone

combination therapy, metformin combination therapy, Metformin plus sulfonylurea combination therapy, add-on therapy to basal insulin, and monotherapy all have been studied.

MATERIALS AND METHODS:

Materials: Linagliptin was purchased from Dermactect Pharma and consultants, India, HPMC, PVPK30, DMSO, and Glycerin were purchased from Loba Chemie Pvt Ltd, Pearl Chemicals & Akshar Chemicals Pvt Ltd India.

Method: Formulation of Linagliptin Mucoadhesive Buccal Patches: The mucoadhesive buccal patches were prepared using solvent casting method, employing hydroxypropyl methylcellulose (HPMC) as the primary mucoadhesive polymer in all formulation trials. Polyvinylpyrrolidone K30 (PVPK30) was incorporated as a film stabilizer, while propylene glycol and glycerin served as plasticizers. Initially, HPMC was dispersed in distilled water and allowed to hydrate for 1-2 hours with occasional stirring.

Separately, the remaining excipients, along with linagliptin dissolved in dimethyl sulfoxide (DMSO), were added to the polymer-excipient blend with gentle mixing to avoid air entrapment. The final formulation was cast into 1×1 inch silicone molds. The patches were dried either by air drying for 24-48 hours at room temperature or by oven drying at 45°C for 6-8 hours. Once dried, the patches were carefully removed from the molds and stored in aluminum foil pouches or airtight Zip lock bags until further evaluation.

The effect of individual polymers and their compositions at different ratios has been studied considering the % of drug release.

TABLE 1: PILOT BATCHES BLANK AND DRUG LOADED

Sr. no.	Ingredient	F1	F2	F3	F4 (Drug + PEG)	F5 (Drug + PVP)	F6 (Drug + PVP)
1	Linagliptin	—	—	—	3 mg	3 mg	3 mg
2	Carbopol 940	0.5%	—	—	—	—	—
3	HPMC K4M	1.5%	1.5%	2.25%	1.5%	2.25%	2.25%
4	PVP K30	1.0%	—	1.0%	—	1.0%	1.0%
5	PEG 400	—	1.33%	—	1.33%	—	—
6	Propylene Glycol	1.0%	1.33%	1.5%	1.33%	1.5%	1.5%
7	Glycerine	1.0%	1.33%	1.5%	1.33%	1.5%	1.5%
8	DMSO	—	—	—	2.5%	2.5%	2.5%
9	Distilled Water	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%	q.s. to 100%

TABLE 2: FINAL FORMULATION (F7)

Sr. no.	Ingredient	% w/v	Role of Ingredients
1	Linagliptin	3mg	Anti diabetic agent (API)
2	HPMC K4M	2.25%	Film former, mucoadhesive
3	PVP K30	1.35%	Binder, film stabilizer
4	Propylene Glycol	1.50%	Plasticizer
5	Glycerine	1.50%	Plasticizer, softener
6	DMSO	2.50%	Drug solvent
7	Distilled Water	94.50%	Main solvent

Evaluation of Mucoadhesive Linagliptin Buccal Patches:

Organoleptic Test: This test evaluates the physical characteristics of the buccal patch, such as its color, texture, appearance, flexibility, and odor. The method involves examining the patch visually for uniformity in color and appearance, looking for cracks, air bubbles, or particles, sniffing for any disagreeable scent, and gently stretching the patch to evaluate its flexibility and smoothness.

Weight Uniformity: The weight uniformity test ensures that the same amount of formulation is used in each buccal patch, which is essential for precise dosing. Ten individual patches are weighed using a digital analytical scale, and the weights of each patch are compared to the average to make sure they are within acceptable limits.

Thickness Measurement: Patch consistency is evaluated in this test, which affects mucosal adherence and drug release. The thickness of each patch is measured at several points using a micrometer screw gauge. Calculating the average thickness ensures consistency in the formulation.

Swelling Index: The swelling index measures the patch's ability to absorb moisture, which is necessary for mucoadhesion. The patch is first weighed before being immersed in phosphate buffer (pH 6.8) for a set amount of time at 37°C.

After swelling, surplus moisture is wiped away and the final weight is recorded. The swelling index is determined by calculating the percentage increase in weight.

Folding Endurance: This test evaluates the patch's flexibility and mechanical strength. Until a patch fails or exhibits obvious fissures, it is folded repeatedly in the same location. Its folding endurance refers to the amount of folds it can withstand before breaking.

pH Evaluation: This test establishes the buccal patch's surface pH to make sure it is in harmony with the buccal mucosa and does not irritate it. To record the pH value, a few drops of distilled water are added to the patch, which is then held in contact with the electrode of a pH meter.

Content Uniformity: The consistency of content guarantees that the medication is dispersed equally across the patches. A spectrophotometric technique is used to measure the amount of medicine present in a single patch after it has been dissolved or extracted in an appropriate solvent. To ensure uniformity, this procedure is performed for several patches.

Calibration Curve: In order to quantify drug content in subsequent tests, this test establishes the link between drug concentration and absorbance. A calibration curve is generated after standard solutions of the medication at different known doses are made and their absorbance is assessed with a UV spectrophotometer.

FTIR: FTIR analysis determines the functional groups and looks for potential drug-exipient interactions. An FTIR spectrophotometer is used to record the spectra of the formulation and the pure medicine, and the distinctive peaks are compared to determine compatibility.

In-vitro Dissolution Studies: The rate and degree of medication release from the patch over time are ascertained by this test. Samples are taken at prearranged intervals, the patch is submerged in a dissolving media (usually phosphate buffer), the drug content is evaluated, and the cumulative release vs. time is shown.

Kinetic Modeling: The drug release mechanism from the patch is examined using kinetic modeling. Numerous kinetic models, including zero-order, first-order, Higuchi, and Korsmeyer–Peppas

equations, are fitted to the in vitro drug release data. By analyzing the correlation coefficient (R²) values, the best-fitting model is identified.

Mucoadhesive Strength Test: This test measures the adhesion strength of the patch to the mucosal surface, which is crucial for retention at the application site. The patch is adhered to a biological membrane (Goat buccal mucosa), and the force required to detach it is measured using a weighing balance

RESULT AND DISCUSSION: The solvent casting process was successfully used for developing the mucoadhesive buccal patch of linagliptin. This procedure produced a constant and stable film by improving the drugs even distribution across the patch. Two blank batches were first made in order to check compatibility with proper film formation. Later, after the patch was successfully prepared, the medication (linagliptin) was added. Quality control in patch manufacturing necessitates close monitoring of critical components, such as the API's temperature

sensitivity, mechanical qualities like folding endurance and tear resistance, and its performance attributes like uniformity, impurity level, and dissolution rates, in order to guarantee the final product's safety and effectiveness. This investigation ensures the buccal patches' quality and effectiveness.

Analytical Test:
Organoleptic Test: The technique is visually assessing the patch for uniform color and look, checking for cracks, air bubbles, or particles, smelling for any unpleasant odor, and gently stretching the patch to assess its smoothness and flexibility. According to the formulation design, the patches had a smooth Texture, light or no smells, and a uniform Color ranging from white to off white and translucent. Visual inspection confirmed that the surface was consistently level and free of air bubbles, cracks, and particulate matter. The final formulation (F7) showed good flexibility, bending easily without breaking or cracking, making it most appropriate for buccal application.

TABLE 3: PHYSICAL CHARACTERISTICS OF FORMULATIONS (F1-F7)

Formulation code	Color	Odor	Texture	Appearance	Flexibility
F1	White	Odorless	Rough	Air bubbles present	Poor
F2	White to off-white	Odorless	Rough	Air bubbles present	Poor
F3	White to off white	Odorless	Slightly rough	Air bubbles present	Poor
F4	Translucent	Odorless	Smooth	Transparent, no air bubbles	Good
F5	Translucent	Odorless	Smooth	Uniform, flat, no air bubbles	Good
F6	Translucent	Odorless	Smooth	Uniform, flat, no air bubbles	Good
F7	Uniform & Translucent	Odorless	Smooth	Uniform, transparent & flat, no air bubbles	Good

Weight Uniformity: Ten patches are weighed separately with a digital analytical scale, and their weights are compared to the average to ensure they fall within permissible ranges.

TABLE 4: WEIGHT UNIFORMITY

Sample no.	Weight (g)
1	0.15
2	0.18
3	0.17
4	0.18
5	0.15
6	0.14
7	0.18
8	0.19
9	0.17
10	0.16

The weights ranged from 0.14 g to 0.19 g, with a mean of 0.167 g. The minimal variation between

samples indicates the formulation was dispersed evenly throughout the preparation process. Since the results meet the accepted requirements for weight consistency, they ensure precise dosage for each patch.

Thickness Measurement: A micrometer screw gauge is used to measure thickness at various positions on each patch. The average thickness is calculated to guarantee consistency in the formulation. Five randomly chosen patches were measured for thickness using a micrometer screw gauge. The observed thickness values ranged from 1.92 mm to 2.00 mm, with an average thickness of 1.956 mm. Based on the measurement the patches are consistently thick, which is required to offer

mucoadhesive properties and sustained drug release.

TABLE 5: THICKNESS MEASUREMENTS

Sample no.	Thickness (mm)
S1	1.95
S2	2.00
S3	1.92
S4	1.98
S5	1.93

Swelling Index: The patch is first weighed before being immersed in phosphate buffer (pH 6.8) for a set amount of time at 37°C. After swelling, surplus

moisture is wiped away and the final weight is recorded. The swelling index is determined by calculating the percentage increase in weight. The swelling index was determined by calculating the percentage increase in patch weight after immersion in phosphate buffer (pH 6.8) at 37°C. The swelling percentage ranged from 261.58% to 275.28%, indicating a strong capability for water absorption. Such swelling behavior is needed to facilitate mucoadhesion and controlled drug release. Sample B5 exhibited the greatest swelling index at 275.28%.

TABLE 6: SWELLING INDEX

Sample	Initial Weight (g)	Final Weight (g)	% Increase
B1	0.176	0.656	272.72%
B2	0.175	0.650	271.42%
B3	0.174	0.630	262.06%
B4	0.177	0.640	261.58%
B5	0.178	0.668	275.28%

Folding Endurance: This test evaluates the patch's flexibility and mechanical strength. Until a patch fails or exhibits obvious fissures, it is folded repeatedly in the same location. Its folding endurance refers to the amount of folds it can withstand before breaking.

The patches' adequate mechanical strength and flexibility were demonstrated by the folding endurance values, which ranged from 305 to 317 folds. This quality is essential for long-lasting handling during use and application. The folding endurance of all the patches was found satisfactory.

TABLE 7: FOLDING ENDURANCE

Sample no.	Folding endurance
Sample 1	305
Sample 2	310
Sample 3	317
Sample 4	312
Sample 5	308

pH Evaluation: To record the pH value, a few drops of distilled water are added to the patch, which is then held in contact with the electrode of a pH meter.

TABLE 8: PH EVALUATION

Sample no.	pH
S1	7.46
S2	7.49
S3	7.41
S4	7.45
S5	7.47

Mucosal compatibility was assessed by measuring the patches' surface pH. The pH values fell between 7.41 to 7.49, which is nearly neutral and matches the pH of the buccal mucosa. This reduces the risk that the buccal mucosa will become irritated.

Content Uniformity: A spectrophotometric technique is used to measure the amount of medicine present in a single patch after it has been dissolved or extracted in an appropriate solvent. To ensure uniformity, this procedure is performed for several patches. In order to make sure Linagliptin was dispersed evenly, the medication contained within five patches was examined. The content as a percentage varied from 95.67% to 114.33%. The majority of patches demonstrated constant drug loading throughout the formulation and fell within the allowed limits specified by pharmacopeia recommendations.

TABLE 9: CONTENT UNIFORMITY

Sr. no.	Percentage content (%)
1	109.33%
2	114.33%
3	111.67%
4	98.67%
5	95.67%

Calibration Curve: In order to quantify drug content in subsequent tests, this test establishes the link between drug concentration and absorbance. A calibration curve is generated after standard

solutions of the medication at different known doses are made and their absorbance is assessed with a UV spectrophotometer. A calibration curve for Linagliptin was established by preparing standard solutions of known concentrations and

measuring their absorbance using UV-visible spectroscopy. The data exhibited a strong linear correlation between concentration and absorbance, confirming the validity of the analytical method used for drug quantification in the patches.

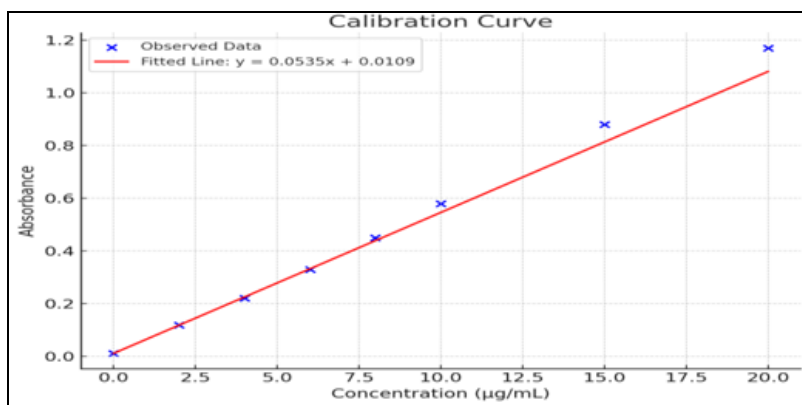


FIG. 1: CALIBRATION CURVE

FTIR: FTIR analysis determines the functional groups and looks for potential drug-excipient interactions. An FTIR spectrophotometer is used to record the spectra of the formulation and the pure medicine, and the distinctive peaks are compared to determine compatibility. FTIR spectra of pure Linagliptin and the formulated buccal patches were recorded to investigate any potential chemical

interactions between the drug and excipients. The characteristic peaks corresponding to functional groups of Linagliptin were preserved in the formulation spectrum with minor shifts, indicating no significant chemical incompatibility and confirming the successful incorporation of the drug into the patch matrix.

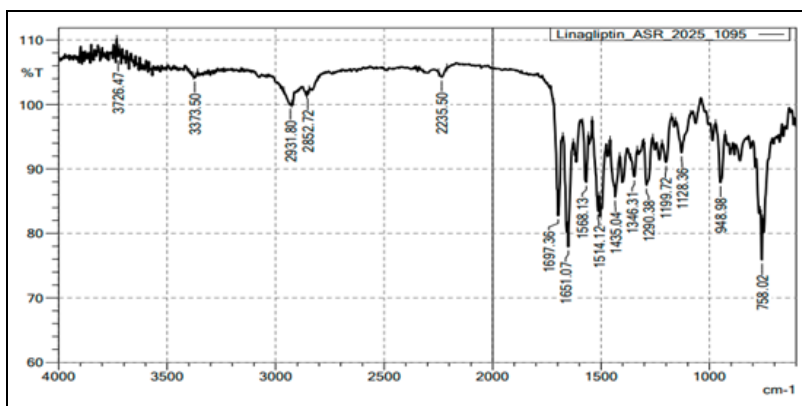


FIG. 2: FTIR OF LINAGLIPTIN

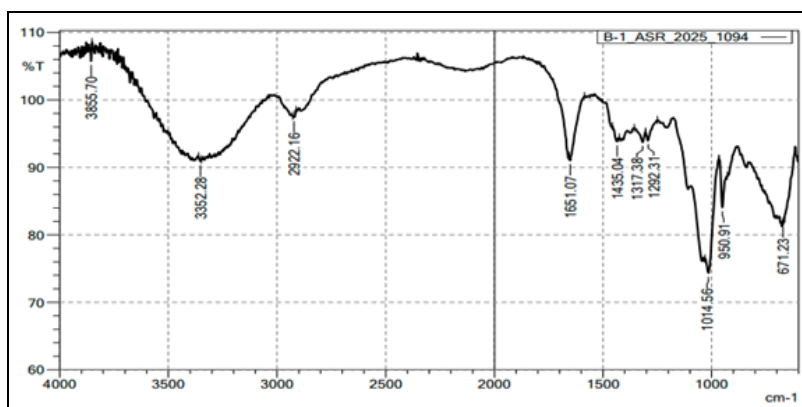


FIG. 3: FT IR SPECTRA OF PREPARED DRUG LOADED BUCCAL FILM

TABLE 10: FT IR SPECTRA INTERPRETATION

Functional Group	Linagliptin (Pure Drug)	B-1 (In-Situ Formulation)
C–Cl Stretching	758.02 cm ⁻¹	671.23 cm ⁻¹
Aromatic C–H Bending	948.98 cm ⁻¹	950.91 cm ⁻¹
C–N / C–O Stretching	1128.36 cm ⁻¹	1014.56 cm ⁻¹
C–H Deformation (CH ₂ /CH ₃)	1290.38 – 1346.31 cm ⁻¹	1292.31 – 1317.38 cm ⁻¹
CH ₂ Bending	1435.04 cm ⁻¹	1435.04 cm ⁻¹
C=C / C=N Stretching	1651.07 – 1697.36 cm ⁻¹	1651.07 cm ⁻¹
C–H (sp ³) Stretching	2852.72 – 2931.80 cm ⁻¹	2922.16 cm ⁻¹
N–H / O–H Stretching	3373.50 – 3726.47 cm ⁻¹	3352.28 – 3855.70 cm ⁻¹

Pharmacological:

In-vitro Dissolution Studies: The rate and degree of medication release from the patch over time are ascertained by this test. Samples are taken at prearranged intervals, the patch is submerged in a dissolving media (usually phosphate buffer), the drug content is evaluated, and the cumulative release vs. time is shown. The drug release profile of the patches was studied over a period of 300 minutes. An initial lag phase was observed with 0% release at time zero, followed by a gradual increase. At 5 minutes, approximately 4.83% drug release was observed, which increased to 91.16% by 300

minutes. The sustained release profile indicates effective drug delivery from the patch over an extended period.

TABLE 11: (F7) IN-VITRO DISSOLUTION STUDY

Time (min)	% Drug Release
0	0.00
5	4.83
30	18.00
60	33.66
120	55.83
180	70.00
240	81.83
300	91.16

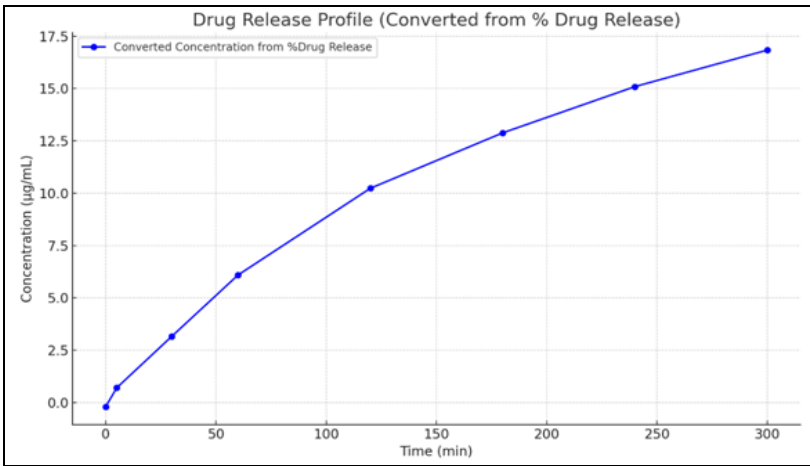


FIG. 4: DRUG RELEASE PROFILE FOR LINAGLIPTIN

Kinetic Modeling: The drug release mechanism from the patch is examined using kinetic modeling. Numerous kinetic models, including zero-order, first-order, Higuchi, and Korsmeyer–Peppas equations, are fitted to the *in-vitro* drug release data.

By analyzing the correlation coefficient (R²) values, the best-fitting model is identified. To clarify the drug release process, the *in-vitro* dissolution data were fitted to a number of kinetic models. The zero-order model (R² = 0.9965) was closely followed by the Korsmeyer–Peppas model,

which had the highest correlation coefficient (R² = 0.9985).The release exponent (n = 0.9318) indicates anomalous transport, implying that diffusion and polymer relaxation mechanisms operate together to limit drug release.

TABLE 12: RELEASE KINETICS

Parameter	F7
Zero-order (R ²)	0.9965
First-order (R ²)	0.9067
Higuchi model (R ²)	0.9889
Korsmeyer–Peppas (R ²)	0.9985
Release exponent (n)	0.9318

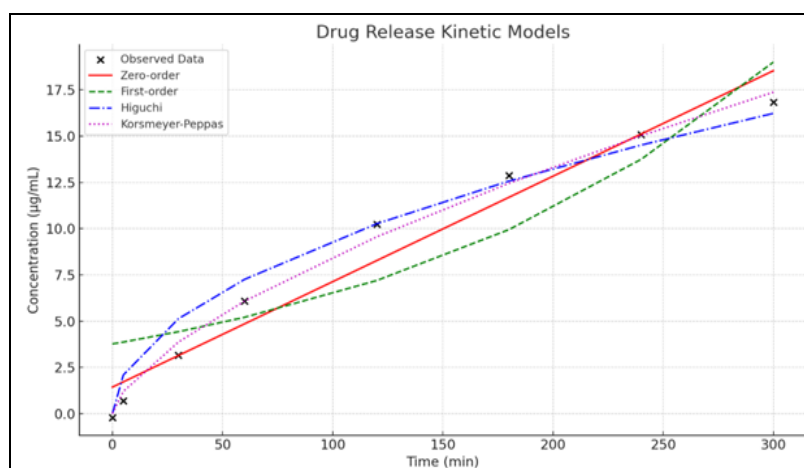


FIG. 5: DRUG RELEASE KINETIC MODELS

Mucoadhesive Strength Test: This test measures the adhesion strength of the patch to the mucosal surface, which is crucial for retention at the application site. The patch is adhered to a biological membrane (Goat buccal mucosa), and the force required to detach it is measured using a weighing balance. The mucoadhesive strength of the patches was evaluated by measuring the force required to detach the patch from a mucosal surface. The readings, which varied from 51 to 54 g, indicate that the patches had enough adhesive power to stick to the buccal mucosa for the duration of the application.

TABLE 13: MUCOADHESIVE STRENGTH

Sample	Mucoadhesive Strength (g)
S1	51
S2	53
S3	52
S4	54
S5	52

CONCLUSION: Development and evaluation of mucoadhesive buccal patches of linagliptin for the efficient treatment of Type II Diabetes Mellitus was the main goal of the current project. Linagliptin, a DPP-4 inhibitor with good pharmacokinetics, was chosen for buccal administration in order to improve therapeutic efficacy and patient compliance. The solvent casting method was effectively used to create the patches, and the chosen excipients and polymers guaranteed good flexibility, mucoadhesive properties, and compatibility with the buccal environment. A safe buccal administration method requires consistency, sustained drug release, and good adhesion, all of which were validated by evaluation measures.

This study demonstrates how buccal patches could be a novel Alternative to traditional oral dose forms, including advantages such as increased bioavailability, better patient compliance, and avoiding first-pass metabolism. The results encourage more research and development of these technologies for improved diabetes care.

Future Scope: Optimizing the composition of polymers to improve retention time, drug release, and mucoadhesion. Examining several mucoadhesive polymers to enhance formulation stability and patient comfort. Using penetration enhancers, drug permeability through the buccal mucosa is improved. Potential use of similar formulations for additional anti diabetic medications or combination treatments; enhancement of formulation scalability for commercial production; and patient-friendly dosage formats.

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