ORIGINAL ARTICLE

Microwave-induced Graft Copolymerization of Acrylamide onto Kondagogu Gum: Synthesis, Optimization, and Characterization

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Abstract

This study aimed to develop a microwave-assisted graft copolymerization technique for acrylamide onto Kondagogu gum using potassium persulfate as an initiator, with the objective of improving grafting efficiency through statistical optimization. Graft copolymerization was carried out under controlled microwave irradiation conditions using Kondagogu gum, acrylamide monomer, and potassium persulfate initiator; the reaction mixture was subsequently cooled, precipitated with acetone, dried, and ground. Central Composite Design (CCD) was employed to evaluate the effects of acrylamide concentration, initiator level, and irradiation time on grafting performance. The results demonstrated uniform and rapid heating under microwave irradiation, leading to a significant enhancement in grafting efficiency. CCD analysis revealed that acrylamide concentration and initiator level were the most influential parameters affecting grafting yield, with significant interaction effects (AB and BC). Under optimized conditions (acrylamide 24.99 g, initiator 0.154 g, irradiation time 88.9 s), predicted grafting yield and efficiency values of 94.10% and 82.84%, respectively, were achieved with a desirability value of 1.000. Successful graft copolymer formation was confirmed by FTIR spectroscopy through the appearance and shifting of characteristic amide and hydroxyl bands. Swelling studies indicated that the grafted gum exhibited enhanced water uptake compared to the native polymer, reflecting improved hydrophilicity. Overall, microwave-assisted grafting proved to be a rapid, efficient, and environmentally friendly method for modifying natural gums, and the optimized acrylamide-grafted Kondagogu gum demonstrated enhanced physicochemical and swelling properties, making it suitable for pharmaceutical and biomedical applications.

Key words: acrylamide, central composite design, Fourier transform infrared spectroscopy, grafting efficiency, Kondagogu gum, microwave-assisted grafting, swelling studies

INTRODUCTION

Plant-derived polysaccharides are widely used in various industries due to their excellent biodegradability, sustainability, cost-effectiveness, and abundance. However, their limitations – such as poor solubility, weak mechanical and colloidal properties, and limited degradability – restrict their broader application. These shortcomings can be addressed through graft copolymerization, which introduces functional groups onto the polysaccharide backbone to enhance properties such as rheology, hydrophilicity, charge, molecular aggregation, and complexation ability. Grafted polysaccharides exhibit improved performance and are employed as flocculants, decolorizing agents, thickeners, adsorbents, drug carriers, and even electrical conductors across industries such as chemical processing, dyeing, biomaterials, food, agriculture, papermaking, and wastewater

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treatment. Conventionally, natural polysaccharides have served as food and pharmaceutical excipients owing to their biodegradability, biocompatibility, availability, and low cost. However, drawbacks such as pH-dependent solubility, uncontrolled hydration, viscosity changes, and short shelf life limit their utility. These issues can be mitigated through chemical modifications such as etherification, cross-linking, and especially graft copolymerization, which is considered the most effective method. The goal of this study was to synthesize and analyze graft copolymers of acrylamide (AAm) with Kondagogu gum (KG).[1-3]

By grafting with synthetic monomers such as acrylic acid, AAm, and acrylonitrile, novel copolymers with enhanced flocculation and controlled release profiles can be developed. While conventional initiator-driven grafting methods are time-consuming and offer low efficiency, microwave-assisted grafting provides rapid energy transfer, leading to higher grafting efficiency and faster reactions.

MATERIALS AND METHODS

Materials

- Natural polymer: KG (plant-derived polysaccharide).
- Monomer: AAm.
- Initiator: Potassium persulfate (APS).

Methods

Microwave-assisted graft copolymerization of natural KG with AAm was performed using potassium persulfate (APS) as a free-radical initiator. The reaction was conducted under microwave irradiation, which promotes dipolar rotation and ionic conduction within the matrix, generating heat through molecular friction and dielectric loss. This mechanism enables uniform and rapid heating, improving grafting efficiency compared to conventional methods.

Synthesis and optimization of grafted KG

Graft copolymerization of natural gums with polyacrylamide (PAM) was carried out through a microwave-assisted free-radical polymerization method using potassium persulfate (APS) as an initiator.

Polymerization procedure

Microwave-assisted graft copolymerization was employed for synthesizing AAm-grafted KG copolymers. The required quantities of KG and AAm monomer were mixed in a beaker and dissolved in 100 mL of Millipore water. The mixture was stirred on a magnetic stirrer at 50°C until complete dissolution.

The initiator (APS) was then added, and the reaction mixture was stirred for an additional 15 min. The resulting solution was subjected to microwave irradiation under controlled conditions. Immediately after irradiation, the reaction vessel was cooled in an ice bath to terminate the reaction. Any unreacted initiator or residual by-products were removed using acetone as a washing solvent. The graft copolymers were dried in a hot air oven and subsequently ground into a fine powder.[4] The grafting yield and grafting efficiency were calculated using the following equations:

$$\text{Grafting yield (\%)} = (\text{Weight of grafted material/Weight of original material})\ 100$$

$$\text{Grafting efficiency (\%)} = (\text{Weight of grafted polymer-weight of Kondagogu gum})/(\text{weight of acryl amide})\ 100$$

Scheme: Microwave-assisted synthesis of KG-AAm graft copolymer

Initiation

KG–OH + M⟶KG–O• + M•(Microwave irradiation)

Propagation

KG–O• + M ⟶ KG–OM•
KG–OM• + M ⟶ KG–OMM•
KG–OMM• + M ⟶ KG–OM•

Termination

KG–OM• + KG–OM• ⟶ Grafted polymer.

Experimental design

A central composite design (CCD) was employed to optimize the grafting process using Design Expert software. This statistical approach assesses the robustness of the experimental design in terms of the signal-to-noise ratio.

A total of 20 experiments were conducted, considering three independent variables and two dependent responses:

Independent variables

AAm concentration (X_1)

Initiator concentration (X_2)

Radiation time (X_3).

Dependent variables

Percentage grafting (Y_1)

Percentage grafting efficiency (Y_2).

A particular quality metric for evaluating the robustness of the design in terms of the signal/noise ratio is CCD. The tested lower and upper values for each variable were used to determine the various values for the factor. As indicated in Table 2, this calls for a total of 20 experiments. Using three independent variables and two dependent variables, this was utilized to optimize the grafting process. The dependent variables chosen were grafting percentage (Y1) and grafting efficiency (Y2), while the independent variables were percentage of monomer (AAm) (X1), initiator (X2), and radiation time (X3).

Different concentrations of three CSPPs were chosen:

A = Acrylamide with low (10 g), medium (17.5 g), and high (25 g) levels;

B = Initiator with low (0.15 g mg), medium (0.2 g), and high level (0.25 g) levels; and

C = Irradiation time low (30 s), medium (60 s), and high level (90 s).

The software named Design expert was used to develop the CCD and the polynomial equation generated was given below:

$Y= \beta 0+ \beta 1.A+ \beta 2.\ B+ \beta 3.C+ \beta 4.A.B+ \beta 5.A.C+ \beta 6.C+ \beta 7.A^2+ \beta 8.B^2+ \beta 9.C^2$

Where, Y = dependent variable, β_0 = arithmetic mean value of the 15 responses, and β_1 (β_1, β_2, β_3, $\beta_{4....}$ β_9); the estimated coefficient of the corresponding factor A, B, and C which is the average value of running each factor one-by-one to its low value and high value.

The response is different when three factors interact where the interaction term (A.B, A.C, and B.C) is different. The quadratic model is explored under the terms of A2, B2, and C2 that are polygons. The coefficients of a polynomial equation may be positive and thus a synergistic effect or may be negative and thus antagonistic effect.[5-8]

Comparison of various statistical parameters, including coefficient of variation, multiple correlation coefficient (R2), adjusted multiple correlation coefficient (adjusted R2), predicted residual sum of square and graphically through Contour Plot and 3D response surface graph provided by design expert software were used to determine the statistically best fitting model of the experiment (linear, two factor interaction, and quadratic). The level of significance in the case when p-value was less than 0.05 was considered.

Levels of independent variables in CCD for KG and design matrix of CCD for grafting of polymer are tabulated in Tables 1 and 2.

Preformulation studies

The preformulation stage provides fundamental knowledge about the polymers, ensuring the selection of suitable components for subsequent formulation steps.

Compatibility studies (Fourier transform infrared spectroscopy [FTIR] analysis)

FTIR spectroscopy was employed to assess the physicochemical compatibility between KG and AAm by detecting any potential interactions or complex formation between functional groups.

Swelling studies of ungrafted and grafted gums

Swelling behavior was investigated by immersing 0.2 g each of ungrafted and grafted KG in 50 mL of distilled water for varying durations (30–240 min). After each interval, samples were filtered through a 100-mesh sieve, drained for 15 min, and reweighed.[9-12]

The percentage swelling was calculated using the following equation:

$$\text{Swelling}(\%) = \frac{\text{Weight of swollen polymer} \text{-weight of dry polymer}}{\text{Weight of swollen polymer}} \times 100$$

RESULTS AND DISCUSSION

FT-IR studies

FTIR spectrum of KG [Figure 1] shows typical peaks with different functional groups including -OH, -CH 3 CO, -COO -, and -CH 3 CO. The significant absorption bands were at 1,721 cm^{-1}, 1,637 cm^{-1}, 1,412 cm^{-1}, and 1,249 cm^{-1} that proved the existence of ester, carboxylate, and hydroxyl functional groups characteristic of natural polysaccharides.

Table 1: Levels of independent variables in central composite design for Kondagogu gum

Factor	Name	Units	Low-level	Mid-level	High-level
A	Acrylamide amount	g	10	17.5	25
B	Potassium persulfate amount	g	0.15	0.2	0.25
C	Irradiation time	s	30	60	90

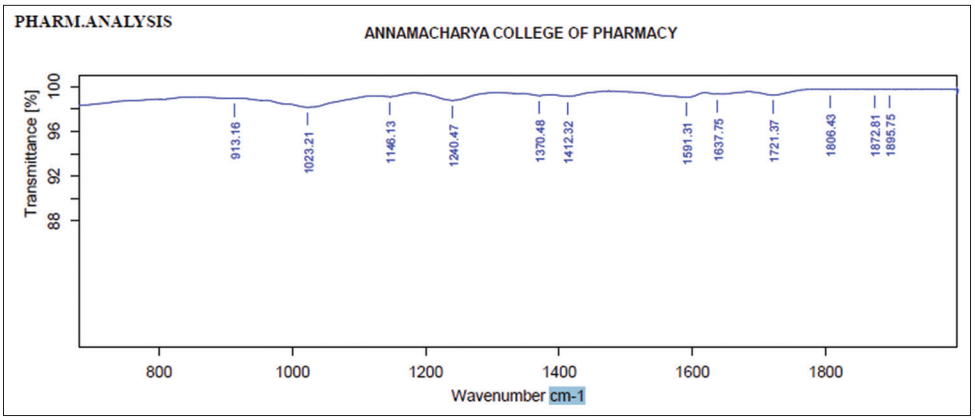

Figure 1: Fourier transform infrared spectroscopy spectrum of Kondagogu gum

Table 2: Design matrix of CCD for grafting of polymer

Standard	Run	Factor 1	Factor 2	Factor 3
		A: Acrylamide	B: Potassium persulfate	C: Radiation time
		g	g	S
19	1	17.5	0.2	60
12	2	17.5	0.28409	60
8	3	25	0.25	90
10	4	30.1134	0.2	60
18	5	17.5	0.2	60
15	6	17.5	0.2	60
1	7	10	0.15	30
9	8	4.88655	0.2	60
2	9	25	0.15	30
4	10	25	0.25	30
3	11	10	0.25	30
5	12	10	0.15	90
6	13	25	0.15	90
14	14	17.5	0.2	110.454
7	15	10	0.25	90
11	16	17.5	0.11591	60
17	17	17.5	0.2	60
13	18	17.5	0.2	9.54622
16	19	17.5	0.2	60
20	20	17.5	0.2	60

CCD: Central composite design

CH 3 CO Stretching: The C=O stretching vibration of the acetyl (-CH 3 CO) group appears at 1721 cm^{-1}, indicating the presence of ester or carboxylic acid functional groups.

COO-stretching: Peaks at 1637 cm^{-1} and 1412 cm^{-1} represent the asymmetric and the symmetric stretching vibrations of the carboxylate groups and are typical of gums based on polysaccharides.

C O Stretching: The absorption peak at 1,249 cm^{-1} is the C O stretching vibration in the acetyl group.

Figure 2 in the FTIR spectrum of acrylamide indicates that there is a strong C=O band at 1,726 cm^{-1}. The C absorption at 1,358 cm^{-1} corresponds to C N stretching, and a band at 1,646 cm^{-1} is attached to C H stretching vibrations, proving the presence of amide functional groups.[13,14]

FTIR spectra of AAm-grafted KG [Figure 3] reveal a broad absorption band in the 3,200–3,000 cm^{-1} region, resulting from the overlap of the O–H stretching band of KG and the N-H stretching band of AAm. This confirms successful grafting of AAm chains onto the gum backbone. Additional shifts in characteristic peaks further support the formation of a new graft copolymer structure.

Microwave-assisted graft copolymerization was employed to synthesize AAm-grafted KG. The experimental design utilized a CCD through Design-Expert software (Version 7.0, Stat-Ease Inc., USA) to evaluate the effects of three independent variables – AAm concentration (A), potassium persulfate concentration (B), and radiation time (C) – on two dependent responses: % grafting yield (%G) and % grafting efficiency (%GE).

The components and their compositions are summarized in Table 2. Initially, weighed quantities of KG and AAm were dissolved in 100 mL of millipore water under continuous stirring at 50°C. Potassium persulfate (initiator) was added and the reaction mixture was irradiated using microwave energy. After cooling in an ice bath, the product was washed with acetone to remove unreacted monomers and dried in a hot air oven. The resulting copolymer was ground into fine powder and analyzed for %G and %GE.[15]

The % grafting yield ranged from 20% to 88%, while the % grafting efficiency varied from 42.42% to 78.86%. The analysis of variance (ANOVA) results for the % grafting yield (Table 3) indicated that the model was statistically significant ($F = 3.23$, $P = 0.0361$), with significant interaction terms AB and BC. The adequacy of the model was confirmed by an

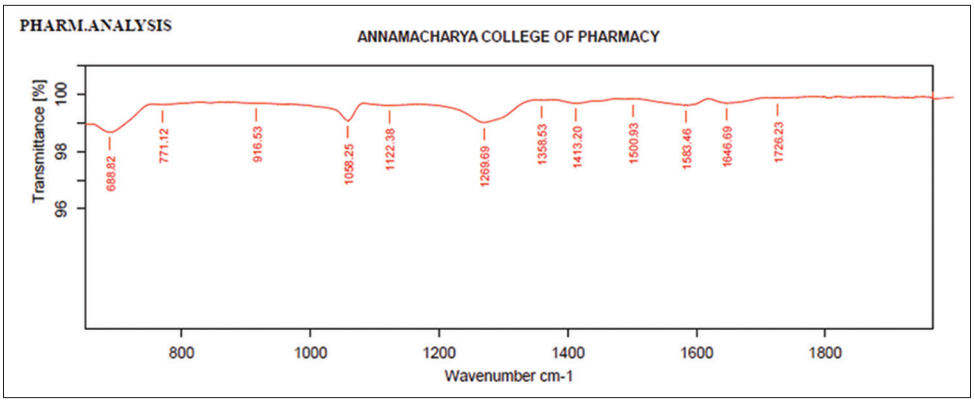

Figure 2: Fourier transform infrared spectroscopy spectrum of acrylamide

Table 3: Experimental design matrix and responses for grafted Kondagogu gum

Standard	Run	Factor 1	Factor 2	Factor 3	Response 1	Response 2
		A: Acrylamide	B: Potassium persulfate	C: Radiation time	Grafting yield (%)	Grafting efficiency (%)
		G	G	S	%	%
19	1	17.5	0.2	60	44.57	52.24
12	2	17.5	0.28409	60	92.57	57.53
8	3	25	0.25	90	27.6	36.62
10	4	30.1134	0.2	60	77.43	76.49
18	5	17.5	0.2	60	44.57	52.24
15	6	17.5	0.2	60	44.57	52.24
1	7	10	0.15	30	20	42.42
9	8	4.88655	0.2	60	56.25	70
2	9	25	0.15	30	74	74.4
4	10	25	0.25	30	57.2	59.38
3	11	10	0.25	30	88	78.86
5	12	10	0.15	90	50	60.61
6	13	25	0.15	90	85	82.3
14	14	17.5	0.2	110.454	67.65	67.35
7	15	10	0.25	90	35	48.57
11	16	17.5	0.11591	60	34.29	46.51
17	17	17.5	0.2	60	44.57	52.24
13	18	17.5	0.2	9.54622	36	49.9
16	19	17.5	0.2	60	44.57	52.24
20	20	17.5	0.2	60	44.57	52.24

Adeq Precision ratio of 8.17, suggesting an adequate signal-to-noise ratio.

The final regression equation for % grafting yield in terms of coded factors is expressed.

$$\{\%\ \text{Grafting yield}\} = 53.42 + 6.33A + 5.62B + 0.85C - 15.90AB + 0.55AC - 15.45BC$$

This model enables prediction of grafting yield within the experimental design space, showing that the interaction between AAm concentration and initiator concentration has a strong influence on yield.[16]

The F-value of the model is 3.23 which reveals its importance. There is also only 3.61 probability that the F-value this huge can be attributed to noise. The model terms are regarded as important in the event that the *P*-value falls below 0.0500. Notable model terms used are AB and BC. The terms of the model do not matter when the values are beyond 0.1000. The model better reduction would also occur when a model has a great number of redundant terms (other than the necessary ones to represent hierarchy).

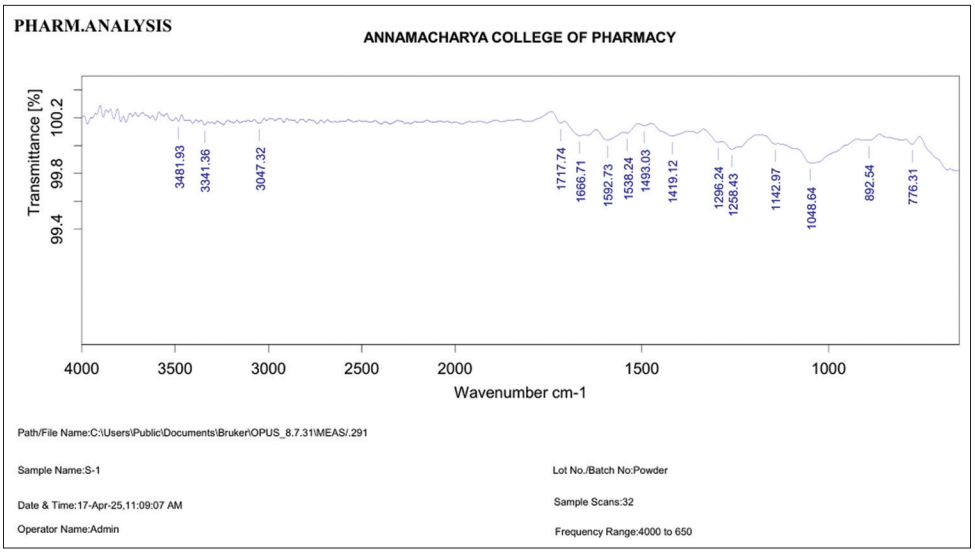

Figure 3: Fourier transform infrared spectroscopy spectrum of acrylamide grafted polymer (SAMPLE 1)

Table 4: Response 1: % grafting yield

Source	Sum of squares	Df	Mean square	F-value	*P*-value	
Model	4923.34	6	820.56	3.23	0.0361	Significant
A-acrylamide	546.87	1	546.87	2.15	0.1660	
B-potassium persulfate	432.06	1	432.06	1.70	0.2147	
C-radiation time	9.90	1	9.90	0.0390	0.8465	
AB	2022.48	1	2022.48	7.96	0.0144	
AC	2.42	1	2.42	0.0095	0.9237	
BC	1909.62	1	1909.62	7.52	0.0168	
Residual	3301.17	13	253.94			
Lack of fit	3301.17	8	412.65			
Pure error	0.0000	5	0.0000			
Cor total	8224.51	19				

Table 5: Fit statistics

Standard deviation	15.94	R2	0.5986
Mean	53.42	Adjusted R2	0.4134
C.V%	29.83	Predicted R2	−0.4866
		Adeq precision	8.1739

The effect of various factors on grafting efficiency was tabulated in Table 4. Negative predicted R2 implies that total average may be more useful in predicting than the current model. Some cases may also give a higher-order model more accuracy in prediction. Adeq Precision is used to measure the signal-to-noise ratio. Its best ratio is above four. Your percentage of 8.174 shows you possess a sufficient signal. This model may be applicable in the design space. Table 5 depicts the fit statistics of the model.

Coefficient estimate indicates how much change in response to change in factor value should happen at all other factors remaining constant. In an orthogonal design, the mean of each of the runs forms the intercept. The coefficients are adjustments about the average, depending on the factor settings. A VIF is considered to be one when the factors are orthogonal; VIFs above one are considered to be multi-colinearity; the stronger the correlation between the factors, the larger the VIF. VIFs below 10 are considered to be reasonable.

Final equation in terms of coded factors

Grafting yield (%) +53.42+53.42+6.33 A+5.62 B+0.8515 C−15.90 AB+0.5500 AC−15.45 BC

Coefficients in Terms of Coded Factors were tabulated in Table 6.

Given certain levels of each factor, it is possible to make predictions concerning the response based on the equation in the form of coded factors. The high and low levels of the factors are defaultly represented by +1 and −1, respectively. The coded equation may be applied to estimate the relative

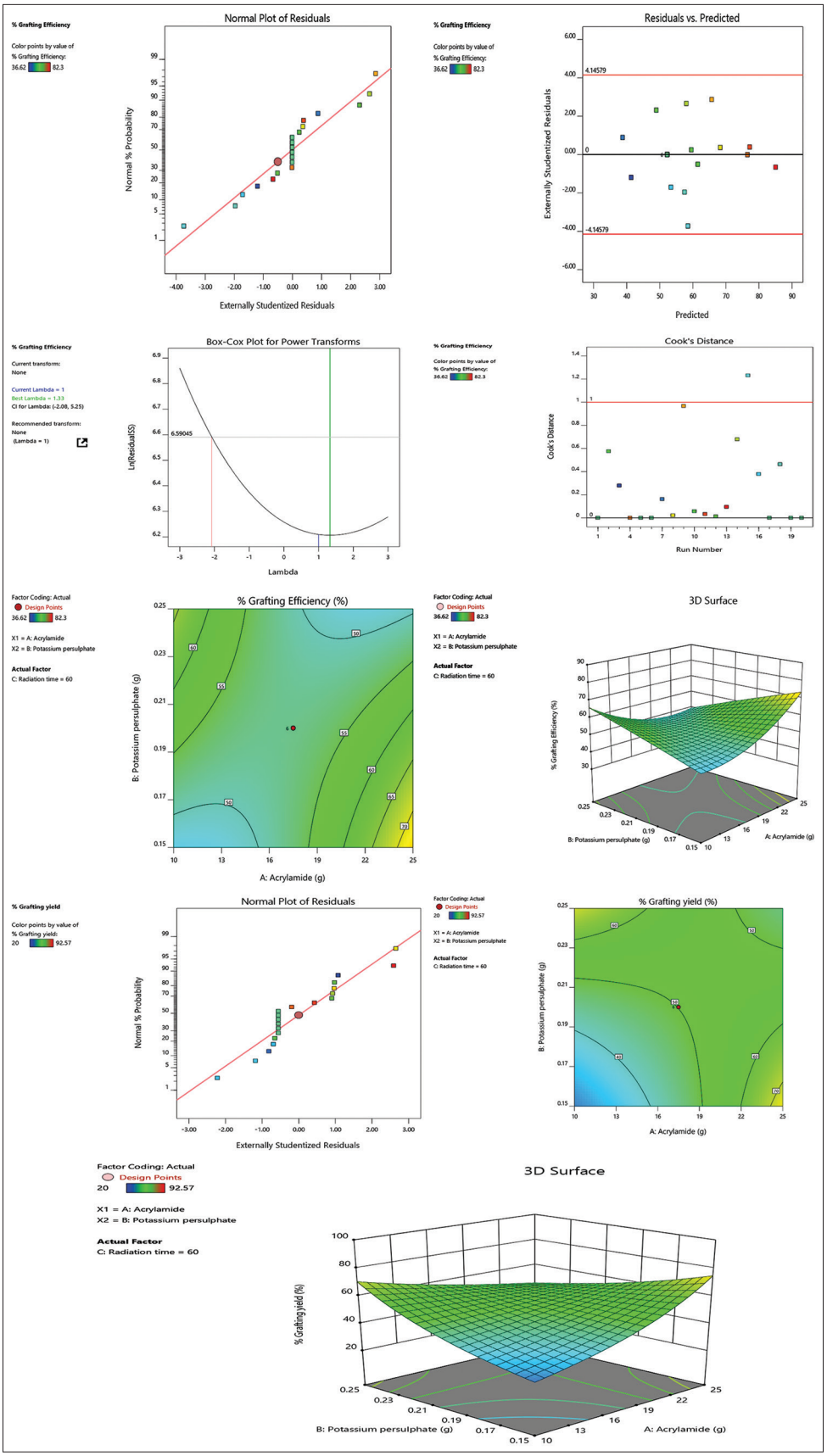

Figure 4: Contour plot, half-normal plots showing the effect of factors on responses

Table 6: Coefficients in terms of coded factors

Factor	Coefficient estimate	Df	Standard error	95% CI low	95% CI high	VIF
Intercept	53.42	1	3.56	45.72	61.12	
A-acrylamide	6.33	1	4.31	−2.99	15.64	1.0000
B-potassium persulfate	5.62	1	4.31	−3.69	14.94	1.0000
C-radiation time	0.8515	1	4.31	−8.46	10.17	1.0000
AB	−15.90	1	5.63	−28.07	−3.73	1.0000
AC	0.5500	1	5.63	−11.62	12.72	1.0000
BC	−15.45	1	5.63	−27.62	−3.28	1.0000

CI: Confidence interval

Table 7: Response 2: % grafting efficiency

Source	Sum of squares	Df	Mean square	F-value	*P*-value	
Model	2570.49	9	285.61	5.74	0.0058	Significant
A-Acrylamide	81.46	1	81.46	1.64	0.2295	
B-Potassium persulfate	23.64	1	23.64	0.4752	0.5063	
C-Radiation time	0.3503	1	0.3503	0.0070	0.9348	
AB	909.51	1	909.51	18.29	0.0016	
AC	1.10	1	1.10	0.0220	0.8850	
BC	778.94	1	778.94	15.66	0.0027	
A^2	731.69	1	731.69	14.71	0.0033	
B^2	2.07	1	2.07	0.0416	0.8426	
C^2	55.17	1	55.17	1.11	0.3170	
Residual	497.35	10	49.73			
Lack of fit	497.35	5	99.47			
Pure error	0.0000	5	0.0000			
Cor total	3067.84	19				

Table 8: Fit statistics

Standard deviation	7.05	R^2	0.8379
Mean	58.23	Adjusted R^2	0.6920
C.V. %	12.11	Predicted R^2	−0.2523
		Adeq precision	9.2776

importance of the factors by comparing the coefficients of the factors.[17-22]

ANOVA for quadratic model

The F-value of the model is 5.74 which shows its importance. Only 0.58% is the probability that this high F-value was due to noise. It is considered to be important when the *P*-value is lower than 0.0500. Model terms that are significant in this case are AB, BC, and A2. The value of the model terms does not matter when the values exceed 0.1000. Model reduction has a potential of making model better when it has too many unnecessary terms (other than those necessary to support hierarchy).

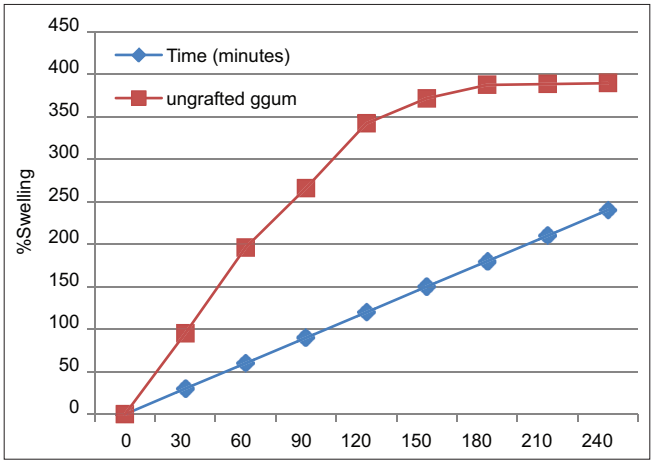

Figure 5: Swelling capacity of ungrafted and grafted gums

Final equation in terms of coded factors

Grafting efficiency (%) = +52.29+2.44 A−1.32 B+0.1602 C−10.66 AB−0.3700 AC−9.87 BC+7.13A^2 −0.3787 B^2+1.96 C^2

Table 9: Various factors affecting grafting efficiency

Name	Goal	Lower limit	Upper limit	Lower weight	Upper weight	Importance
A: Acrylamide	Is in range	10	25	1	1	3
B: Potassium persulfate	Is in range	0.15	0.25	1	1	3
C: Radiation time	Is in range	30	90	1	1	3
Percentage grafting yield	None	92.57	20	1	1	3
Percentage grafting efficiency	Maximize	36.62	82.3	1	1	3

Table 10: Effect of factors on responses

Number	Acrylamide	Potassium persulfate	Radiation time	Percentage grafting yield	Percentage grafting efficiency	Desirability (selected)
1	24.995	0.154	88.918	94.097	82.842	1.000
2	25.000	0.150	90.000	102.222	85.067	1.000
3	24.967	0.151	86.717	95.391	82.932	1.000
4	24.737	0.151	89.835	99.083	83.754	1.000
5	24.737	0.153	89.472	94.498	82.506	1.000
6	24.463	0.151	89.639	96.627	82.579	1.000
7	24.998	0.156	89.989	92.028	82.385	1.000
8	24.936	0.150	86.208	96.179	83.046	1.000
9	24.650	0.151	88.621	96.083	82.688	1.000
10	24.851	0.151	87.065	95.696	82.824	1.000
11	24.880	0.150	87.320	97.337	83.343	1.000
12	24.647	0.153	89.658	94.573	82.372	1.000
13	24.641	0.150	88.433	96.952	82.886	1.000
14	24.650	0.153	89.080	94.651	82.343	1.000
15	24.993	0.150	89.505	101.422	84.807	1.000
16	24.845	0.154	88.788	93.411	82.342	1.000
17	24.460	0.151	88.574	96.015	82.314	1.000
18	24.972	0.152	86.156	94.260	82.580	1.000
19	24.743	0.151	88.918	97.022	83.141	1.000
20	24.970	0.152	87.372	94.982	82.883	1.000
21	24.977	0.151	89.292	99.386	84.246	1.000
22	24.790	0.153	89.875	95.690	82.973	1.000
23	24.989	0.152	86.868	94.316	82.690	1.000
24	24.943	0.150	84.752	94.267	82.421	1.000
25	24.952	0.153	89.330	96.472	83.443	1.000
26	24.847	0.151	88.604	97.951	83.556	1.000
27	24.468	0.152	89.631	95.793	82.365	1.000
28	24.947	0.152	86.556	93.821	82.443	1.000
29	24.810	0.154	89.804	94.450	82.669	1.000
30	24.272	0.150	89.811	96.870	82.309	1.000
31	25.000	0.150	82.786	92.590	81.917	0.992
32	25.000	0.155	84.868	88.764	80.909	0.970
33	25.000	0.162	90.000	84.276	80.027	0.950
34	25.000	0.150	76.830	85.627	79.487	0.938
35	25.000	0.150	74.597	83.000	78.535	0.918

(*Contd*...)

Table 10: (*Continued*)

Number	Acrylamide	Potassium persulfate	Radiation time	Percentage grafting yield	Percentage grafting efficiency	Desirability (selected)
36	25.000	0.150	74.130	82.727	78.436	0.915
37	22.959	0.150	90.000	89.995	78.252	0.911
38	25.000	0.150	73.648	82.225	78.252	0.911
39	10.000	0.250	30.000	84.425	77.231	0.889
40	10.000	0.250	30.005	83.642	77.066	0.885
41	10.059	0.250	30.000	84.360	77.059	0.885
42	10.000	0.250	30.462	83.976	77.005	0.884
43	10.000	0.249	30.000	82.712	76.870	0.881
44	10.176	0.250	30.000	84.230	76.717	0.878
45	25.000	0.150	69.281	77.876	76.628	0.876
46	10.000	0.250	31.436	83.378	76.601	0.875
47	10.000	0.250	31.732	83.164	76.473	0.872
48	10.000	0.248	30.000	80.645	76.419	0.871
49	22.577	0.150	88.303	85.780	76.325	0.869
50	10.000	0.250	32.415	82.675	76.177	0.866
51	25.000	0.150	67.966	76.634	76.156	0.865
52	10.000	0.247	30.000	78.972	76.040	0.863
53	10.000	0.250	32.796	82.403	76.013	0.862
54	10.675	0.250	30.000	83.679	75.301	0.847
55	10.791	0.250	30.000	83.551	74.979	0.840
56	10.000	0.244	30.000	74.478	74.959	0.839
57	10.000	0.250	35.660	80.406	74.801	0.836
58	25.000	0.176	89.996	68.926	74.179	0.822
59	11.100	0.250	30.139	83.105	74.082	0.820
60	25.000	0.150	58.247	68.310	72.896	0.794
61	12.065	0.250	30.000	82.172	71.686	0.768
62	10.000	0.234	30.000	61.980	71.338	0.760
63	25.000	0.150	51.866	63.561	70.978	0.752
64	12.468	0.250	30.000	81.742	70.730	0.747
65	10.000	0.250	46.368	73.549	70.584	0.744
66	10.000	0.232	30.000	59.639	70.532	0.742
67	25.000	0.150	44.423	58.623	68.966	0.708
68	10.000	0.250	54.270	69.036	67.792	0.682
69	25.000	0.150	30.418	50.768	65.832	0.640
70	25.000	0.150	30.114	50.615	65.774	0.638
71	25.000	0.174	30.007	54.368	65.021	0.622
72	25.000	0.225	30.000	64.079	62.885	0.575
73	10.000	0.250	71.433	60.559	62.663	0.570
74	10.000	0.250	74.760	59.098	61.817	0.552
75	13.498	0.150	90.000	54.410	60.441	0.521
76	10.000	0.166	90.000	47.399	59.635	0.504
77	10.001	0.172	90.000	47.812	59.627	0.504
78	10.001	0.155	90.000	46.739	59.616	0.503

(*Contd*...)

Table 10: (*Continued*)

Number	Acrylamide	Potassium persulfate	Radiation time	Percentage grafting yield	Percentage grafting efficiency	Desirability (selected)
79	10.000	0.185	90.000	48.613	59.578	0.503
80	10.000	0.193	90.000	49.103	59.524	0.501
81	10.000	0.202	90.000	49.703	59.436	0.499
82	10.000	0.222	82.882	50.919	59.230	0.495

Table 11: Swelling capacity of ungrafted and grafted gums

S. No.	Time (min)	Percentage swelling	
		Ungrafted Kondagogu gum	Grafted gum
1	0	0	0
2	30	95	212.5
3	60	196	409
4	90	266	561
5	120	342	635
6	150	371.5	721
7	180	387.5	711.5
8	210	388.5	716
9	240	389.5	717

At certain levels of each factor, it is possible to make predictions of the response in terms of coded factors using the equation. The high and the low levels of the factors are by default represented by the number +1 and −1, respectively. The coded equation can be applied to find the relative importance of the factors by comparing the factor coefficients.

A shortcoming according to the calculated R2, the total mean can be a stronger predictor of your response than the existing model. There are also some cases where a higher-order model can give better predictions. Adeq Precision is used to measure the signal-to-noise ratio. The ideal ratio is more than four. A previous ratio of 9.278 shows that have a sufficient signal. It is possible to navigate through the design space by using this idea. The effect of various factors on % Grafting Efficiency and fit statistics were represented in tabular form in Tables 7 and 8.

Figure 4 represents contour plot, half normal plots showing effect of factors on responses. Tables 9 and 10 represents the upper and lowe limits of various factor and their effect on grafting efficiency. Swelling capacity of ungrafted and grafted gums with respect to time has been tabulated in Table 11.

The swelling capacity of ungrafted and grafted gums was determined and represented in Figure 5.

CONCLUSION

Microwave-assisted graft copolymerization of KG with AAm was successfully achieved using potassium persulfate (APS) as an initiator. The use of microwave irradiation provided rapid, uniform, and energy-efficient heating, resulting in higher grafting efficiency compared to conventional methods. Optimization using CCD revealed a significant influence of monomer, initiator concentration, and irradiation time on grafting yield and efficiency. FTIR analysis confirmed successful grafting through the appearance of characteristic peaks corresponding to both KG and AAm functional groups. The broad band in the 3,200–3,000 cm^{-1} region indicated the presence of O–H and N–H stretching vibrations, validating the formation of the graft copolymer. The statistical model demonstrated strong correlation and predictive accuracy, as indicated by adequate precision and high R^2 values. Interaction terms (AB and BC) significantly affected the grafting performance, highlighting the importance of variable interplay in the process. The optimized conditions – acrylamide 24.99 g, APS 0.154 g, and irradiation time 88.9 s – yielded maximum desirability (1.000). Under these conditions, the predicted grafting yield and efficiency were 94.10% and 82.84%, respectively, demonstrating excellent process optimization. Microwave-assisted synthesis effectively reduced reaction time while improving product uniformity and purity. The graft copolymer exhibited enhanced physicochemical stability and potential for pharmaceutical and biomedical applications. Swelling studies revealed improved hydrophilicity and water uptake capacity in the grafted polymer compared to the native gum. The developed polymerization method provides a sustainable and reproducible approach for natural polymer modification. This study establishes KG-PAM graft copolymer as a promising biopolymer for controlled drug delivery and related applications. Overall, microwave-assisted grafting offers a rapid, eco-friendly, and efficient strategy for producing value-added biopolymers from renewable natural sources.

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CONFLICT OF INTEREST

The authors have stated that they have no conflicts of interest with this study.

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