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Valorization of corn silk through incorporation in instant mix and analyzing its shelf life by kinetic modelling

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A B S T R A C T

Corn silk (*Zea mays* L.), an abundant agricultural waste, contains various bioactive compounds that exhibit promising health benefits. The current study focuses on development and optimization of corn silk-based instant mix using response surface methodology. The optimized product, with 14.66% corn silk, 10% sugar and 0.22% xanthan gum in a skim milk powder base, scored 0.925 desirability. The physico-chemical and sensory parameters of optimized mix closely aligned with expected values. The instant mix packaged in metallised polyester yielded superior preservation of quality indicators over 120 days compared to low-density polyethylene (LDPE) and high-density polyethylene (HDPE). The microbial load in corn silk instant mix was observed across packaging materials and highlighting hydroxyl methyl furfural (HMF) as the primary predictor of product stability, the study calculated a 94.95 days half-life at 10 °C. Corn silk's rich bioactive compound supports its integration into nutraceuticals and instant mixes, mitigating food waste while enhancing nutritional value.

Novelty statement.

In this study, corn silk powder was utilized for the development of the instant mix. This innovative approach transforms corn silk, typically discarded as agricultural waste, into a commercially sustainable product that delivers the nutrients of corn silk to a broader population. Despite fresh corn silk being a perishable commodity, it has very low storage shelf life. The developed instant mix effectively preserves its nutritional value for up to six months, offering a sustainable and nutritious option for consumers.

1. Introduction

The utilization of agriculture by-products waste materials in the formulations and developments of functional food products has gained increasing attention in recent years (Shameena Beegum et al., 2019). Corn silk (*Stigma maydis* L.) originates from female flowerers of corn plants and is constituted by stigma. Fresh corn silk shows a yellow-brown or light green color and its threads are smooth 10 to 20 cm in length (Samaila et al., 2022). Corn silk provides vital nutrients such as maizeric acid, resin, sucrose, mucilage, and fibers (Mada et al., 2020). They also contain compounds that function as diuretics, modify blood sugar levels, and aid in the reduction of inflammatory responses (Riuwpassa et al., 2020). A wide range of nutrients and bioactive compounds such as carbohydrates, proteins, vitamins, minerals (Bakar et al., 2023; Mada et al., 2020), volatile and fixed oils, and natural antioxidants including flavonoids are present (Kirrella et al., 2023; Ratha et al., 2023). Furthermore, it is a rich source of phenolic chemicals that may have health-promoting properties (Ratha et al., 2023). Asian

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civilizations, particularly in China, have traditionally employed corn silk to make tea as a nutritious and medicinal beverage (Mada et al., 2020). Due to the high level of phytochemicals and antioxidant activities corn silk may be useful for human being. As a result, it can be used in food processing and manufacturing of food products as an alternative food ingredient and dietary fiber to help prevent various types of chronic illnesses (Shahzad et al., 2022). The different kind of nutrients and phytochemicals shows several biological properties such as antioxidant, antibacterial, anti-diabetic, and anti-fatigue properties (Kaur et al., 2022). In China, it's an edible part used for traditional medicine for the treatments of rheumatoid arthritis, gout, rheumatism, oedema, cystitis, and renal disorders and it also shows good antimicrobial properties (Naeem, 2022). Due to its numerous health benefits, it can be used for the development of value-added food products in different forms like biscuits, crackers, bread, alcoholic and non-alcoholic beverages, patties, meatballs, and traditional foods items such as chapati, parantha, dal, and ladoo (Kaur et al., 2022).

Corn silk was added to meat products (beef patties) at different levels (2–6%) and it helps to enhance the protein and minerals levels and also reduces the lipid content without affecting the sensory parameters of the beef patties prepared product (Rosli et al., 2011). They are safe and non-toxic in prior studies utilizing male and female rat models (Wang et al., 2011). There were no negative effects on the samples fed corn silk on their body weight, urine system, body water content, clinical chemistry, and organ weight over the study period (Ha et al., 2018). The instant food mix is prepared using different types of ingredients including cereals, pulses, condiments, spices, and other food ingredients. These products are simple, convenient, and less time for preparation by offering an easy and readily available homemade option (Dhiman et al., 2017). With a compound yearly growth rate of 6.9%, the market for instant food mix products is anticipated to expand to $2.93 billion by 2030. With the high dietary fiber content, vitamins, minerals, and other health advantages, instant mixes have the potential to serve as healthy foods (Meticulous Market Research Pvt. Ltd., 2024). The current research on instant food mix products focuses on enhancing nutritional value, optimizing flavor and texture, and improving convenience through advanced techniques. These products include instant instant khadi mix, instant dhokla mix, instant sooji upma mix, instant vegetable pulav mix, instant rava idli mix, pumpkin soup mix (Dhiman et al., 2017; Food Premix Market, 2023). Apart from these there is a challenge such as nutritional degradation of bioactive compounds during processing, use of additives, maintaining sensory quality, and consumer perception issues remain (Islam et al., 2018). Ongoing efforts aim to address these problems to meet consumer demands and improve product quality. Based on these problems the current study was to develop the novel corn silk-based instant mix beverage.

Many researchers have continually looked at the remarkable advantages of corn silk which was previously thought to be a waste of agricultural materials. It contains high amount of moisture content that affects the storability of products and also it contains the high amount of fiber that affect the texture properties of products, which might be affect the on sensory parameters (mouthfeel and overall texture) of the product. Additionally, the flavor of corn silk may not be universally appealing, potentially altering the taste profile in ways that may not be desirable for consumers. Therefore, the primary goal of the current study is to develop an instant mix food product by incorporating corn silk, leveraging its nutritional properties to create a functional and marketable food material. Additionally, this research study aims to contribute to the understanding of the shelf life dynamics of the developed product using kinetic modelling.

2. Materials and methodology

2.1. Raw materials

The current study proposes is to development of instant corn silk product with addition of sugar, skim milk powder, and xanthan gum as ingredients that help to improving sensory acceptability, nutritive and techno-functional properties of the instant mix. The sugar (Trust classic, India), xanthan gum (Indiana, India), and skimmed milk powder (Amul, India) were obtained from the local supermarket of Jalandhar (Punjab, India). The *Zea mays* (G5417) variety of corn silk was used for the powder preparation and the powder was manufactured as per the procedure explained by Singh, Inbaraj, et al. (2022). The freshly harvested baby corn (G5417) was collected at the silking stage (10 days of emergence) from the agricultural field of Lovely Professional University, Punjab. The corn silk was separated out from the cobs and washed with running tap water to remove any foreign particles. After that all the corn silk was blanched at 100 °C for 60 s then it was spread on a clean surface and cut into smaller pieces. The corn silk was dried in a tray drying oven (Labfit India Pvt. Ltd., Mumbai, India) at 50 °C for 4 h. The dried Corn silk was crushed manually, ground in a commercial mechanical electric grinder (Rex 500, Bajaj Electrical and Electronics Pvt. Ltd., Punjab, India), and after that sieved to pass through 22 mesh sieves size. The obtained fine powder was stored in an airtight container and used for further study work. The processing flow chart for corn silk powder preparation is shown in (ESI Fig. 1).

2.2. Chemicals, standards, and reagents

For the experimental study work, all required chemicals are procured from LobaChemie (Mumbai, India) and Sigma-Aldrich (Steinheim, Germany) Company. The chemicals and reagents, which are used during the research study work include oxalic acid, trichloroacetic acid, Folin−Ciocalteu reagent, sodium carbonate, ethanol, gallic acid, 2,2-diphenyl-1-picrylhydrazyl (DPPH), thiobarbituric acid, phenolphthalein indicator, ethanol, potassium hydroxide was used. Plate count agar, violet red bile lactose agar, and potato dextrose agar were procured from HimediaPrivate Laboratories (Mumbai, India).

2.3. Experimental design

The development of a corn silk-based instant mix of various formulations and experimental work was carried out using the Design Expert (version 16) a statistical software package. The independent variables such as corn silk powder (A), sugar (B) xanthan gum (C), and skimmed milk powder (D) used to develop of instant mix and based on the design treatments run (17) obtained from the Box Behnken model. The current study works different types of independent variables within specified ranges: A ranged from 5 (−1) to 15 (+1), 5(−1) to 10 (+1) for B, 0.10 (−1) to 0.30 (+1) for C, and 74.8 (−1) to 89.8 (+1) for D were used. The optimization of different experiment treatments is represented in Table 1. The preparation of instant corn silk-based mix was prepared according to different experimental runs. In the next steps for the preparation of instant mix, all the ingredients are weighed as per the treatments and mixed for 2 min. The prepared ingredients formulation was mixed by adding 180 mL of R.O warm water (80 °C) and filled into glass bottles after which the bottles were pasteurized in boiling water at 100 °C for 15 min Table 1).

2.4. Physico-chemical analysis

The instant mix sample moisture content was measured as per the procedure described by AOAC (2005) and in physicochemical analysis such as bulk density, tapped density, and water absorption capacity, and was performed as per the procedure by Singh, Rasane, et al. (2022).

2.4.1. Bulk density

The bulk density of the different corn silk-based instant mix samples was carried out as the methodology outlined by Singh et al. (2022) and eq. 1 was used to calculate the bulk density of corn silk instant mix sample.

Table 1
a. Optimization of levels of various constituents in corn silk-based instant mix using response surface methodology and its sensory attributes, physico-chemical, and antioxidant contents.

Run	Experimental variables				Sensory attributes				
	CSP (%)	Sugar (%)	XG (%)	SMP (%)	CA	BT	FA	Mouth feel	OA
1	5.00	5.00	0.20	89.80	8.80	8.40	6.50	8.40	8.40
2	15.00	5.00	0.20	79.80	8.20	8.10	6.30	8.00	7.40
3	5.00	10.00	0.20	84.80	8.60	8.20	8.00	8.10	8.20
4	15.00	10.00	0.20	74.80	7.50	8.70	8.80	8.70	8.80
5	5.00	7.50	0.10	87.40	8.70	7.20	7.50	7.90	7.40
6	15.00	7.50	0.10	77.40	7.70	7.30	7.20	7.60	7.40
7	5.00	7.50	0.30	87.20	8.70	7.20	7.50	7.40	7.80
8	15.00	7.50	0.30	77.20	7.70	7.10	7.80	7.50	7.40
9	10.00	5.00	0.10	84.90	8.50	7.20	6.20	7.40	7.20
10	10.00	10.00	0.10	79.90	7.80	7.60	7.80	7.60	7.80
11	10.00	5.00	0.30	84.70	8.50	7.00	6.40	7.40	7.80
12	10.00	10.00	0.30	79.70	7.90	6.80	8.40	7.00	7.90
13	10.00	7.50	0.20	82.30	8.20	8.40	7.40	8.20	8.20
14	10.00	7.50	0.20	82.30	8.30	8.20	7.60	8.30	8.20
15	10.00	7.50	0.20	82.30	8.30	8.40	7.40	8.10	8.00
16	10.00	7.50	0.20	82.30	8.20	8.30	7.30	8.20	8.40
17	10.00	7.50	0.20	82.30	8.40	8.60	7.80	8.70	8.50

Note: Where, CSP, Corn silk powder; XG, Xanthan gum; SMP, Skim milk powder; CA, Color and appearance; BT, Body and texture; FA, Flaour and aroma; OA, Overall acceptability.

$$\text{Bulk density (g/mL)} = \frac{\text{Weight of powder sample taken (g)}}{\text{Volume of sample (mL)}} \quad (1)$$

2.4.2. Tapped density

The tapped density of the instant mix sample was carried out as per the process explained by Singh et al. (2022). The graduated measuring cylinder (250 mL) was used and the 50 ± 10 taps/min were applied for the sample. The tapped density was calculated using below eq. 2.

$$\text{Tapped density (g/mL)} = \frac{\text{Powdered sample weight (g)}}{\text{Volume of sample (mL)}} \quad (2)$$

2.4.3. Water absorption capacity (WAC)

The water absorption capacity (WAC) of the instant mix sample was evaluated using the centrifugal method described by Budnimath et al. (2023). A 0.1 g sample of the powder was suspended in 10 mL of distilled water and incubated at room temperature for 30 min. The suspension was then centrifuged at 1431 ×*g* for 30 min. The resulting sediment was collected and weighed. The WAC (g/g) was calculated using the formula provided below.

$$\text{WAC (g/g)} = \frac{\text{Weight of sediments (g)}}{\text{Weight of dry sample taken (g)}} \quad (3)$$

2.4.4. Swelling capacity

The swelling capacity of the dehydrated sample was assessed using a method previously described by Budnimath et al. (2023). A 1.0 g sample was placed into a 10 mL measuring cylinder, and 5 mL of distilled water was carefully added. The initial volume occupied by the sample was recorded. The sample was left undisturbed in the water for 1 h, after which the volume occupied after swelling was recorded. The swelling capacity was then calculated using the following formula.

$$\text{Swelling capacity (mL/g)} = \frac{\text{Volume of sample (mL)}}{\text{Sample of weight (g)}} \quad (4)$$

2.4.5. Viscosity

The viscosity measurements of instant mix sample were performed with a Brookfield viscometer as per the methodology described by Howard et al. (2010). The Brookfield viscometer at 50 rpm was used to measure the viscosity of prepared instant mix different samples. The measurement of viscosity was done by using the SC4–21 spindle, and the results are expressed in cPs units.

2.5. Shelf life analysis

The storage conditions for selected corn silk instant mix sample the storage temperature (10, 25, and 27 °C), and packaging materials such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), and metallised polyester pouches (MP) with based physical, chemical and microbial parameters were tested for 120 days storage period days with 30 days interval of time.

2.5.1. Computation of reaction kinetics

The zero and first-order reaction kinetics were used to check chemical changes in the corn silk-based instant mix beverage. To obtain a zero and first-order reaction rate constants (k) following equations were applied.

$$C - Co = -k \quad (5)$$

$$ln\frac{C}{Co} = -k \quad (6)$$

where, C is the reactant concentration at time (t) and C_0 is the reactant initial concentration.

For temperature-dependent processes, the Arrhenius equation was used to create a model.

The Arrhenius equation was used to characterize the temperature dependence of 'k'

$$k = A_0 e^{\frac{-E_a}{RT}} \quad (7)$$

where, A_0 = Arrhenius equation, R = Universal gas constant, 8.314 J/mol °K.

T = Absolute temperature, °K, Ea = Activation energy, J/mol.

The thermodynamic equation parameters were obtained using mathematical equations based on absolute reaction rate theory, according to Rasane et al. (2019). Thermodynamic equation parameters were derived by using mathematical expressions based on absolute reaction rate theory.

$$k = \frac{k_{B.}T}{h} e^{\frac{\Delta S^*}{R}} . e^{\frac{-\Delta H^*}{RT}} \quad (8)$$

where, K_B = Boltzmann's constant, 1.38×10^{-23} J/K

H = Plank's constant, 6.63×10^{-34} J.S.

ΔS^* = entropy of activation, J/mol°K.

ΔH^{*} = enthalpy of activation, J/mol.

The enthalpy was calculated from activation energy (E_a) obtained from the experimentally obtained reaction rate constants using the following relationship:

$$\Delta H^{*} = E_a - RT$$

The free energy of activation (ΔG^{*}, kJ/mol) was obtained from the following relationship:$\Delta G^{*} = \Delta H^{*} - T\Delta S^{*}$.

2.5.2. Effect of various storage conditions on the stability of the optimized corn silk instant mix

The time it takes for quality metrics to degrade to an unfavorable level, i.e. the time it takes for quality parameters to return to the level desired by consumers, is referred to as the product's shelf life. The half-life time explains why 50% of quality criteria have degraded from their original value (Veerapandian, 2014). The formula used to calculate the half-life of the optimized instant mix is mentioned below:

$$\text{Zero order reaction} = \frac{A_o}{2k_o} \quad (9)$$

$$\text{First order reaction} = \frac{ln2}{k} \quad (10)$$

$$\text{Second order reaction} = \frac{1}{(k^2A^0)} \quad (11)$$

where, k = rate constant.

2.6. Chemical analysis

2.6.1. Hydroxy methyl furfural (HMF)

The concentration of hydroxyl methyl furfural (HMF) in an instant mix sample was calculated as per the process explained by Aggarwal et al. (2019). The 3 g of sample was thoroughly mixed with 7 mL of distilled water. Subsequently, 5 mL of 0.3 M oxalic acid was added to the test sample, which was then heated in a boiling water bath for 60 min. After cooling, 5 mL of a 40% trichloroacetic acid solution was added. The resulting precipitate was filtered through Whatman filter paper (No. 42). A 0.5 mL sample of the filtrate was placed in a 5 mL test tube, mixed with 3.5 mL of distilled water and 1 mL of 0.05 M thiobarbituric acid solution, and incubated in a water bath at 40 °C for 50 min. A UV–visible spectrophotometer was used to measure the absorbance of sample at wavelength 443 nm and HMF content in the instant mix sample is expressed in μmol/g.

2.6.2. Thiobarbituricacid value (TBA)

The thiobarbituric acid content in the instant mix sample was determined using the procedure described by Şayin Sert and Coşkun (2022). First, 4 g of the instant mix was weighed and mixed with 100 mL of 20% trichloroacetic acid and 100 mL of distilled water. This mixture was allowed to stand at room temperature for 10 min and then filtered through Whatman No. 1 filter paper. A 5 mL aliquot of the filtrate was taken for further analysis, to which 5 mL of 10 mM thiobarbituric acid was added. The mixture was then incubated at 95 °C for 30 min. After incubation, the optical density of the sample was measured at 532 nm using a UV–visible spectrophotometer. The TBA content in the instant mix sample was calculated using the following formula:

$$\text{TBA content} = 7.8 \times \text{Absorbance at 532 nm}$$

2.6.3. Free fatty acid content (FFA)

The FFA content of the samples was determined using the process explained by Bordoloi et al. (2020). Firstly, 2 g sample was dissolved in 50 mL of an ethanol solvent in a conical flask (250 mL). A few drops of phenolphthalein indicator (1% phenolphthalein in 95% ethanol) were added, and the mixture was titrated against a 0.10 N potassium hydroxide solution until a pink color persisted for 15 s. The titration value was then used to calculate the acid value and free fatty acid content using the following formula.

$$\text{Acid value (mg KOH/g)} = \frac{\text{Titrate value} \times \text{Normality of KOH} \times 56.1}{\text{Weight of sample taken for analysis (g)}}$$

where, 1 mL N/10 KOH = 0.028 g oleic acid.

2.7. Total phenol content and antioxidant activity

A sample ratio of 1:10 was used throughout the extractions, which were conducted using an 80% ethanol solution. The total phenolic content and antioxidant activity of the instant mix sample were then determined by centrifuging this mixture at 8000 rpm for 15 min.

The total phenolic content of the samples was determined using the Folin–Ciocalteu reagent, based on the method by Hussain et al. (2021) with slight adjustments. A known quantity of ethanolic extracts was mixed with 0.5 mL of 0.5 N Folin–Ciocalteu reagent at room temperature. To alkalize the medium for the oxidation-reduction reaction between the phenolic compounds and the Folin reagent, 7.5% Na_2CO_3 was added. The mixture was then left at 23 °C for 2 h. Absorbance was measured at 760 nm using a spectrophotometer. A calibration curve was constructed using a gallic acid solution, and the total phenolic content was expressed as gallic acid equivalents (GAE) in mg/100 g of sample.

The total antioxidant activity were determined using the methods previously outlined by Hussain et al. (2024), the ability of the sample extracts to scavenge 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical was estimated. Briefly, 0.1 mL of ethanoic extracts were mixed with a 2.9 mL of DPPH solution and the absorbance of the resultant solution was measured at wavelength 517 nm using a spectrophotometer after a 30 min incubation period. The inhibition percentage of DPPH radical scavenging activity was determined using below equation.

$$\textbf{DPPH radical sacavenging activity}\ (\%) = \frac{\text{Absorbance of control} - \text{Absorbance of sample}}{\text{Absorbance of control}} \times 100$$

2.8. Microbial assay

The microbial analysis, including total plate count, and yeast and coliform counts of the instant mix sample, was conducted following the method described by Siddique et al. (2023). A 1 g sample was aseptically mixed with 9 mL of distilled water and thoroughly shaken to homogenize. Serial dilutions were then prepared for each treatment, and the samples were incubated at 37 °C for 24–48 h. The total plate count was determined using nutrient agar, while the yeast and mould counts were assessed using potato dextrose agar. The results for total plate count, yeast, and coliform counts were expressed as colony-forming units per gram (cfu/g) based on the colonies counted on the petri dishes.

2.9. Sensory evaluation

The developed instant mix sample underwent sensory analysis utilizing a 9-point hedonic scale, descriptive analysis and attributes including color and appearance, body and texture, flavor and sweetness, mouthfeel and overall acceptability. 20 semi-trained panellists ($n = 20$; 10 = male, 10 = female) made up the group and their statement of understanding and consent was recorded. The process of sensory evaluation was approved by the ethical committee of the university with reference number LPU/CA/024/13/04/13058. Using the aforementioned analytical criteria, shelf-life research for the optimized items was carried out. Chemical kinetics was utilized to determine the optimal product's shelf life (Rasane et al., 2019).

Table 1

b. Optimization of levels of various constituents in corn silk-based instant mix using response surface methodology and its sensory attributes, physico-chemical, and antioxidant contents.

Run	Experimental variables				Physico-chemical and antioxidant contents							
	CSP (%)	Sugar (%)	XG (%)	SMP (%)	MC (%)	BD (g/cm^3)	TD (g/cm^3)	WAC (g/g)	SC (ml/g)	TA (%)	Viscosity (cPs)	TPC (mg GAE/g)
1	5.00	5.00	0.20	89.80	10.60	0.33	0.51	0.91	12.52	1.12	6785.43	34.26
2	15.00	5.00	0.20	79.80	7.40	0.43	0.42	1.02	13.22	1.64	6454.75	127.32
3	5.00	10.00	0.20	84.80	11.00	0.47	0.56	1.34	14.55	1.15	6542.48	44.56
4	15.00	10.00	0.20	74.80	7.10	0.52	0.75	1.74	14.86	1.63	6432.15	140.21
5	5.00	7.50	0.10	87.40	11.30	0.35	0.56	1.37	13.64	1.21	5661.62	54.97
6	15.00	7.50	0.10	77.40	7.50	0.43	0.61	1.64	14.37	1.66	5428.48	142.16
7	5.00	7.50	0.30	87.20	12.00	0.50	0.74	1.67	14.23	1.16	7842.76	49.21
8	15.00	7.50	0.30	77.20	7.80	0.47	0.72	1.63	15.21	1.62	7354.28	139.48
9	10.00	5.00	0.10	84.90	8.80	0.35	0.51	1.21	13.42	1.37	5357.26	124.62
10	10.00	10.00	0.10	79.90	7.60	0.42	0.62	1.72	14.29	1.45	5621.18	134.84
11	10.00	5.00	0.30	84.70	8.00	0.44	0.59	1.33	13.27	1.35	7642.42	126.54
12	10.00	10.00	0.30	79.70	9.40	0.60	0.80	1.91	16.74	1.44	7642.62	137.56
13	10.00	7.50	0.20	82.30	7.60	0.54	0.65	1.62	15.47	1.40	6975.47	127.49
14	10.00	7.50	0.20	82.30	7.50	0.55	0.68	1.43	15.11	1.39	6758.24	129.47
15	10.00	7.50	0.20	82.30	7.40	0.60	0.64	1.47	14.93	1.34	6752.24	134.21
16	10.00	7.50	0.20	82.30	7.40	0.54	0.62	1.34	15.11	1.35	6845.79	129.56
17	10.00	7.50	0.20	82.30	7.60	0.53	0.61	1.39	16.01	1.34	6623.59	127.69

Note: Where, CSP, Corn silk powder; XG, Xanthan gum; SMP, Skim milk powder; MC, Moisture content; BD, Bulk density; TD, Tapped density; WAC, Water absorption capacity; SC, Swelling capacity; TA, Titrable acidity; TPC, Total phenol content.

2.10. Statistical data analysis

The design experiments for the development of corn silk instant mix were all carried out in triplicates, and the data were statistically analyzed using Duncan's multiple tests and SPSS V. 22 (SPSS Inc., Chicago, IL, USA). The collected data from the numerous trials are shown as mean and standard deviation values, taking into account the indicated significant (>0.05) *p*-values.

3. Results and discussion

3.1. Optimization of corn silk-based instant mix

A Box-Behnken design was used to determine optimum levels of variables through 17 experiments (Table 1 a). Corn silk powder along with sugar as sweetener, xanthan gum as stabilizer and skimmed milk powder (SMP) as filler was used to prepare the different treatments of the instant mix. The optimization criteria for an instant mix beverage using three main process variables including corn silk powder (5–15%, maximize), sugar (5–10%, in range), and xanthan gum (0.1–0.3%, in range), each with set goals and importance levels as shown in **ESI Table 6**. It also specifies response variables, including color and appearance (7.5–8.8, none), body & texture (7.5–8.8, maximize), flavor and sweetness (6.8–8.7, maximize), mouthfeel (6.2–8.8, in range), overall acceptability (7–8.7, maximize), moisture content (7.1–12, none), bulk density (0.333–0.601, in range), tapped density (0.42–0.8, in range), water absorption index (0.91–1.91, maximize), swelling capacity (12.52–16.74, in range), viscosity (5357.26–7842.76, none), acidity (1.12–1.66, minimize), and total phenol content (34.26–142.16, maximize). These criteria are designed to balance various selected sensory parameters and physico-chemical properties to create an optimal instant mix beverage formulation.

The sensory scores of the powdered instant mix along with physicochemical and antioxidant properties in (Table 1 a) were analyzed in response to the variables. The sensory parameters reveal that when the percentage of corn silk in the instant mix increased, it significantly affected the sensory parameters (color and appearance) of the instant mix prepared product. The optimal sensory parameters (flavor and sweetness) are achieved at 10 to 11% sugar combined with moderate 7 to 9% corn silk powder. Conversely, higher corn silk powder percentages with lower sugar content result in reduced flavor and sweetness of the instant mix product as shown in (Fig. 1; F). The corn silk powder and sugar showed the significant effect ($p < 0.05$) on the mouthfeel sensory parameters as shown in (Fig. 1; G). The optimal mouthfeel score for the instant mix product were achieved with sugar concertation of 8–9% and corn silk powder concentration of 6–9% observed.

3.2. Physicochemical properties of corn silk-based instant mix

The various physicochemical properties responses values are shown in (Table 1 b). The increase in the amount of corn silk powder in the instant mix increased the bulk density and reduces the tapped density of instant mix. The bulk density for 5% corn silk was found to be in the range of 0.333 to 0.495 g/cm^3, for 10% corn silk the range was 0.348 to 0.601 g/cm^3, and for 15% corn silk, the values were in the range of 0.431 to 0.516 g/cm^3 were observed. The percentage of corn silk powder in the instant mix increased also the tapped density of the prepared product was increased. Our findings results of bulk density and tapped density of formulated instant mix product agreed with those reported by Wadibhasme et al. (2020), they also reported the incorporation of amla powder increases these parameters value in instant drink mix. Another investigation revealed the increase in bulk density and tapped density values of flour prepared from different ranges of mixing the pigmented 3 rice varieties flour (Kweesar et al., 2022). The extruded snacks were prepared from virgin coconut oil cake and the bulk density ranged from based extruded snacks bulk density ranged from 127.50 to 225.85 kg/m^3 were observed. The moisture content of products shows a significant effect on bulk density parameters (Shameena Beegum et al., 2019).The corn silk powder is ability to absorb moisture and form a cohesive matrix with other ingredients during preparation of instant mix. As corn silk powder hydrates, it fills in void spaces between particles, leading to an increase in bulk density properties. Additionally, its cohesive properties contribute to improved packing efficiency, resulting in higher tapped density values. This phenomenon is attributed to the swelling capacity of corn silk powder, enhancing the overall structural integrity of the prepared product (Waliullah et al., 2020).

The water absorption capacity of corn silk-based instant mix increased when the corn silk powder concentration were increased. The high level of polysaccharides, fiber and protein content of corn silk, effect on water absorption capacity of the products and which promotes water retention and swelling when hydrated. The other ingredients such as ugar, xanthan gum, and skim milk powder, the fiber in corn silk powder synergizes with the gel-forming properties of xanthan gum, enhancing the beverage's viscosity and water-holding capacity (Awolu

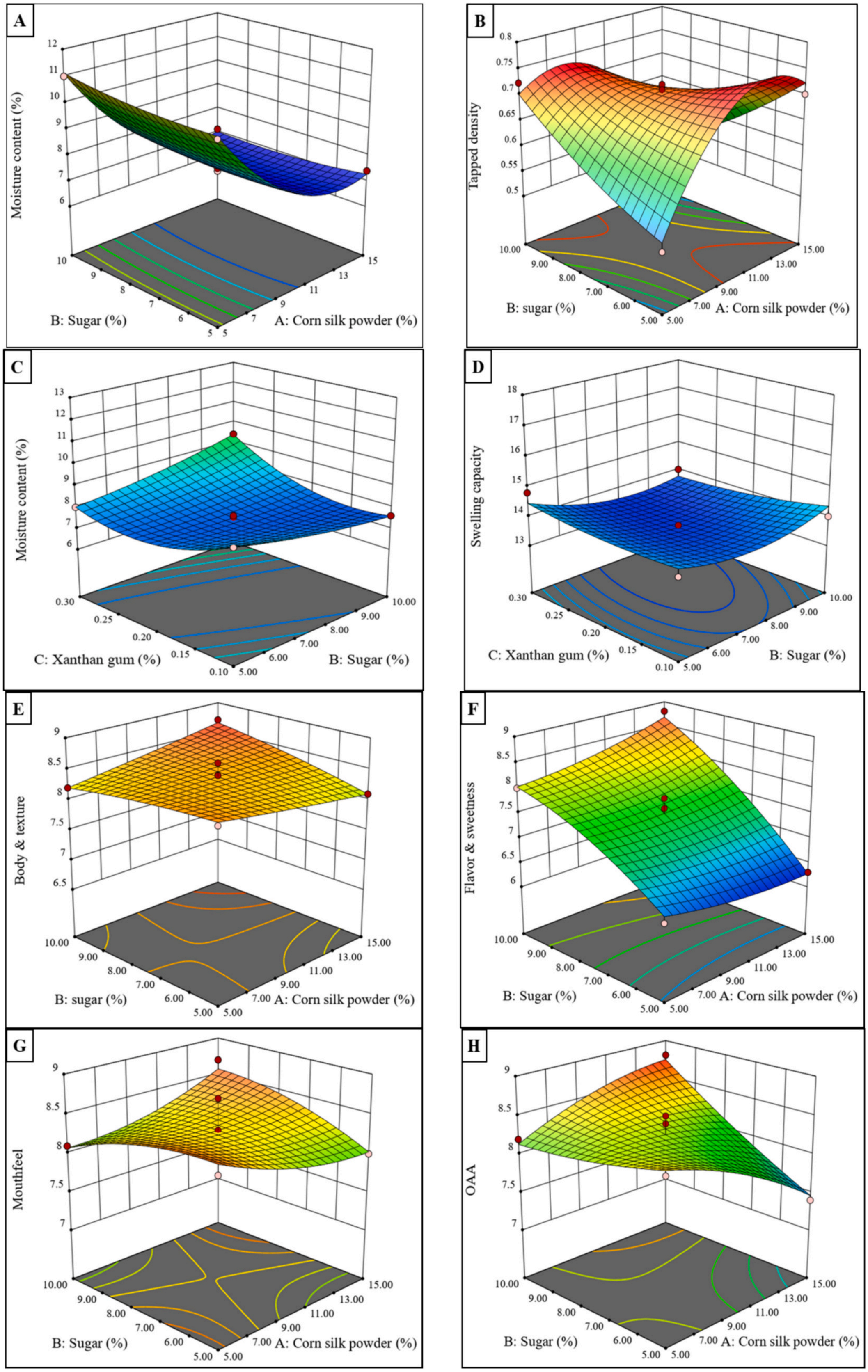

Fig. 1. The interactive effect of selected ingredients on, A and C: moisture content; B: Tapped density; D: Swelling capacity; E: Body and texture; F: Flavor and sweetness; G: Mouthfeel; H: Overall acceptability (OAA).

et al., 2019; Han et al., 2022). Sneha and Haripriya (2018) reported an increase in water absorption capacity in germinated amaranth flour-based instant dosa mix when compared to untreated and roasted instant dosa mix. The water absorption capacity of 2.81 to 2.90% was desirably reported for the composite flour yam bean (*Pachyrhizus* spp.) seed flour to add to the bread and sausage (Kisambira et al., 2015). In another study, the WAC for the WAC for rice flour (2.39%), corn flour (2.18%), and coconut milk residue (7.12%) were observed (Pandiselvam et al., 2023).

The corn silk instant mix swelling capacity was increased when the corn silk powder percentage high in the product. The 5% formulation showed a swelling capacity of 12.52 to 14.55 mL/g which increased in the 15% formulation by the range of 13.22 to 15.21 mL/g. The ready-to-eat snack made with different flour combinations (rice, kersting's peanut, and lemon pomace) and a swelling capacity that 14 to 18 g/cm were observed in snacks (Awolu et al., 2019). The higher swelling capacity is due to high exposure of internal structure in corn silk starch presents (Kisambira et al., 2015). It can absorb water and form a gel-like matrix, increasing the viscosity of the instant mix. This mechanism of action facilitates the retention of water within the instant mix, resulting increased in swelling capacity and improved stability of the final product (Singh et al., 2022). The swelling power of native starch and flour may be influenced by the development of a protein-amylose complex. The results followed Ansari et al. (2020) in their study of *moringa oleifera* flower powder-based instant soup mix. They also showed an increase in the swelling capacity as the incorporation of *moringaoleifera* flower powder increased.

The viscosity of corn silk-based instant mix increased from 5 to 15% incorporation by the range of 6785.43 to 7354.28 cPs respectively. Our results were equivalent to the soup prepared with a combination of ashwagandha root powder and moringa pods which increased the viscosity of the prepared product (Kamble et al., 2019). The high amount of zinc present in corn silk powder (83.75 ± 1.80 μg/g) might be a reason for an increase in viscosity as zinc has a crosslinking impact on starch chains at low doses. Zinc cation is bivalent, meaning it has two extra protons. As a result, it can pull two oxygen atoms from free electron pairs in different starch chains (Kristanti & Herminiati, 2019). The starch content is responsible for the increase in viscosity (amylopectin and amylose) of food products (Pratiwi et al., 2021).

Corn silk contains different kinds of various types of phenolic compounds and they show good antioxidant activity effects (Singh et al., 2022). Total polyphenolic content also increased in the formulations from lower to higher incorporation and the highest value was observed in 15% incorporation (142.16 mg/GAE g). Corn silk powder showed the significant ($p < 0.05$) effect on the total phenol content parameters during the preparation of instant mix beverages due to its inherent

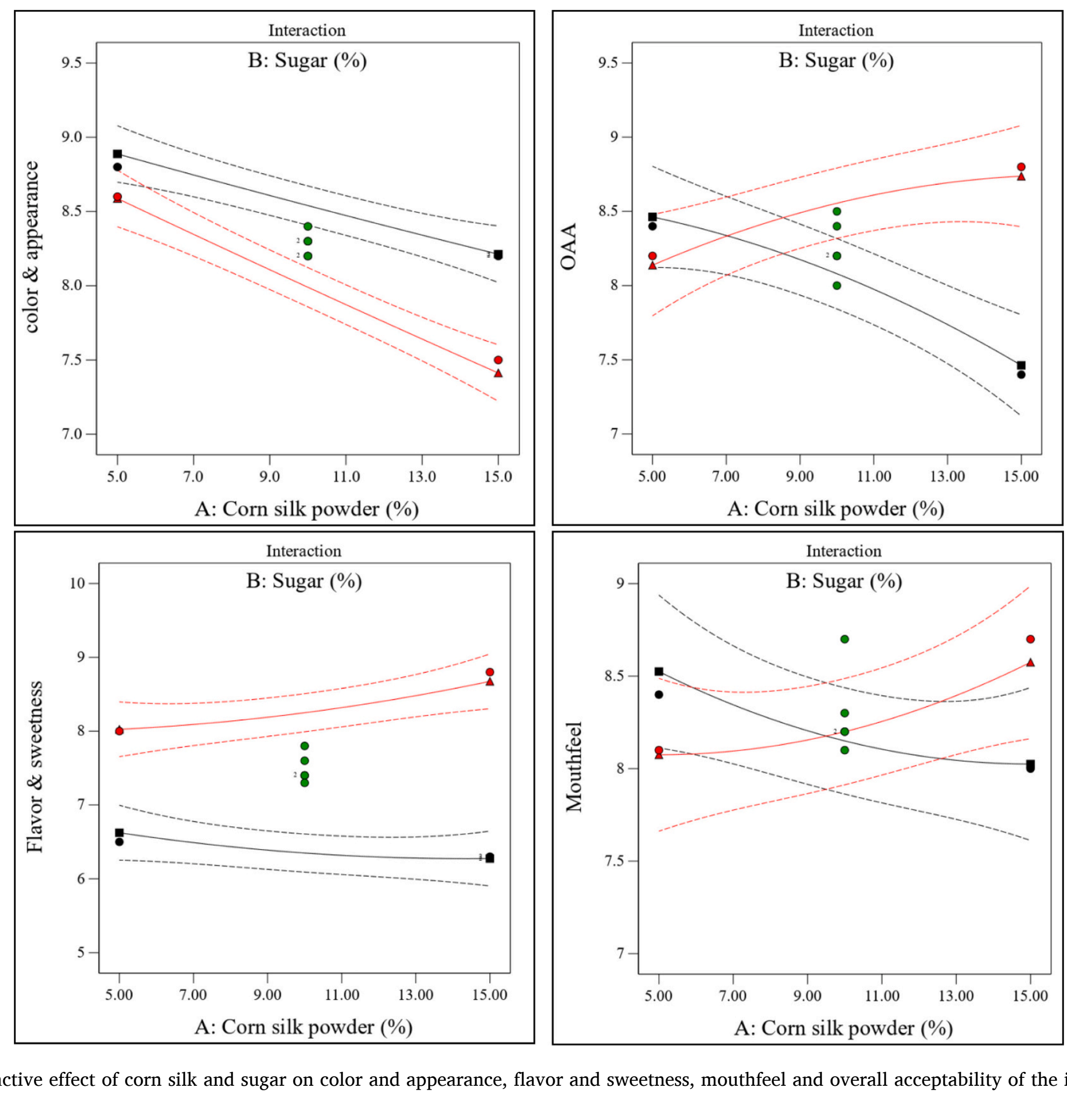

Fig. 2. Interactive effect of corn silk and sugar on color and appearance, flavor and sweetness, mouthfeel and overall acceptability of the instant premix.

antioxidant properties. These properties likely arise from the presence of bioactive compounds such as flavonoids and phenolic acids compounds, which can scavenge free radicals and inhibit oxidative stress (Lapčík et al., 2023). Similar results were observed in the formulation of instant banana milk powder and the values were increased by 7.73 to 9.13 mg/100 g as per increase in banana powder (Kumar et al., 2021).

3.3. Effect of variables on physico-chemical parameters of corn silk instant premix

It is evident from (ESI Table 1) that corn silk has a significant role in defining parameters such as moisture content, acidity, total phenolic content, bulk density, water absorption index, swelling capacity, and viscosity of the corn silk-based instant premix. The linear effect is shown in (ESI Fig. 2). The acidity, total phenolic content, bulk density, water absorption index, and swelling capacity of the instant mix are significantly ($p < 0.05$) increased due to corn silk powder. It can be shown that corn silk has a considerable significant effect ($p < 0.05$) on the product moisture content and viscosity parameters. Additionally, it was noted that the interaction between corn silk and sugar had a significant negative effect on the instant mix product moisture content (Fig. 1;A), although the interaction had a positive effect on the instant mix tapped density parameters (Fig. 1;B). In the instant mix, the percentage of sugar shows a significant ($p < 0.05$) effect on selected experiment parameters including the bulk density, tapped density, water absorption index, and swelling capacity of the product. However, the interaction of corn silk with xanthan gum has no significant effect ($p > 0.05$) on any parameter of the product. Whereas, xanthan gum has a positive significant ($p < 0.05$) effect on different parameters including moisture, bulk density, tapped density, water absorption index, swelling capacity, and viscosity of the product. Along with sugar, xanthan gum has a positive interactive effect on the moisture content (Fig. 1;C) and the swelling capacity of the product (Fig. 1;D).

3.4. Effect of variables on the sensory properties of the instant mix

Other sensory criteria, including texture, sweetness and flavor, mouthfeel, and general acceptability, did not exhibit any significant ($p > 0.05$) effects on these parameters shown in (ESI Table 2). However, the corn silk powder has a significant ($p < 0.05$) effect on the color and appearance parameter of the instant mix. In (ESI Fig. 3) depicts the linear effect. In contrast to corn silk powder, sugar, however, has a positive significant ($p < 0.05$) impact on the flavor and sweetness of instant mix. Contrarily, corn silk and sugar had an interactively beneficial effect that had a greater impact on the body and texture of the instant mix than did xanthan gum, although the degree of the effect appears to be lower as shown in (Fig. 1;E). In (Fig. 2), sensory attributes such as color and appearance, flavor and sweetness, mouthfeel, and overall acceptability of instant mix showed corn silk and sugar both had significant effects on these parameters observed. It could, therefore, be stated that corn silk and sugar are principal components affecting the sensory characteristics of the corn silk-based instant premix.

Table 2
Predicted and observed optimum responses.

Responses	Predicted values	Observed values
Moisture content	7.100^{a}	7.0 ± 0.12^{a}
Acidity	1.619^{a}	1.59 ± 0.25^{a}
Total Polyphenolic content	140.677^{a}	146.30 ± 12.14^{a}
Bulk density	0.522^{a}	0.49 ± 0.24^{b}
Tapped density	0.744^{a}	0.77 ± 0.04^{a}
Water absorption index	1.705^{a}	1.70 ± 0.17^{a}
Swelling capacity	15.292^{b}	16.00 ± 0.47^{a}
Color and appearance	7.455^{b}	8.0 ± 0.22^{a}
Body and texture	8.555^{a}	8.0 ± 0.21^{b}
Flavor and sweetness	8.700^{a}	7.5 ± 0.03^{b}
Mouthfeel	8.492^{a}	8.0 ± 0.27^{b}
Overall acceptability	8.706^{a}	8.5 ± 0.31^{b}

Note: The obtained results from various experiments are represented in mean and standard deviation values ($n = 3$) with displayed significant (>0.05) p-values taken into consideration. The values represented with different superscripts are significantly different.

3.5. Optimum levels of variables for corn silk-based instant mix

As observed in (ESI Fig. 4), the optimum level of variables for the most desirable product includes 14.66% corn silk, 10% sugar, and 0.22% xanthan gum in a base of skimmed milk powder (made up to 100%). The desirability observed for the said formulation was observed to be high at the rate of 0.925. The observed predicted responses along with the observed values are shown in (Table 2). It was evident from (Table 2), that the observed and predicted value holds no significant difference ($p > 0.05$), except sensory acceptability.

3.6. Effect of storage on corn silk-based instant mix

The selected corn silk-based instant mix formulation of the various parameters such as moisture content, overall acceptance, and microbial count (total plate count, yeast, and mould count) was assessed every 30 days as shown in (Table 3). The instant mix's moisture content plays a big role in deciding how stable the product will be over the course of storage. As indicated in (Table 3), the moisture content did not significantly change over the storage time, fluctuating from 7.06 ± 0.0.53% initially to 8.68 ± 0.22% in LDPE pouches at 37 °C, 8.87 ± 0.31% in LDPE pouches at 25 °C, and 8.33 ± 0.39% in LDPE pouches at 10 °C. In comparison to the other two packing materials, the low-level moisture content of all the chosen packaging materials rose in MP packaging under various storage circumstances. A rise in moisture content during storage may result from the diffusion of vapors through microscopic pores in packaging materials to absorb moisture from the environment (Sharma et al., 2011).

The instant mix samples are packed into different types of packaging materials and different storage conditions, the results obtained for microbial total plate count are shown in (Table 3). The packaging materials LDPE, HDPE, and MP at 37 °C storage conditions were 26.31–42.14 × 10^2 cfu/g observed, which were highest as compared to the other two storage conditions (10 and 25 °C) shown in (Table 3). According to Oliveira et al. (2019), if the overall microbial count of the instant mix is $<1 \times 10^4$ cfu/g, the product is microbiologically safe. The values were in the safe range henceforth, the total plate count showed even after 180 days of storage the treatments of the instant mix were microbiologically safe.

The yeast and mould count of any food products was dependent on the duration and temperature of the storage conditions used. For the formulated instant mix product the yeast and mould count was 4.95 ± 0.11 reported after 120 days of storage and also safe for consumption. Our results showed that corn silk incorporation in the RTS beverage showed a reduction in the microbial count although the values increased with storage time. The results were in line with a study on the microbiota of steeped and cured baby corn (Kaur et al., 2009) as well as research on the development of RTS using orange juice and *aloe vera* gel (Kausar et al., 2020).

The overall acceptability of the developed instant mix at various temperatures showed a reduction in the scores, however, the difference was not significant. The scores ranged from 8.50 ± 0.25 in the initial days has reduced to 8.01 ± 0.04 in the instant mix sample stored at 37 °C in MP packaging materials. Among all the packaging materials, metallised polyester has shown the highest overall acceptability. Chemical kinetics was used to forecast the shelf life of the developed instant mix because the values for overall acceptability, however, were >5. As a result, prediction values were calculated.

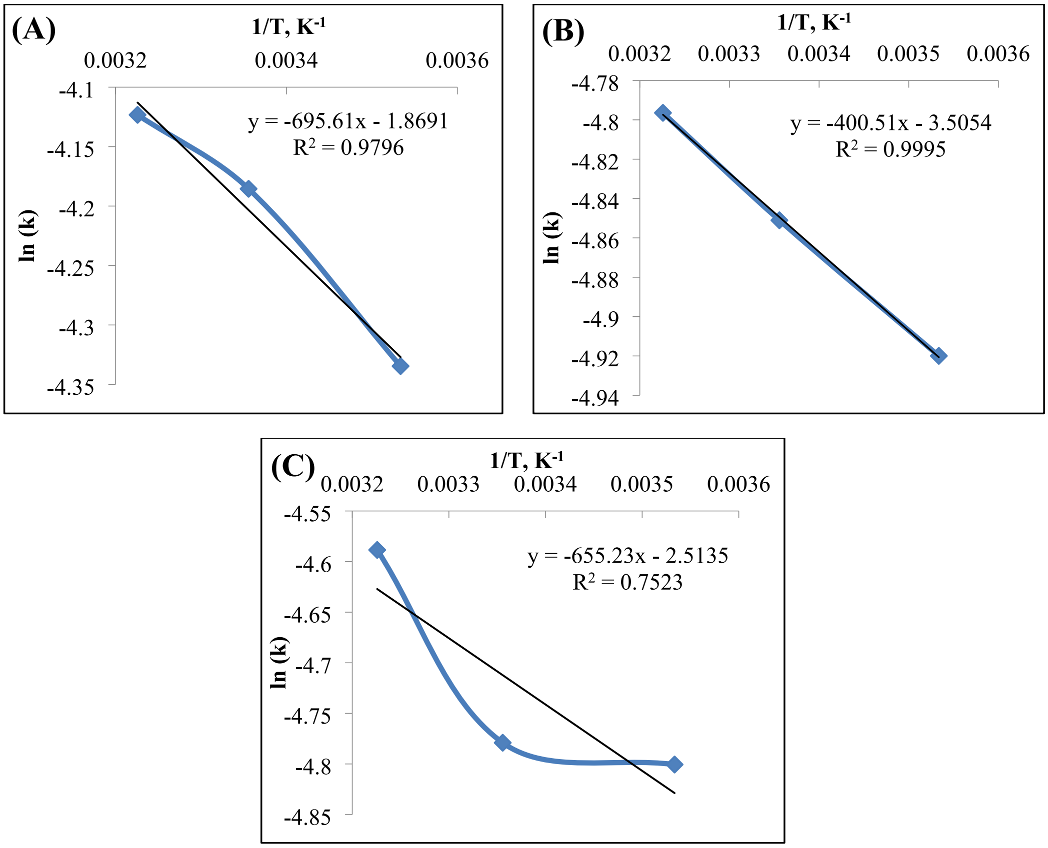

Fig. 3. A: Changes in the TBA content of the instant mix from corn silk stored at different temperatures and its Arrhenius plot, B: Changes in the HMF content of the instant mix from corn silk stored at different temperatures and its Arrhenius plot, C: Changes in the FFA content of the instant mix from corn silk stored at different temperatures, in metalized polyester and its Arrhenius plot.

3.7. Predictive modelling by chemical analysis

3.7.1. Changes in thiobarbituric acid (TBA) value of corn silk-based instant mix

The emergence of secondary oxidation products such as carbonyl compounds is monitored using thiobarbituric acid reactive substances (TBARS). During processing and storage, milk fats can undergo chemical and physical changes, such as autoxidation and the synthesis of trans fatty acids compounds, which results in the production of low molecular weight molecules (aldehydes, ketones, and lactones) and a decrease in the sensory quality of food (Semma, 2002). The increase in TBA content during the storage period in the corn silk-based instant mix due to the skimmed milk powder was used as a filler ingredient and the obtained results were shown in (Table 4). The formulated instant mix product a TBA values were increased after 120 days during storage conditions $_{10}$, 25, and 37 °C for different selected packaging materials such as LDPE, HDPE, and MP in 0.576–0.905, respectively observed as shown in (Table 4). (Fig. 3; A) displays the TBA value's Arrhenius plot. For 180 days in packing materials containing 98% N_2, the TBA values in instant pearl millet kheer mix increased from 0.067 to 0.613 at various storage temperatures (8, 25, 37, and 45 °C) (Bunkar et al., 2012). Another study found that after 12 months of storage in several packing materials, including polypropylene (PP) and metallised polyester (MP), the TBA levels in instant wheat porridge (dalia) increased from 0.05 to 0.089 mg malonaldehyde/kg (Ayub Khan et al., 2012). The storage stability of radish fiber-rich snacks in PEP pouches at different storage temperatures (room and refrigeration) for the initial day to 6 months of storage the TBA value 0.03 to 0.58 mg malonaldehyde/kg was reported (Gupta & Premavalli, 2011). In the current investigation, similar findings were made and the low-temperature storage condition of the corn silk-based instant mix was quite acceptable.

3.7.2. Changes in free fatty acid content (FFA) value of corn silk-based instant mix

Free fatty acids are a sign of the oxidative breakdown of the fats in food containing oil or fat. The fats in food items are easily hydrolyzed due to the action of lipase enzymes during storage (Jain et al., 2014). The rise in FFA levels in stored products may occur due to the breakdown of hydroperoxide since lipases are denatured during heat processing treatments (Ayub Khan et al., 2012). The FFA content of instant mix product are shown in (Table 4) during selected storage days. In the different storage conditions (10, 25, and 37 °C) for the 120 day storage period in optimized baby food formulation, the FFA content was 0.52 μeq/g, which increased by 1.45–1.95 μeq/g, respectively observed (Ayub Khan et al., 2012). In the fiber-rich snacks prepared from radish in this study, the FFA content values were reported at different storage conditions (Gupta & Premavalli, 2011). The Arrhenius plot for FFA value is shown in (Fig. 3; C).

The high value of FFA can indicate lipid oxidation, leading to rancidity, off-flavors, and reduced shelf life, negatively impacting the product's quality and consumer acceptance (Han et al., 2023). According to the Food Safety and Standards Authority of India (FSSAI), free saturated fatty acids should not exceed 0.1 g/100 g or 100 mL of food products (Food Safety and Standards (Advertising and Claims) Regulations, 2018). The FFA level value 1.45 ± 0.09 to 1.86 ± 0.19 μeq/g were found in an instant mix product stored at different packaging materials and temperature after 120 days of storage is generally considered good. This low value indicates that the product has maintained its quality well, with minimal lipid oxidation and rancidity. Typically, maintaining FFA levels below 1% is desirable to ensure the sensory and nutritional quality of the product. Thus, an FFA value suggests the product remains fresh and suitable for consumption.

Table 3
Shelf life study of corn silk-based instant mix at various temperatures during storage conditions.

Storage days	Temperature of storage	Packaging material	Moisture (%, fw)	Total plate count (CFU×10^2/g)	Yeast and mould count (CFU×10^2/g)	Overall acceptability
0th day	10	LDPE	7.06 ± 0.053^{dB}	0.27 ± 0.01^{eC}	0.05 ± 0.00^{eC}	8.50 ± 0.25^{aA}
		HDPE	7.06 ± 0.053^{dB}	0.27 ± 0.01^{eC}	0.05 ± 0.00^{eC}	8.50 ± 0.25^{aA}
		MP	7.06 ± 0.053^{dB}	0.27 ± 0.01^{eC}	0.05 ± 0.00^{eC}	8.50 ± 0.25^{aA}
	25	LDPE	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eB}	0.05 ± 0.00^{eB}	8.50 ± 0.25^{aA}
		HDPE	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eB}	0.05 ± 0.00^{eB}	8.50 ± 0.25^{aA}
		MP	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eB}	0.05 ± 0.00^{eB}	8.50 ± 0.25^{aA}
	37	LDPE	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eA}	0.05 ± 0.00^{eA}	8.50 ± 0.25^{aB}
		HDPE	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eA}	0.05 ± 0.00^{eA}	8.50 ± 0.25^{aB}
		MP	7.06 ± 0.053^{dA}	0.27 ± 0.01^{eA}	0.05 ± 0.00^{eA}	8.50 ± 0.25^{aB}
30th day	10	LDPE	7.53 ± 0.13^{cB}	0.26 ± 0.03^{dC}	0.05 ± 0.00^{cC}	8.59 ± 0.16^{bA}
		HDPE	7.47 ± 0.18^{cB}	0.22 ± 0.04^{dC}	0.05 ± 0.00^{cC}	8.48 ± 0.17^{bA}
		MP	7.44 ± 0.13^{cB}	0.31 ± 0.06^{dC}	0.06 ± 0.00^{cC}	8.65 ± 0.11^{bA}
	25	LDPE	7.68 ± 0.53^{cA}	2.38 ± 0.04^{dB}	0.15 ± 0.01^{cB}	8.42 ± 0.35^{bA}
		HDPE	7.62 ± 0.78^{cA}	2.42 ± 0.01^{dB}	0.14 ± 0.02^{cB}	8.57 ± 0.25^{bA}
		MP	7.55 ± 0.43^{cA}	2.47 ± 0.08^{dB}	0.14 ± 0.01^{cB}	8.53 ± 0.31^{bA}
	37	LDPE	7.63 ± 0.43^{cA}	7.63 ± 0.44^{dA}	7.63 ± 0.45^{cA}	7.63 ± 0.46^{bB}
		HDPE	7.87 ± 0.13^{cA}	7.83 ± 0.19^{dA}	7.83 ± 0.20^{cA}	7.87 ± 0.16^{bB}
		MP	7.50 ± 0.33^{cA}	7.50 ± 0.34^{dA}	7.5 ± 0.35^{cA}	7.50 ± 0.36^{bB}
60th day	10	LDPE	7.76 ± 0.02^{bB}	0.34 ± 0.12^{cC}	0.05 ± 0.04^{dC}	8.46 ± 0.26^{abA}
		HDPE	7.86 ± 0.12^{bB}	0.38 ± 0.05^{cC}	0.04 ± 0.01^{dC}	8.22 ± 0.35^{abA}
		MP	7.65 ± 0.14^{bB}	0.17 ± 0.10^{cC}	0.05 ± 0.02^{dC}	8.05 ± 0.42^{abA}
	25	LDPE	8.23 ± 0.13^{bA}	9.57 ± 0.30^{cB}	1.2 ± 0.08^{dB}	8.63 ± 0.24^{abA}
		HDPE	8.15 ± 0.04^{bA}	7.47 ± 0.14^{cB}	1.52 ± 0.03^{dB}	8.77 ± 0.06^{abA}
		MP	8.16 ± 0.07^{bA}	7.61 ± 0.72^{cB}	1.22 ± 0.06^{dB}	8.06 ± 0.68^{abA}
	37	LDPE	8.34 ± 0.03^{bA}	8.34 ± 0.04^{cA}	8.34 ± 0.05^{dA}	8.37 ± 0.03^{abA}
		HDPE	8.23 ± 0.17^{bA}	8.67 ± 0.90^{cA}	1.26 ± 0.11^{dA}	7.92 ± 0.42^{abA}
		MP	8.11 ± 0.10^{bA}	8.11 ± 0.11^{cA}	8.11 ± 0.12^{dA}	8.11 ± 0.13^{abA}
90th day	10	LDPE	8.16 ± 0.14^{aB}	0.63 ± 0.08^{bC}	0.08 ± 0.02^{aC}	8.52 ± 0.15^{bcB}
		HDPE	8.07 ± 0.09^{aB}	0.44 ± 0.10^{bC}	0.08 ± 0.02^{aC}	7.42 ± 0.51^{bcB}
		MP	7.97 ± 0.34^{aB}	0.37 ± 0.06^{bC}	0.08 ± 0.03^{aC}	7.76 ± 0.50^{bcB}
	25	LDPE	8.62 ± 0.22^{aA}	10.07 ± 0.04^{bB}	2.42 ± 0.17^{aB}	8.71 ± 0.05^{bcB}
		HDPE	8.27 ± 0.37^{aA}	10.27 ± 0.07^{bB}	2.56 ± 0.12^{aB}	8.07 ± 0.35^{bcB}
		MP	8.25 ± 0.03^{aA}	10.33 ± 0.41^{bB}	2.66 ± 0.11^{aB}	8.08 ± 0.25^{bcB}
	37	LDPE	8.76 ± 0.10^{aA}	8.76 ± 0.11^{bA}	8.76 ± 0.12^{aA}	8.76 ± 0.13^{bcB}
		HDPE	8.52 ± 0.16^{aA}	21.31 ± 0.02^{bA}	2.48 ± 0.32^{aA}	7.57 ± 0.05^{bcB}
		MP	8.27 ± 0.21^{aA}	8.27 ± 0.22^{bA}	8.27 ± 0.23^{aA}	8.27 ± 0.24^{bcB}
120th day	10	LDPE	8.33 ± 0.39^{aB}	0.67 ± 0.24^{aC}	0.10 ± 0.01^{bC}	8.23 ± 0.27^{cA}
		HDPE	8.45 ± 0.41^{aB}	0.91 ± 0.10^{aC}	0.12 ± 0.07^{bC}	8.27 ± 0.15^{cA}
		MP	8.15 ± 0.11^{aB}	0.55 ± 0.22^{aC}	0.08 ± 0.01^{bC}	8.39 ± 0.12^{cA}
	25	LDPE	8.87 ± 0.31^{aA}	17.41 ± 3.17^{aB}	4.77 ± 0.12^{bB}	7.27 ± 0.22^{cB}
		HDPE	8.61 ± 0.17^{aA}	24.17 ± 2.05^{aB}	3.72 ± 0.12^{bB}	7.66 ± 0.35^{cB}
		MP	8.26 ± 0.12^{aA}	22.38 ± 3.0^{0aB}	4.21 ± 0.11bB	8.17 ± 0.37^{cB}
	37	LDPE	8.68 ± 0.22^{aA}	25.31 ± 4.08^{aA}	4.09 ± 0.12^{bA}	8.04 ± 0.10^{cB}
		HDPE	8.84 ± 0.10^{aA}	42.14 ± 6.20^{aA}	3.95 ± 0.09^{bA}	7.77 ± 0.24^{cB}
		MP	8.30 ± 0.01^{aA}	26.31 ± 2.30^{aA}	4.95 ± 0.11^{bA}	8.01 ± 0.04^{cB}

Note: Variations between the selected packaging materials and different storage conditions used for various parameters were tested using Analyses of Variance (ANOVA) and Duncan's multiple tests. The obtained results from various experiments are represented in mean and standard deviation values with displayed significant (>0.05) p-values taken into consideration. The various groups were shown with different letters in the same column.

3.7.3. *Changes in HMF content value of corn silk-based instant mix*

The persistence of Maillard reactions leads to the production of HMF content in foods which rises with temperature and storage duration (Jha et al., 2012). For the 120 day storage periods, the HMF concentration values in the optimized instant mix sample were 5.2 mol/g at three storage temperatures (10, 25, and 37 °C), which increased by 12.88, 12.49, and 14.67 mol/g, respectively shown in (Table 4). It may be proven that when the storage temperature rises, HMF generation rises as well. For 180 days in packing materials containing 98% N_2, it was discovered that the HMF concentration in instant pearl millet kheer mix increased from 4.87 to 21.43 mol/g at various storage temperatures (8, 25, 37, and 45 °C) (Bunkar et al., 2012). Jha et al. (2012) found that after 24 weeks of storage, the HMF concentration increased from 5.0 to 21.74 mol/L at 30 °C, showing that both the total and free HMF levels in

Table 4
TBA, FFA and HMF values of corn silk-based instant mix at various temperatures during storage conditions.

Days of storage	Temperature (°C)	Packaging material	TBA	FFA (μeq/g)	HMF (μmol/g)
0th day	10	LDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eC}	5.2 ± 0.00^{eC}
		HDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eC}	5.2 ± 0.00^{eC}
		MP	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eC}	5.2 ± 0.00^{eC}
	25	LDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eB}	5.2 ± 0.00^{eB}
		HDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eB}	5.2 ± 0.00^{eB}
		MP	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eB}	5.2 ± 0.00^{eB}
	37	LDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eA}	5.2 ± 0.00^{eA}
		HDPE	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eA}	5.2 ± 0.00^{eA}
		MP	0.108 ± 0.00^{cA}	0.52 ± 0.00^{eA}	5.2 ± 0.00^{eA}
30th day	10	LDPE	0.167 ± 0.08^{cA}	0.66 ± 0.04^{dC}	5.40 ± 0.14^{dC}
		HDPE	0.178 ± 0.05^{cA}	0.70 ± 0.05^{dC}	5.90 ± 0.21^{dC}
		MP	0.153 ± 0.10^{cA}	0.60 ± 0.04^{dC}	5.32 ± 0.23^{dC}
	25	LDPE	0.175 ± 0.13^{cA}	0.73 ± 0.06^{dB}	5.82 ± 0.23^{dB}
		HDPE	0.189 ± 0.14^{cA}	0.75 ± 0.07^{dB}	5.90 ± 0.15^{dB}
		MP	0.162 ± 0.16^{CA}	0.69 ± 0.05^{dB}	5.93 ± 0.42^{dB}
	37	LDPE	0.185 ± 0.14^{cA}	0.82 ± 0.01^{dA}	6.25 ± 0.16^{dA}
		HDPE	0.196 ± 0.10^{cA}	0.80 ± 0.10^{dA}	6.34 ± 0.03^{dA}
		MP	0.177 ± 0.14^{cA}	0.74 ± 0.12^{dA}	5.89 ± 0.12^{dA}
60th day	10	LDPE	0.217 ± 0.07^{cbA}	0.71 ± 0.08^{cC}	6.39 ± 0.17^{cC}
		HDPE	0.243 ± 0.19^{cbA}	0.78 ± 0.04^{cC}	6.83 ± 0.10^{cC}
		MP	0.203 ± 0.03^{cbA}	0.79 ± 0.02^{cC}	6.92 ± 0.24^{cC}
	25	LDPE	0.229 ± 0.10^{cbA}	0.79 ± 0.14^{cB}	6.12 ± 0.12^{cB}
		HDPE	0.267 ± 0.06^{cbA}	0.80 ± 0.09^{cB}	6.52 ± 0.32^{cB}
		MP	0.214 ± 0.13^{cbA}	0.81 ± 0.23^{cB}	7.49 ± 0.29^{cB}
	37	LDPE	0.256 ± 0.22^{cbA}	0.90 ± 0.04^{cA}	7.26 ± 0.27^{cA}
		HDPE	0.298 ± 0.17^{cbA}	0.89 ± 0.11^{cA}	7.98 ± 0.23^{cA}
		MP	0.202 ± 0.15^{cbA}	0.85 ± 0.14^{cA}	7.12 ± 0.24^{cA}
90th day	10	LDPE	0.301 ± 0.25^{bA}	1.28 ± 0.17^{bC}	8.92 ± 0.06^{bC}
		HDPE	0.356 ± 0.18^{bA}	1.20 ± 0.20^{bC}	9.56 ± 0.32^{bC}
		MP	0.278 ± 0.16^{bA}	0.91 ± 0.20^{bC}	8.83 ± 0.11^{bC}
	25	LDPE	0.398 ± 0.14^{bA}	1.85 ± 0.29^{bB}	9.21 ± 0.06^{bB}
		HDPE	0.413 ± 0.24^{bA}	1.48 ± 0.23^{bB}	9.82 ± 0.16^{bB}
		MP	0.365 ± 0.35^{bA}	0.93 ± 0.32^{bB}	9.00 ± 0.12^{bB}
	37	LDPE	0.456 ± 0.40^{bA}	1.56 ± 0.10^{bA}	10.78 ± 0.06^{bA}
		HDPE	0.498 ± 0.46^{bA}	1.80 ± 0.12^{bA}	11.23 ± 0.23^{bA}
		MP	0.412 ± 0.14^{bA}	1.02 ± 0.09^{bA}	9.84 ± 0.16^{bA}
120th day	10	LDPE	0.636 ± 0.35^{aA}	1.49 ± 0.06^{aC}	12.35 ± 0.46^{aC}
		HDPE	0.656 ± 0.26^{aA}	1.50 ± 0.01^{aC}	12.88 ± 0.22^{aC}
		MP	0.576 ± 0.24^{aA}	1.45 ± 0.09^{aC}	12.13 ± 0.21^{aC}
	25	LDPE	0.725 ± 0.42^{aA}	1.59 ± 0.04^{aB}	12.49 ± 0.41^{aB}
		HDPE	0.797 ± 0.39^{aA}	1.95 ± 0.03^{aB}	13.23 ± 0.12^{aB}
		MP	0.705 ± 0.21^{aA}	1.58 ± 0.12^{aB}	12.25 ± 0.63^{aB}
	37	LDPE	0.805 ± 0.32^{aA}	1.85 ± 0.07^{aA}	14.29 ± 0.29^{aA}
		HDPE	0.905 ± 0.13^{aA}	1.86 ± 0.19^{aA}	14.67 ± 0.33^{aA}
		MP	0.803 ± 0.71^{aA}	1.68 ± 0.11^{aA}	13.78 ± 0.14^{aA}

Note: Variations between the selected packaging materials and different storage conditions used for various parameters were tested using Analyses of Variance (ANOVA) and Duncan's multiple tests. The obtained results from various experiments are represented in mean and standard deviation values with displayed significant (>0.05) p-values taken into consideration. The various groups were shown with different letters in the same column.

instant kheer mix increased with storage duration. At 37 and 45 °C, respectively, during 16 and 8 weeks of storage, the total HMF content increases from 30.4 to 56.3 mol/L. The instant kodo millet-based porridge mix was stored under different temperatures (8, 25, and 37 °C) for 28 day storage period, and HMF content was reported 0.009–0.029 μmol/100 g, respectively (Bunkar et al., 2012). The effect of HMF content on instant kudo millet-based porridge mix was studied by Bunkar et al. (2020) where they reported that HMF content increases with increased temperature and the lowest content was observed at 8 °C (0.013 μmol/100 g). Non-enzymatic browning processes like Maillard reactions usually happen more slowly in dry environments and at lower temperatures, but they become more common at 35 °C (Chavhan et al., 2023).

Based on the shelf life study, in comparison to LDPE, HDPE, and MP pouches have shown less degradation in terms of TBA, FFA, and HMF values. Therefore, the values of the instant mix stored in metallised polyester have been selected for chemical kinetics and prediction of shelf life.

A first-order reaction ($n = 1$) kinetics model best captured the kinetics of HMF content formation in the basundi mix and fermented infant food pre-mix produced with nutricereals (Rasane et al., 2014; Ruhil et al., 2010). Similar sped-up reaction kinetics for HMF are revealed in the current study. The Arrhenius plot (In versus k) (Fig. 3; B) showed a straight line. The reaction's apparent activation energy (Ea) is 3.48 10^6 M/week, and the Arrhenius constant (A_0) is 11.25 kJ/mol as shown in (ESI Table 3). The instant mix stored at 10 to 37 °C the enthalpy of activation (H), entropy of activation (S), and the free energy of activation (G) for HMF content were 8.90 to 8.68 kJ/mol, −266.56034 to −261.66444 J/mol °K, and 75.44 to 82.55 kJ/mol observed.

The optimized corn silk-based formulation's change in TBA values was discovered to follow first-order reaction kinetics. TBA has a single straight line in the Arrhenius plot (ln versus k). (ESI Table 3) revealed that the Ea and A_0, and for TBA formation were 19.51 kJ/mol and 2.32

$\times 10^8$ weeks respectively. For 10 to 37 °C, the activation enthalpy (H) ranged from 17.16 to 16.94 kJ/mol, the activation entropy (S) from −261.66444 to −260.67131 J/mol °K, and the activation free energy (G) from 74.06 to 80.82 kJ/mol (ESI Table 3).

The kinetics of free fatty acids content generation in corn silk-based instant mix were used for the first-order reaction kinetics. FFA was represented by a single straight line in the Arrhenius plot in (Fig. 3; C). The plot yielded Ea and A_0 values for FFA of 18.54 kJ/mol and 2.70 $\times 10^8$ M/week respectively. The storage temperature condition (10 to 37 °C), the enthalpy of activation (H), the entropy of activation (S), and the free energy of activation (G) changed from 16.20 to 15.97 kJ/mol, −261.66444 to 260.67131 J/mol °K, and 75.16 to 82.21 kJ/mol were observed in (ESI Table 3) represented these values. In (ESI Table 4), shows the half-life of the instant mix to be 94.95 days at 10 °C stored in MP packaging material.

4. Conclusion

The corn silk-based instant mix constituted of corn silk powder along with skimmed milk powder, sugar, and xanthan gum showed that the optimum acceptable concentration of powdered corn silk in the product was 14.67%. The product showed a desirability of 0.925 and was acceptable on physico-chemical and sensory parameters. The instant mix selected product was packaged in MP pouches and storage condition at 10 °C temperature, the results obtained were noticeably better than when it was packaged in LDPE and HDPE packaging materials. The results of the chemical reaction kinetics used to estimate the product's half-life and among HMF, FFA, and TBA, HMF is a superior predictor of the shelf life of the instant mix with a predicted half-life of 94.95 days of corn silk-based instant mix. This product has a vast potential to commercialize. Corn silk, being an unutilized by-product of agriculture processing sector and the prepared product can also help to earn the extra income to the processors.

Declarations

Ethical approval

Not applicable.

Competing interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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Availability of Data and Materials.

Data will be made available on request.

CRediT authorship contribution statement

Jyoti Singh: Writing – original draft. **Sawinder Kaur:** Visualization, Supervision. **Sanju Bala Dhull:** Visualization, Supervision. **Mahendra Gunjal:** Visualization, Resources, Investigation. **Vikas Kumar:** Supervision. **Amine Assouguem:** Supervision. **Riaz Ullah:** Supervision, Investigation, Funding acquisition. **Zafar Iqbal:** Resources, Supervision. **Ahmed Bari:** Supervision, Methodology. **Sezai Ercisli:** Visualization, Supervision. **Prasad Rasane:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2024.101554.

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