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ENHANCED SHELF LIFE AND NUTRITIONAL PROFILE OF KIWI (*Actinidia deliciosa*) THROUGH OSMO-CONVECTIVE DRYING

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ABSTRACT

This study explores the osmo-convective drying of *Actinidia deliciosa* (kiwi) using honey and salt-sugar solutions. Osmo-convective dehydration has been identified as a highly efficient method of preservation that significantly enhances the quality of the end product, at the same time minimizing energy consumption. In this comprehensive research, *Actinidia deliciosa*, or simply kiwi fruit, was treated with osmotic dehydration, which made use of honey besides a binary solution of salt and sugar, and subsequently, the treatment was preceded by a convective drying treatment. The different process parameters, such as water loss, solid gain, and total mass loss, were examined systematically and scientifically. The comparative study conducted between fresh kiwi fruit and osmo-dried samples revealed that the treated fruits exhibited superior nutritional value, more vibrant color, and improved texture, making them highly suitable as healthy snack options. Among the different treatments evaluated, the honey-based osmosis process produced the highest quality end product, outperforming the other methods. A six-month shelf life was ensured by the optimized honey-based osmo-convective drying process, which produced a 9.6% solid gain, 26.3% water loss, and 90% enhanced vitamin C retention. This energy-efficient method encourages kiwi fruit processing that is sustainable.

Keywords: Fruit dehydration, Honey Treatment, Nutritional Quality, SDG 12, Sustainable Food Processing, Drying Methods.

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INTRODUCTION

From 2008 to 2019, total fruit production increased from 60 to 98 million metric tons, approximately, which includes the primary fruits such as bananas, mangoes, apples, and papayas. The nation has a sizable export market and is a top producer of affordable fruits and vegetables. Fresh mangoes, Mango pulp, fresh grapes, and dried walnuts are important exports.[1, 2] Fruits and vegetables are dehydrated to minimize packaging requirements, increase storage stability, and decrease transportation costs. Fruits such as mangoes, guavas, and bananas can be easily dried, but they must be harvested at the appropriate stage of ripeness. About 80% of fruits and vegetables are moist, making them unsuitable for prolonged storage under normal circumstances. This results in product loss and inadequate cold storage facilities. Hence, to extend the lifespan and also make it available in the off seasons, the fruits and vegetables are dried. With an 83% moisture content, kiwis are susceptible to spoiling quickly after harvest. Drying increases shelf life; however, traditional techniques frequently result in quality degradation. Research on natural osmotic agents, such as honey, for kiwi drying in India is scarce. By addressing food preservation through low-resource, sustainable processing, our approach advances SDG 12. Technologies such as freeze drying, spray drying, vacuum drying, steam drying, hot air drying, and heat pump drying offer significant potential for producing dried goods and powders. Because of the treatment process, the moisture level, weight, and volume of the products are reduced.[3] However, drying also lowers the nutritional value of the product, causing changes in colour and appearance that are not desirable. Conventional drying is associated with some inherent challenges, such as long duration, higher energy consumption, high operating cost, and low-quality products. To overcome these issues, osmotic dehydration can be associated with conventional drying. Osmotic dehydration is a process that uses a hypertonic (osmotic) solution to partially remove water.[4]This method increases the product's shelf life and yields a higher

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quality result than a typical drying process. Mild heat treatment improves the product's organoleptic qualities by promoting color and flavor retention after osmotic dehydration.[5] *Actinidia deliciosa*, or edible kiwifruit, is found in many woody wine species. It is oval and is roughly 5 to 8 cm in length and a diameter of 4.5 to 5.5 cm. It has thin, hair-like, fibrous, sour, but edible, and is golden or light green meat with tiny edible black seeds in a series. Kiwi fruit offers a sweet flavor and soft texture. It contains 83% water and 15% carbohydrates, with minimal protein and fat.It does not have a noticeable amount of other micronutrients and is especially high in vitamins C, K, and E. Kiwifruit pulp contains carotenoids, such as beta-carotene, lutein, and zeaxanthin.

EXPERIMENTAL

Raw material

Fresh kiwis were collected from the local market of Chennai. Shape, consistent size, and ripeness were the criteria used to choose the fruit. To get rid of the unwanted material that was still on the surface, they were cleaned with deionized water. The samples were sliced into bits after being carefully pulled off. Before being subjected to experimental investigation, the raw materials were stored in a refrigerator.

Preparation of Osmotic Solution

The osmotic agent used in this present study is honey. The essential amount of honey (35%, 45%, 55% w/w) is dissolved in the required amount of distilled water. Stirring was performed in an agitated vessel for the complete dissolution of the osmotic agent.

Osmo-Convective Drying

In a water bath, a known sample weight was soaked in varying osmotic agent concentrations and incubated at different temperatures. To stop osmotic solution evaporation loss during the experiments, the flasks were covered. The investigations were performed at different concentrations of osmotic solution, feed-to-solution ratio, osmotic time, and temperatures. Samples were collected at regular intervals, wiped with filter paper, and weighed. Each condition was tested three times, and the mean values were used to determine dehydration properties such as solid gain, mass reduction, and water loss over time.

Determination of Osmotic Dehydration Properties

The material was kept in a water bath at various temperatures after being immersed in flasks containing varied osmotic agent concentrations. To stop osmotic solution evaporation loss during the experiments, the flasks were covered.[6]

$$WL\,\% = \frac{(M_0 - m_0) - (M - m)}{M_0} \quad (1)$$

$$SG\% = \frac{(m - m_0)}{M_0} \quad (2)$$

$$WR\% = WL - SG \quad (3)$$

Where M_o represents the fresh fruit's initial mass before the osmotic treatment (g). Following time "t" of osmotic treatment, M represents the mass of kiwi (g), m represents the dry mass of kiwi (g), and m_o represents the dry mass of fresh fruit or vegetable (g).

RESULTS AND DISCUSSION

Moisture Content Analysis

125g of the sample was peeled and cut into thin slices. After that, they were subjected to drying at 50°C in a hot air oven until their weight remained constant. It took 7 hours to reach constant weight.[7]The ultimate moisture content of the dried kiwi was less than 20% (Fig.-1). The dried product has a minimum 6-month shelf life at this moisture content.

The samples' moisture content dropped as the drying temperature increased. The reduction in moisture loss was fast at the initial stage and then decreased slowly. This is due to the presence of bound and unbound moisture in the samples.

Based on the above characteristic curve, the kinetic equation for drying of kiwi is given by:

$$y = k\,e^{-t} \quad (4)$$

Rewriting the above equation,

$$\frac{M}{M_0} = 68.11\, e^{-0.16t} \quad (5)$$

M is the dry basis moisture at time "t," t is the drying period, y is the moisture ratio, and Mo is the starting dry basis moisture. Higher temperatures were shown to cause a greater rate of moisture loss, which significantly shortened the drying time.

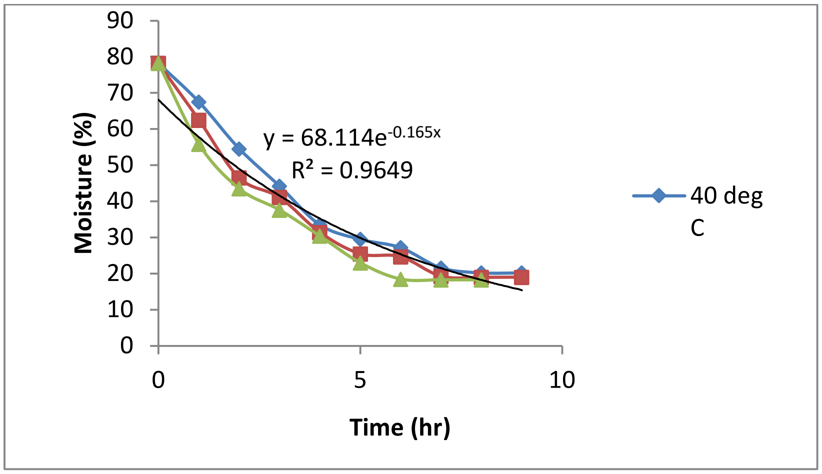

Fig.-1: Variation of Moisture Content During Osmo-Convective Drying of *Actinidia deliciosa* Samples

Optimization of Process Parameters

The regression equation (Table-1) includes four linear terms (A, B, C, D), four square terms (A^2, B^2, C^2, D^2), six interaction terms (AB, AC, AD, BC, BD, CD), and one block term. ANOVA was used to assess the empirical mathematical model at a significance level of 5%. The statistical significance of the second-order model equation was assessed regarding the F-value (Table-3). Typically, the calculated F-value must exceed the tabulated F-value to reject the null hypothesis, indicating that not all regression coefficients are zero.[8] Osmotic dehydration was analyzed using a Box-Behnken Design with four factors: solution concentration, drying temperature, solution temperature, and time.[9] Table-1 shows parameter codes, and Table 2 presents the experimental design and results.

Table-1: Coded Value of Physical Parameters

Code	Parameter	Unit	Low Range	High Range
A	Osmotic solution temperature	(°C)	35	55
B	Osmotic solution concentration	(w/w%)	50	60
C	Immersion time	(min)	110	130
D	Drying temperature	(°C)	40	60

Table-2: Design Table

Run	A	B	C	D	Water loss		Solid gain		Mass reduction	
					Actual	Predicted	Actual	Predicted	Actual	Predicted
1	35	50	130	40	19.1	18.221	5.2	5.113	12.5	12.406
2	55	55	120	50	12.9	13.092	3.6	3.696	9.1	9.263
3	55	50	130	60	19.1	19.271	4.2	4.696	11.5	11.556
4	35	50	130	60	19.5	20.138	4.6	4.408	10.2	10.256
5	45	55	100	50	22.6	21.808	3.6	3.863	9.4	9.4461
6	35	50	110	60	18.2	17.438	4.6	4.563	10.1	10.240
7	45	55	120	50	26.1	25.867	9.5	9.433	15.2	15.317
8	45	55	140	50	23.2	23.409	5.8	5.679	13.4	13.379
9	45	55	120	30	18.5	17.742	3.8	3.863	9.8	9.9625
10	35	60	130	60	17.5	17.738	4.2	4.312	10.5	10.747
11	45	55	120	50	26.2	25.867	9.3	9.433	15.4	15.317
12	45	65	120	50	21.1	21.258	4.5	4.462	10.2	10.329
13	45	55	120	70	18.3	18.475	4.8	4.879	12.1	11.963

14	25	55	120	50	11.8	11.025	4.2	4.245	10.6	10.463
15	45	55	120	50	26.3	25.866	9.2	9.433	15.5	15.317
16	55	60	130	40	19.4	19.655	4.8	4.979	11.3	11.198
17	45	55	120	50	24.6	25.867	9.4	9.433	15.3	15.316
18	35	60	110	60	17.8	18.288	3.5	3.492	8.7	8.5316
19	35	50	110	40	11.3	13.821	3.5	3.592	9.2	9.340
20	35	60	130	40	18.4	18.971	6.1	6.342	15.1	15.048
21	45	55	120	50	26.1	25.867	9.6	9.433	15.3	15.317
22	55	60	130	60	18.2	16.771	5.4	5.025	12.5	12.298
23	55	50	110	60	18.3	18.821	5.9	5.375	12.9	12.890
24	45	55	120	50	25.9	25.867	9.6	9.433	15.2	15.317
25	55	60	110	40	20.3	20.755	3.1	3.008	7.4	7.2821
26	55	50	130	40	18.4	19.005	3.6	3.325	8.2	8.306
27	45	45	120	50	20.5	19.758	3.7	3.879	9.25	9.145
28	55	50	110	40	17.6	16.855	2.3	2.329	6.8	6.590
29	35	60	110	40	18.5	17.821	4.2	3.846	9.8	9.782
30	55	60	110	60	19.2	19.571	4.5	4.729	11.3	11.431

Table-3: Analysis of Variance (ANOVA) Results for Water Loss

Source	Sum of Squares	Df	Mean Square	F Value	p-value Prob> F	
Model	443.7722	14	31.69801	27.37175	< 0.0001	significant
A	6.406667	1	6.406667	5.532262	0.0327	
B	3.375	1	3.375	2.914368	0.1084	
C	3.84	1	3.84	3.315903	0.0886	
D	0.806667	1	0.806667	0.69657	0.4170	
AB	0.01	1	0.01	0.008635	0.9272	
AC	5.0625	1	5.0625	4.371552	0.0540	
AD	2.7225	1	2.7225	2.350923	0.1460	
BC	10.5625	1	10.5625	9.120892	0.0086	
BD	9.9225	1	9.9225	8.568242	0.0104	
CD	2.89	1	2.89	2.495562	0.1350	
A^2	326.863	1	326.863	282.2516	< 0.0001	
B^2	49.22012	1	49.22012	42.50238	< 0.0001	
C^2	18.20012	1	18.20012	15.7161	0.0012	
D^2	103.1858	1	103.1858	89.10266	< 0.0001	
Residual	103.1858	1	103.1858			
Lack of Fit	17.37083	15	1.158056	3.813949	0.0763	not significant
Pure Error	15.3575	10	1.53575			
Cor Total	2.013333	5				
Std. Dev.		1.07613	R^2		0.962331	
Mean		19.83	Adj R^2		0.927173	
C.V. %		5.426777	Pred R^2		0.801887	
PRESS		91.3584	Adeq Precision		19.50442	

Impact of Process Parameters on Water Loss

The contour graphs in Fig.-2 demonstrate the gradual impact of process variables on water loss, and it is shown that the independent process variables significantly influenced the dependent variables. The plot revealed that the amount of water lost increased as the ratio of solution to process temperature, solute concentration, and osmosis dehydration time increased. Enough water loss was observed for 55% osmotic solution concentration, 45°C osmotic solution temperature, 120 minutes, and50°C drying temperature, which is relevantly matched accordingly with other literature. Water loss increased with osmotic solution concentration, peaking at 55%, indicating even slight variations enhance dehydration. It is recommended that a higher solution nature make an increment in osmotic pressure, which thereby leads to increased driving forces that are acquired for possible moisture movement.[10]

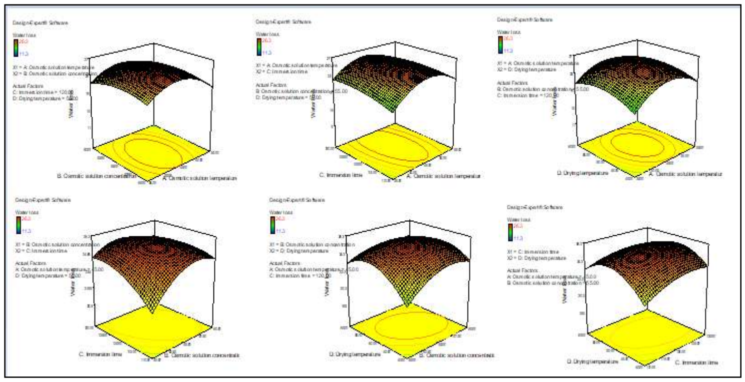

Fig.-2: Surface Plot for Water Loss

Anyhow, further increments in solute particle concentration exceeding a certain level visualized a negative response that can be proven by the shape of the curve being convex. The percentage of solids retained by the involved solutes and the osmotic solution passing through the semi-permeable barrier may be the cause of the decrease in water loss. Besides the solution concentration, the water wastage was also impacted by temperature and the duration offered to osmosis. Changes in the membrane's semi-permeable nature, which permits more water to escape more quickly, could be the cause of the increased water loss. Higher temperatures also made the fluid less viscous, which allowed convective currents to flow through the osmotic solution. This prevented local dilution events and, as a result, increased the osmotic process.

The regression equation is-

$$\text{Water loss} = 25.867 + 0.1517A + 0.375B + 0.4C + 0.183D - 0.025AB - 0.56AC - 0.4125AD - 0.8125BC - 0.7875BD - 0.425CD - 3.45A^2 - 1.34B^2 - 0.815C^2 - 1.939D^2$$

Table-4: ANOVA Results for Solid Gain

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	143.8995	14	10.27854	113.8545	< 0.0001	significant
A	0.45375	1	0.45375	5.026154	0.0405	
B	0.510417	1	0.510417	5.653846	0.0311	
C	4.950417	1	4.950417	54.83538	< 0.0001	
D	1.550417	1	1.550417	17.17385	0.0009	
AB	0.180625	1	0.180625	2.000769	0.1776	
AC	0.275625	1	0.275625	3.053077	0.1010	
AD	4.305625	1	4.305625	47.69308	< 0.0001	
BC	0.950625	1	0.950625	10.53	0.0054	
BD	1.755625	1	1.755625	19.44692	0.0005	
CD	2.805625	1	2.805625	31.07769	< 0.0001	
A^2	51.15241	1	51.15241	566.6113	< 0.0001	
B^2	47.47527	1	47.47527	525.8799	< 0.0001	
C^2	37.2667	1	37.2667	412.8003	< 0.0001	
D^2	43.93527	1	43.93527	486.6676	< 0.0001	
Residual	1.354167	15	0.090278			
Lack of Fit	1.220833	10	0.122083	4.578125	0.0535	
Pure Error	0.133333	5	0.026667			not significant
Cor Total	145.2537	29				
Std. Dev.		0.300463	R^2		0.990677	
Mean		5.343333	Adj R^2		0.981976	
C.V. %		5.62313	Pred R^2		0.950266	
PRESS		7.224	Adeq Precision		33.4378	

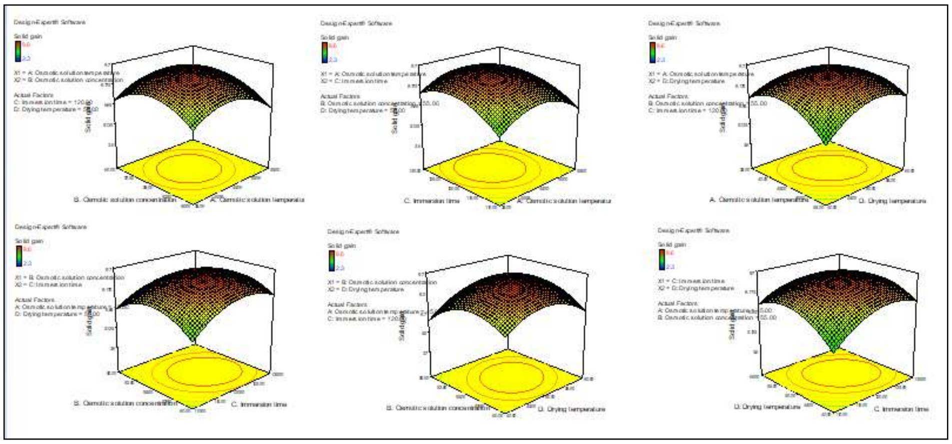

Fig.-3: Surface Plot for Solid Gain

Impact of Process Parameters on Solid Gain

The stable solid gain is displayed in Fig.-3 under different process settings when treated with the osmotic solution. At 5.5% osmotic solution concentration, 45° osmotic solution temperature, and 120 minutes at 60° drying, the highest percentage of solid gain was achieved. This attributed a positive approach between operating parameters and resulted responses. The nature of the graphical plot underwent an equilibrium condition and further dramatized a declining trend.[11]The solid gain probably increased as a function of the osmotic process length, osmotic solution temperature, and sample-to-solution ratio. This event may be owing to cell membrane collapse at increased temperature levels along with solute transfer with a notable increment in solution volume, which could be confirmed through various research findings. Perhaps, solid gain was also impacted by a slight increase in temperature or else increase in solution volume. This affirmed that the gain of solids can be improved by enhancing the solution temperature, or else concentration, or even to solution-to-sample ratio. Such an increment in the range of operating parameters up to the equilibrium region portrayed a negative phenomenon since the solution viscosity would have reduced at elevated temperature levels.[12]It is also overwhelmed by prolonged osmotic duration between the cellular structure agglomerated in the vegetable and that of the solution till the region of equilibrium has occupied the entire pores present in the tissues, and the absence of open pores that would allow the remaining solutes to fully enter.

The regression equation is

$$\text{Solid gain} = 9.4333 - 0.1375A + 0.146B + 0.454C + 0.254167D + 0.106AB - 0.13125AC + 0.51875AD + 0.24375BC - 0.33125BD - 0.41875CD - 1.365A^2 - 1.315B^2 - 1.165C^2 - 1.265D^2$$

Table-5: ANOVA for Mass Reduction

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob> F	
Model	198.996	14	14.214	449.4546	< 0.0001	significant
A	2.16	1	2.16	68.3004	< 0.0001	
B	2.100417	1	2.100417	66.41634	< 0.0001	
C	23.20667	1	23.20667	733.8076	< 0.0001	
D	6	1	6	189.7233	< 0.0001	
AB	0.0625	1	0.0625	1.976285	0.1802	
AC	1.8225	1	1.8225	57.62846	< 0.0001	
AD	29.16	1	29.16	922.0553	< 0.0001	
BC	4.84	1	4.84	153.0435	< 0.0001	
BD	4.6225	1	4.6225	146.166	< 0.0001	
CD	9.3025	1	9.3025	294.1502	< 0.0001	
A^2	50.99646	1	50.99646	1612.536	< 0.0001	

B^2	53.36074	1	53.36074	1687.296	< 0.0001	
C^2	26.13003	1	26.13003	826.246	< 0.0001	
D^2	32.50074	1	32.50074	1027.692	< 0.0001	
Residual	0.474375	15	0.031625			
Lack of Fit	0.406042	10	0.040604	2.971037	0.1205	not significant
Pure Error	0.068333	5	0.013667			
Cor Total	199.4704	29				
Std. Dev.		0.177834	R^2		0.997622	
Mean		11.45833	Adj R^2		0.995402	
C.V. %		1.552007	Pred R^2		0.987782	
PRESS		2.4372	Adeq Precision		69.4015	

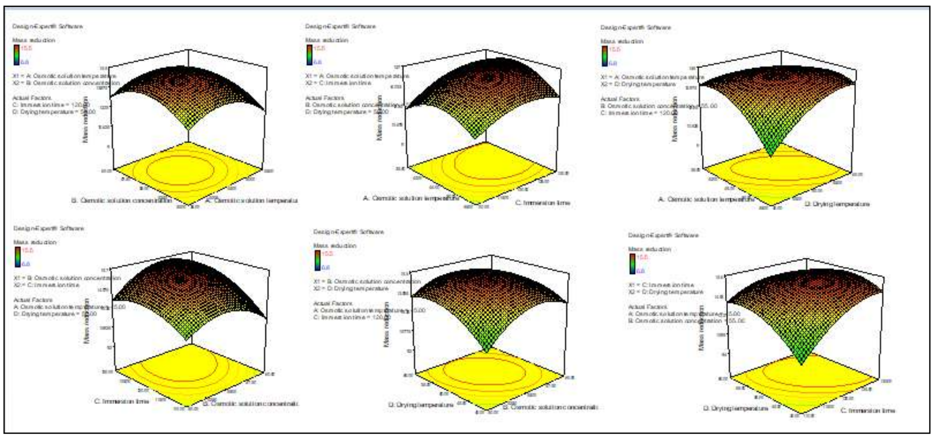

Fig.-4: Surface Plot for Mass Reduction

Influence of Process Parameters on Mass Reduction

Figure-4 shows the rate of mass decrease under different process parameters when treated with an osmotic solution. The greatest weight loss during the osmotic dehydration process happened after 120 minutes at a temperature of 50°C. At 45°C, the comparable osmotic solution concentration was 5.5%.The mass reduction of involved samples tends to increase with a simultaneous rise in process variables till the attainment of maximum ranges. At a temperature of 45°C, a 1:15 sample/solution ratio, a 5.5% experimental solution concentration, and a 120-minute immersion period, the highest mass reduction of solids was observed. There was enough water content reduction from the fruit sample during the osmotic dehydration in its early phases, which persisted until the equilibrium condition was reached.[13] Moreover, the stresses associated with the process of osmotic dehydration would have rendered a major contribution to the aforementioned water loss incident. This could have been a probable reason for the mass reduction of solids during the initial periods.[14] The reduction in solid shrinkage may also be attributed to the fact that the notable solid gain could have made a complete fill along the entire pore distribution involved in the sample parts, and hence eliminated the further mass reduction of the solid material.
The regression equation is-

$$\text{Mass reduction} = 15.317 - 0.3A + 0.296B + 0.983C + 0.5D + 0.0625AB - 0.3375AC + 1.35AD + 0.55BC - 0.537BD - 0.763CD - 1.365A^2 - 1.39B^2 - 0.976C^2 - 1.089D^2$$

The coefficient of determination (R2) and adj-R2 were computed to verify the model's sufficiency and suitability. R2 values were found to be higher than 0.96, indicating 96% compatibility with experimental data. It was discovered that the adj-R2 value was much closer to R2, which further supports the model's importance. All of the responses, CV% values were determined to be low, which seems to indicate that the experiment's results were highly accurate and reliable. The statistical validation of the model was performed with real and anticipated values, which proves the importance of the model in the experiments.

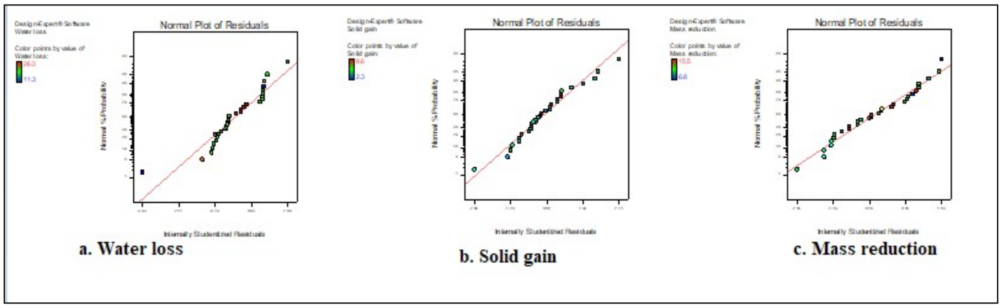

Fig.-5: Validation of Models (Residual plot)

Table-6: Comparative Nutritional Test Results

Parameters	Method	Units	Fresh kiwi	Dried kiwi
Energy (by calculation)	FAO Method	kcal/100g	61	56
Carbohydrate (by difference)	CTL/SOP/FOOD/262-2014	g/100g	14.66	13.2
Total fat	AOAC,19thEdn.2012,954.02	g/100g	0.52	0.46
Protein (N×6.25)	AOAC,19thEdn.2012,986.25	g/100g	1.14	1.08
Sodium as Na	AOAC 19thEdn.2012,969.23	mg/100g	3	2.5
Calcium as Ca	IS 5949:1990(RA.2003)	mg/100g	34	26
Magnesium as Mg	IS 5949:1990(RA.2013)	mg/100g	17	14.3
Potassium as K	AOAC,19thEdn.2012,969.23	mg/100g	312	304
Vitamin C	DGHS Manual 5,2005	mg/100g	92.7	90

CONCLUSION

The goal of this study was to use osmo-convective drying methods to increase the shelf stability of kiwis. With a higher concentration of osmotic solution, the method enhanced mass transfer characteristics like solid growth, weight decrease, and water loss. Quick solute penetration and water removal improved color, flavor, and prevented enzymatic browning, which increased the acceptability of the food as a whole. The method's efficacy was further validated by drying tests carried out at 40°C and 60°C with regulated air velocity. Osmo-convective drying is suggested as an efficient preservation technique for enhancing the quality and prolonging the shelf life of perishable fruits and vegetables in light of the findings.This approach can be scaled for commercial production of dried kiwi snacks or applied to other tropical fruits.

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CONFLICT OF INTERESTS

The authors declare that they have no conflicts of interest regarding the publication of this manuscript.

AUTHOR CONTRIBUTIONS

The present work is aligned with *SDG-12: Responsible Consumption and Production*. All the authors contributed significantly to this manuscript, participated in reviewing/editing and approved the final draft for publication. The research profile of the authors can be verified from their ORCID ids, given below:

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