Optimization of glycerol concentration and drying temperature on the characteristics of moringa leaf vegetable leather (*Moringa oleifera*) using response surface methodology

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Abstract. Moringa leaves (*Moringa oleifera*) contain bioactive compounds with strong potential for functional food applications, yet research on their product development remains limited. Hence, this study formulated and optimized Moringa leaf vegetable leather by adjusting glycerol concentration and drying temperature. The work used a Response Surface Methodology and a Central Composite experimental design. The research was conducted with the following variables: glycerol concentration (2-4%) and drying temperature (45–55°C). The study evaluates the physicochemical properties, antioxidant activity (IC_{50}), and sensory quality of vegetable leather. Higher glycerol increased moisture content and IC_{50}, while higher drying temperatures reduced moisture and affected the antioxidant stability. The optimal conditions were 3.715% glycerol with a drying temperature of 48.506°C. Verification results showing a moisture content of 12.98%, ash content of 6.40%, crude fiber of 4.80%, solubility of 68.62%, and an IC_{50} of 1920.79 ppm. The conduct of sensory evaluation indicates good acceptance with preference scores within $7.07 < \mu < 7.49$. The optimized product met stable physicochemical characteristics, maintained bioactivity, and acceptable sensory quality of vegetable leather, indicating promising potential for the industrial-scale development of moringa leaves as functional foods.

1 Introduction

Moringa oleifera is a tropical plant that is known for its high levels of nutrients and bioactive compounds. Its leaves contain vitamins, minerals, amino acids, phenolics, and flavonoids that contribute to high antioxidant activity. Studies have shown that *Moringa* leaf extracts have antioxidant capacity and biological effects that support health, indicating their potential as a functional food [1]. Other research reported that the bioactive components in *Moringa* leaves can be used for anti-inflammatory activity and free radical scavenging [2]. The nutritional composition of *Moringa* leaves is affected by the leaf age. Young leaves tend to contain higher phenolic levels, while mature leaves have higher crude fiber content. These differences lead to variations in the functional and physical characteristics of Moringa-based food products [3].

Selain In addition to having high nutritional and bioactive compound content, moringa leaves also have advantages over some commonly consumed leafy vegetables, such as spinach, particularly in terms of phenolic compound content and antioxidant activity. Both mature and young *Moringa oleifera* leaves exhibit strong antioxidant activity against free radicals, preventing oxidative damage to key biomolecules and providing significant protection against oxidative stress [4].

The relatively high crude fiber content, particularly in more mature leaves, also makes moringa leaves an attractive raw material for the development of functional food products with distinctive physical and functional characteristics [5]. Therefore, moringa leaves represent a relevant commodity for further investigation in the development of vegetable-based food products.

One potential way to increase vegetable consumption is the development of vegetable leather. This product is a thin sheet produced by concentrating fruit or vegetable puree. The use of a plasticizer plays an important role in determining the product's elasticity and texture. Glycerol is commonly used as a food plasticizer because of its capability to reduce intermolecular hydrogen bonding and increase the flexibility of biopolymer matrices. Previous study of Moringa leaf-based edible films showed that higher glycerol concentrations can improve film elasticity [6].

The development of vegetable leather as an innovative product is based on considerations of consumption practicality. Compared to commonly used powdered forms in food applications, vegetable leather offers advantages as a ready-to-eat product with a more appealing texture. Vegetable leather can be consumed directly as a vegetable-based snack, potentially

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increasing vegetable intake in a convenient manner [7]. Furthermore, the sheet form allows bioactive compounds to remain distributed within the product matrix, unlike powdered products that typically require rehydration or further processing before consumption.

Besides glycerol, drying temperature is also a key factor that determines moisture content, texture, color, and the stability of bioactive compounds. Excessive temperature can degrade heat-sensitive compounds, while low temperature may produce sheets that are overly moist or unstable [8,9]. Research on Moringa leaf-based vegetable leather is still limited, especially in the context of formulation optimization using Response Surface Methodology with a Central Composite Design.

Although several studies have discussed the characteristics of moringa leaves and the development of vegetable leather-based products, systematic investigations that integrate the optimization of moringa leaf vegetable leather formulations while considering variations in plasticizer concentration and drying temperature remain very limited. Previous studies have generally employed a Completely Randomized Design (CRD) and have not specifically focused on the optimization of moringa leaf vegetable leather formulations [10]. Therefore, a structured optimization approach is required to achieve an optimal balance between the physical characteristics of the product, the stability of bioactive compounds, and overall product quality.

Therefore, this study aimed to optimize glycerol concentration and drying temperature to obtain the best characteristics of Moringa leaf vegetable leather using an efficient and standardized statistical approach.

2 Materials and Methods

2.1 Materials

Fresh Moringa leaves were obtained from a local supplier. Food-grade glycerol is used as an additional ingredient. Chemical analysis reagents and DPPH were used to determine the IC_{50} value.

2.2 Screening Stage

The screening stage was carried out prior to optimization using five treatment levels. Glycerol concentrations of 1, 2, 3, 4, and 5% and drying temperatures of 40, 45, 50, 55, and 60°C were applied. In this stage, Moringa leaf vegetable leather was analyzed for moisture content and antioxidant activity expressed as IC_{50} using the DPPH method.

2.2.1 Moisture Content

Moisture content was analyzed using the oven drying method [11]. Approximately 2 g of sample was weighed and dried in an oven at 105°C until constant weight was reached, typically after 4–6 hours, with checks every hour. Moisture content was expressed as a percent on a wet-basis, calculated as the difference between the initial and final weights.

2.2.2 Antioxidant Activity IC_{50}

Antioxidant activity was determined following the method of de Gaulejac et al. [12] with slight modifications. A 0.5 mL aliquot of the sample, previously dissolved in methanol, was mixed with 2 mL of DPPH solution prepared in methanol, vortexed for 2 minutes, and incubated in the dark at room temperature for 30 minutes. The absorbance was measured at 517 nm using a UV–Vis spectrophotometer during the 25–30 minute interval. The percentage of radical scavenging activity was calculated based on the decrease in DPPH absorbance, and the IC_{50} value was determined from the curve relating percentage inhibition to sample concentration.

2.3 Main Experimental Design (RSM and CCD)

Table 1. Experimental Factor and Level of Central Composite Design (CCD)

Factor	Code	Level
Glycerol concentration (%)	X_1	2-4
Drying temperature (˚C)	X_2	45-55

2.4 Observed Parameters

The observed parameters included chemical properties (moisture content, ash content, and crude fiber), physical properties (solubility), and bioactive properties (IC_{50} value after processing).

2.5 Sensory Evaluation

The sensory test involved 30 untrained panelists who evaluated color, taste, texture, and aroma using a 9-point hedonic scale [13].

2.6 Statistical Analysis

The RSM model was analyzed using Design-Expert software for ANOVA, response surface curve generation, and determination of optimal conditions.

3 Results and Discussions

3.1 Raw Materials

The antioxidant activity of fresh *Moringa oleifera* leaves was analyzed, resulting in an IC_{50} value of 54.61 ppm. This indicates that the fresh leaf puree can inhibit oxidation by 50% at a Moringa concentration of 54.61 ppm. The IC_{50} value was classified as strong antioxidant activity, as values between 50 and 100 ppm are generally considered strongly active. When compared with other leafy vegetables, the antioxidant activity of fresh Moringa leaves was stronger than that reported for red spinach (*Amaranthus tricolor* L.), which exhibits IC_{50} values of approximately 64.77 ppm in the DPPH assay [14]. Phytochemical screening by Chukwuebuka [15] identified secondary metabolites in Moringa leaves, including flavonoids, alkaloids, steroids, tannins, saponins, anthraquinones, and terpenoids. Previous studies have demonstrated that Moringa leaves possess high antioxidant activity due to their high polyphenol content [16]. Furthermore, studies on *Moringa oleifera* leaf extracts using different solvents have shown that methanol extracts exhibit strong antioxidant activity, with reported IC_{50} values of approximately 49.30 ppm in the DPPH assay [17]. Sreelatha and Padma [4] also reported that *Moringa oleifera* leaf extracts exhibit significant radical-scavenging capacity due to their high phenolic and flavonoid contents. Although variations in IC_{50} values among studies are expected due to differences in sample preparation and experimental conditions, the IC_{50} value obtained in the present study falls within the range reported in the literature. These findings support the strong antioxidant potential of Moringa leaves for application in functional food products.

3.2 Screening Stage

3.2.1 Glycerol Concentration Evaluation

The screening stage for producing *Moringa oleifera* vegetable leather was carried out by varying glycerol concentration as a plasticizer at five levels (1, 2, 3, 4, and 5%), with a constant drying temperature of 50°C. Based on the one-way ANOVA results, variations in glycerol concentration had a significant effect ($P < 0.05$) on the moisture content and IC_{50} value of the resulting vegetable leather.

Variation in glycerol concentration showed a clear effect on moisture content and antioxidant activity (IC_{50}) of Moringa leaf vegetable leather at drying temperature of 50°C. Increasing glycerol from 1 to 5% raised the moisture content from 12.10 to 15.50%. This occurred because glycerol is hygroscopic; hence, it binds water molecules through hydrogen bonding, leading to higher water retention within the matrix at higher concentrations [18]. The increase in moisture content was followed by an increase in IC_{50} from 1138.67 ppm at 1% of glycerol to 2623.14 ppm at 5%, indicating lower antioxidant activity. This decrease is related to the binding of phenolic compounds within a more plastic, moist matrix, thereby reducing the availability of free phenolics that act as electron donors in antioxidant reactions. Higher moisture levels may also accelerate oxidative degradation of bioactive components during the drying process [19].

Based on this result, a very low glycerol concentration (1%) produced the lowest moisture content and the lowest IC_{50} value, but it may result in vegetable leather with a hard and brittle texture. Otherwise, a high concentration (5%) led to excessive moisture retention, reducing the product stability and weakening its antioxidant activity. Therefore, the range of 2 to 4% glycerol is considered the most suitable, as it provides a balance between moisture content (13.20 to 14.65%) and IC_{50} values (1509.78 to 2252.02 ppm) without causing significant losses in antioxidant activity or extreme textural changes. Formulations within this range produced vegetable leather with good softness, stable structure, and preserved bioactive content. This range was selected as the optimal glycerol concentration for product development.

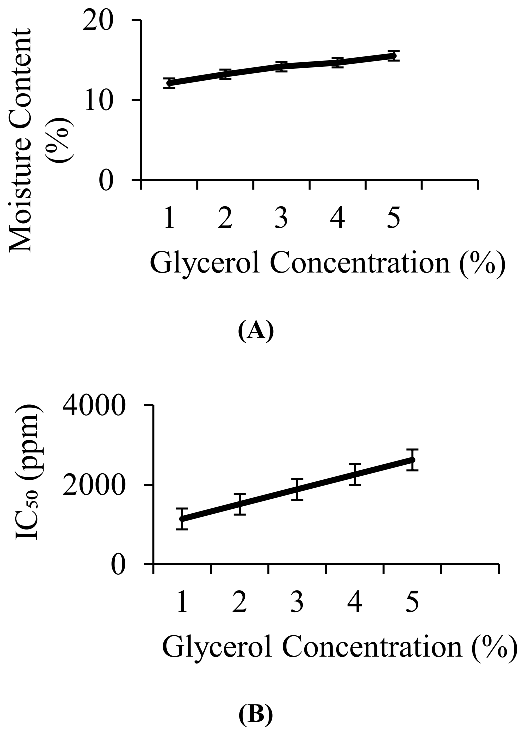


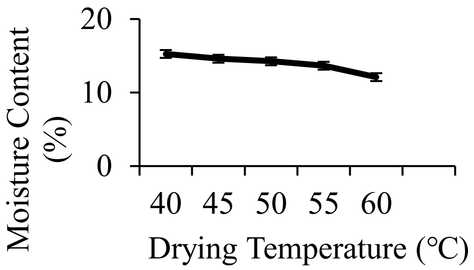
Fig 1. The Effect of Glycerol Concentration on Moisture Content (A) and IC_{50} (B) of Moringa Leaves Vegetable Leather

3.2.2 Drying Temperature Evaluation

The screening stage in formulating Moringa leaf vegetable leather evaluated the effect of drying temperature at five levels (40, 45, 50, 55, and 60°C), with a constant glycerol concentration of 3%. Statistical analysis using one-way ANOVA showed that increasing the drying temperature significantly affected product characteristics, especially on moisture content and IC_{50} values ($P < 0.05$). This confirms that temperature is a critical factor in determining the final quality of vegetable leather.

In general, increasing the drying temperature resulted in a consistent decrease in moisture content from 15.25% at 40°C to 12.10% at 60°C. This reduction occurs because higher temperatures increase the rate of evaporation and the vapor pressure gradient, which enhances the diffusion and release of water from the material matrix [20]. More intense drying at elevated temperatures may also accelerate the formation of a denser film structure due to faster polymer interactions during water removal.

However, higher temperatures negatively affected the antioxidant activity of vegetable leather. This was reflected in the increase in IC_{50} values from 1742.30 ppm to 1945.80 ppm as the temperature increased. This result indicates thermal degradation of phenolic compounds and natural antioxidants in Moringa leaves, which are sensitive to prolonged heat exposure. Higher temperatures can efficiently reduce moisture, but they also reduce the availability of active antioxidant components [21]. A mid-range drying temperature of 45 to 55°C is therefore preferable because it maintains a balance between bioactive stability and the physical quality of the vegetable leather.



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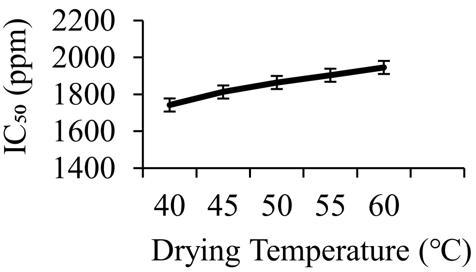

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Fig 2. The Effect of Drying Temperature on Moisture Content (A) and IC_{50} (B) of Moringa Leaves Vegetable Leather

3.3 Optimization Stage

3.3.1 Moisture Content

Based on Figure 3A, the moisture content of Moringa leaf vegetable leather ranged from 12.20% to 14.26%, with a clear tendency to increase as the glycerol concentration increased. The highest value was observed at 4% glycerol and 45°C, reaching 14.26%, while the lowest was recorded at 2% glycerol and 55°C, at 12.20%. The increase in moisture content at higher glycerol levels is linked to its humectant properties, which are due to hydrophilic and hygroscopic hydroxyl groups that form hydrogen bonds with water molecules. These interactions reduce water mobility and hinder evaporation during drying. The hydroxyl groups in glycerol enhance water retention. In addition, glycerol–water interactions within the polysaccharide matrix can alter the material's physical properties and strengthen its water-binding capacity [22].

The effect of drying temperature showed the opposite pattern. Higher temperatures led to lower moisture content. Drying at 55°C produced the lowest values across several treatment combinations, including 12.20% at 2% glycerol and 12.36% at 3% glycerol. Increasing the temperature increases thermal energy, which accelerates water diffusion and evaporation from the product matrix. This results in a lower final moisture content than drying at lower temperatures. Higher drying temperatures accelerate water release and significantly reduce moisture levels in food materials [23]. These findings indicate that low glycerol concentration combined with high drying temperature is the most effective condition for producing vegetable leather with low moisture content, while the highest moisture values tend to occur at high glycerol levels under low drying temperatures.

3.3.2 Ash Content

Based on the data in Figure 3B, the ash content of the moringa leaf vegetable leather ranged from 6.12 to 6.55% with only a small variation between treatments. The lowest value was obtained at 2% glycerol and 45˚C, at 6.12%. The highest value was recorded at 4% glycerol and 55˚C at 6.55%. The data show a tendency for ash content to increase with increasing glycerol concentration, although the differences are not large. This pattern relates to changes in total solids within the product matrix. Higher glycerol levels tend to increase solids retention during drying. The inorganic fraction measured as ash becomes proportionally higher relative to total dry solids [24]. The increase does not originate in glycerol itself but in shifts in the ratio of organic to inorganic solids after drying.

Drying temperature also influenced the measured ash content. Increasing the temperature from 45 to 55˚C produced a tendency toward higher ash values. Several treatments showed higher ash content at 55˚C. Higher temperature accelerates water loss and can increase the loss of some volatile organic components. The remaining mineral fraction becomes proportionally higher relative to the total dry matter. This effect is evident in the 4% glycerol and 55˚C treatment, which produced the highest ash content at 6.55 percent. Although the variation in ash content is narrow, the data indicate that higher glycerol concentration, combined with higher drying temperature, tends to increase ash content by increasing the relative concentration of inorganic solids after drying.

3.3.3 Crude Fiber

Based on the data presented in Figure 3C, the crude fiber content of the moringa leaf vegetable leather ranged from 3.29% to 5.82%, with greater variation among treatments than for other proximate parameters. The lowest fiber value was observed in the formulation containing 2% glycerol at 45°C, yielding 3.29%. The highest value, 5.82%, was obtained in the 4% glycerol treatment at 55°C. This increasing trend suggests that higher glycerol concentrations tend to retain more fiber within the final product. This effect is associated with glycerol's role as a plasticizer, which helps maintain the material's integrity, allowing fiber components to remain less degraded during heating [24,25].

Dietary fiber represents the fraction of carbohydrate that cannot be digested by human digestive enzymes, so its presence in vegetable leather reflects the nutritional aspect of the product, especially in terms of fiber contribution. The increased crude fiber content observed in formulations with higher glycerol levels indicates that glycerol helps retain the fiber fraction within the product matrix during processing and drying. This retention results in a higher crude fiber content in the final product [24,26].

Drying temperature also played an important role in determining crude fiber content. The increased temperature to 55°C resulted in higher fiber values, particularly in the 3% and 4% glycerol formulations. Higher temperatures accelerate water evaporation, increasing the total solid concentration and making the fiber fraction more dominant in the dried product. This trend aligns with findings reported by Berrio et al. [27], who noted that elevated drying temperatures can increase measured crude fiber content because fiber components are more thermally stable than other constituents that tend to diminish during drying.

Overall, the crude fiber content of the moringa vegetable leather was significantly influenced by the interaction between glycerol concentration and drying temperature. Higher glycerol levels helped maintain material stability during drying, while higher temperatures increased solid concentration and retained more fiber within the matrix [24,25]. The most favorable combination in this study was the 4% glycerol treatment at 55°C, which produced the highest crude fiber content.

3.3.4 Solubility

Based on the data in Figure 3D, the solubility of the moringa vegetable leather varied across different combinations of glycerol concentration and drying temperature. The lowest solubility was observed at 2% glycerol and 55°C at 51.10%. The highest solubility was observed at 4% glycerol and 55°C, with 71.36%. This pattern indicates that increasing glycerol concentration can enhance solubility up to a certain level. At higher temperatures, solubility may decrease again due to stronger internal bonding within the matrix formed during drying [24,27].

Overall solubility increases as glycerol concentration rises from 2% to 4%. Glycerol disrupts intermolecular interactions, loosening the matrix and allowing water to penetrate more easily [18]. This mechanism aligns with Pitak and Rakshit [28], who reported that higher plasticizer levels improve the diffusion and dissolution behavior of polysaccharide-based materials. They noted solubility values of 40.90–64.21% for composite edible films made from banana flour and carrageenan. The solubility values in the present study exceed that range. This indicates that the moringa leaf matrix disperses readily in water and responds strongly to the addition of glycerol.

Solubility is mainly affected by drying temperature. Lower temperatures of 45–50°C generally yield higher solubility because the matrix hardens less during dehydration, allowing water to penetrate more effectively during testing. Higher temperatures, such as 55°C, tend to reduce solubility. Intensive heating strengthens interactions among fibers and solid components, producing a denser, less soluble film [29]. This effect is evident at the lowest value of 51.10% observed at 2% glycerol and 55°C. The results show that high temperature can suppress solubility even when a plasticizer is present. High solubility offers advantages for ready-to-eat applications because the material breaks down and disperses easily during consumption and degrades more readily [30]. Balancing glycerol concentration and drying temperature is therefore essential to achieve the desired texture and functional quality of moringa leaf vegetable leather.

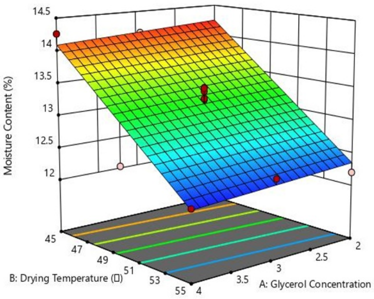
3.3.5 IC_{50} Value

Based on the data in Figure 3E, the IC_{50} values of moringa leaf vegetable leather range from 1203.55 ppm to 3370.53 ppm. These values fall within the weak antioxidant category because all measurements are above 200 ppm. The wide range reflects a clear influence of glycerol concentration and drying temperature on the stability of the antioxidant compounds retained in the product.

The lowest IC_{50} value and the highest antioxidant activity were obtained with 3% glycerol at 45°C, with an IC_{50} of 1203.55 ppm. This result indicates that a moderate glycerol concentration combined with a low drying temperature helps preserve bioactive compounds such as flavonoids, phenolics, vitamin C, and chlorophyll, which play key roles in free-radical scavenging. The milder drying conditions likely reduce thermal degradation and oxidation of these compounds, allowing a greater proportion of antioxidant molecules to remain available to react with free radicals during the IC_{50} assay.

Conversely, the highest IC_{50} value and the lowest antioxidant activity were observed with 4% glycerol at 55°C, with an IC_{50} of 3370.53 ppm. This result suggests that drying at 55°C accelerates thermoxidative degradation of phenolic and flavonoid compounds, which reduces the product’s ability to donate electrons to free radicals. A high glycerol concentration may also dilute the matrix, reducing the total amount of active compounds per unit mass due to the increased liquid phase. In addition, excess glycerol can retain more water during heating, thereby promoting internal oxidative reactions that accelerate antioxidant degradation [18].

The treatment with 3% glycerol at 50°C produced relatively stable IC_{50} values (1598.72–1607.82 ppm), indicating a formulation that maintains structural integrity and preserves antioxidants even though it does not provide the strongest activity. This glycerol concentration appears to represent a balance in which the plasticizer is not high enough to dilute active compounds, yet sufficient to prevent structural damage during heating. These findings highlight that both drying intensity and glycerol concentration influence not only the physical characteristics of the vegetable leather but also directly preserve its bioactive components and antioxidant capacity. This outcome is highly relevant for developing functional moringa leaf-based products with improved bioactivity for food and nutraceutical applications.



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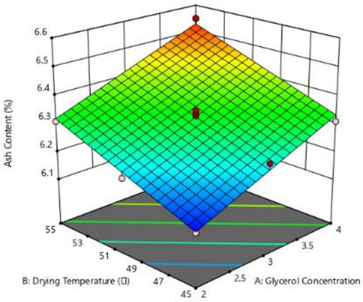

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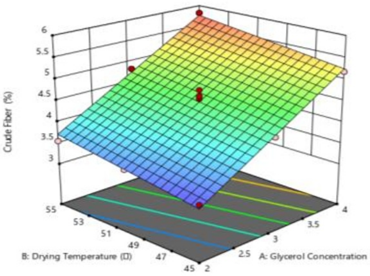

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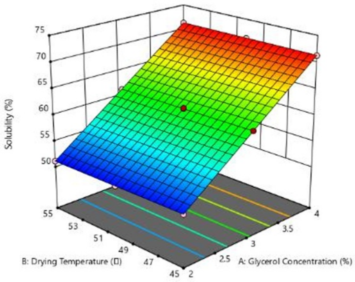

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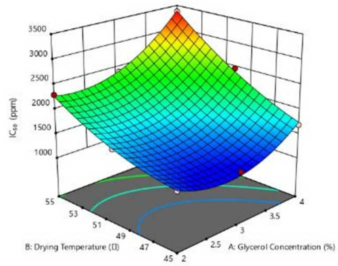

(E)

Fig 3. Three-Dimensional Response Surface Showing the Effects of Glycerol Concentration and Drying Temperature on Moisture Content (A), Ash Content (B), Crude Fiber (C), Solubility (D), and IC_{50} Value (E) of Moringa Leaf Vegetable Leather

3.4 Multi-Responses Optimization

At optimum conditions consisting of 3.715% glycerol and a drying temperature of 48.506°C, the Response Surface Methodology model generated predicted values for several product attributes: moisture content 13.447%, ash content 6.372%, crude fiber 5.136%, solubility 68.518%, and IC_{50} 1877.502 ppm. Verification experiments produced actual values of 12.98% moisture, 6.40% ash, 4.80% fiber, 68.62% solubility, and an IC_{50} of 1920.79 ppm. All measured responses closely matched the predicted values, indicating that the RSM model demonstrated strong predictive accuracy with minimal deviation. The agreement between predicted and verified results indicates the system's stability and confirms that the selected combination of glycerol concentration and drying temperature effectively optimized the physicochemical and functional properties of the moringa leaf vegetable leather.

The predicted and verified results show that the actual values for moisture, ash, fiber, solubility, and IC_{50} closely matched the model estimates. This agreement confirms that the RSM approach effectively captured the effects of glycerol concentration and drying temperature, allowing the interaction between process variables to be controlled to produce consistent product characteristics. The consistency of the verification values demonstrates that the identified optimum is not only mathematically valid but also reproducible under actual processing conditions. These findings indicate that the formulation operates within a stable process range where changes in the two main factors do not cause major deviations in final product quality. The successful alignment between predicted and experimental results supports the use of the RSM-derived optimum as a basis for defining production process standards.

Thus, a glycerol range of 2–4% and a drying temperature of 45–55°C were shown to significantly influence the physical and bioactive properties of the moringa leaf vegetable leather. The optimum condition of 3.715% glycerol and 48.506°C can be recommended as a formulation standard because it demonstrated stability, successful verification, and the ability to produce desirable product characteristics supported by a valid and reproducible model prediction.

Table 2. Comparison of the Predicted and Verified Response Values of Moringa Leaf Vegetable Leather under the Optimum Condition

Response	Prediction Response Value	Verified Response Value
Moisture content	13.447	12.98
Ash content	6.372	6.40
Crude fiber	5.136	4.80
Solubility	68.518	68.62
IC_{50} value	1877.502	1920.79

3.5 Sensory Evaluation

3.5.1 Colour

The vegetable leather exhibited a color value of 6.73±1.14[a], indicating that the panelists found the product visually acceptable despite a reduction in brightness compared with fresh leaves. The color changes of vegetable leather were mainly affected by the drying temperature. Higher temperatures tended to produce darker hues. The final appearance was primarily influenced by chlorophyll stability, the main pigment responsible for the green color of moringa leaves. Chlorophyll is sensitive to heat, oxygen, light, and pH shifts. Blanching and drying, therefore, led to varying degrees of degradation across treatments [31,32]. The optimal temperature of approximately 48.506℃ better preserved the green coloration than higher temperatures, as chlorophyll degradation occurred at a slower rate.

Color changes during drying were mainly driven by several chlorophyll degradation pathways. These included pheophytin formation, chlorophyllide formation, and oxidation. Pheophytinization occurs when chlorophyll encounters acidic conditions and loses its Mg^{2+} ion. This produces pheophytin, which gives a brownish-green appearance [32]. Heat accelerates this reaction, so products dried at higher temperatures appear darker. Hydrolysis that produces chlorophyllide and oxidative reactions during drying also contributed to color shifts. These findings supported previous reports showing that higher temperatures accelerate chlorophyll degradation and reduce the color quality of leaf-based products [33]. The results confirm that controlling the drying temperature is essential for maintaining the visual appearance of moringa leaf vegetable leather.

3.5.2 Taste

The taste score of the moringa leaf vegetable leather at the optimum formulation was 7.40±1.33[b]. This score shows that panelists expressed a relatively high level of liking toward the product's taste. Taste is a key sensory factor. It arises from chemical responses in the taste buds and is integrated with aroma and texture. The perception is subjective, but it remains central to consumer acceptance [34]. Differences in the taste perception of vegetable leather are due to chemical changes during processing. Acidic compounds from the raw materials, volatile compounds formed during heating, and natural sweeteners added in the formulation all influence the final taste profile.

One of the strongest drivers of the taste attribute in this product is the glycerol concentration. Glycerol is defined as an alcohol with three hydroxyl groups that delivers a sweetness level about 0.75 times that of sucrose [35]. Higher concentrations tend to increase the product's perceived sweetness. The sweet taste comes from its chemical nature as an aliphatic organic compound with hydroxyl groups. This aligns with reports that certain alcohols and amino acids can produce a sweet sensation. Previous work also shows that increasing glycerol addition can improve product liking due to its sweetness. At the optimum concentration, glycerol works not only as a plasticizer in the edible film or leather matrix. It also enhances panelists' acceptance of the taste attribute [36].

3.5.3 Texture

The texture score of moringa leaf vegetable leather at 7.40±1.61[a] shows that panelists generally liked the texture at the optimum formulation. Texture is an important parameter in sensory analysis because it directly influences product quality and consumer perception. In vegetable leather, the ideal texture is characterized by good plasticity, moderate moisture content, and an appropriate level of doneness. The product should not break easily, but it should remain easy to chew [37]. This combination reflects the integrity of the natural polymer matrix in moringa leaves after heating and drying. The process produces a compact yet flexible structure.

One key component that strongly influences texture is glycerol, which functions as a plasticizer. Exceeding the optimum glycerol level can reduce panelist preference. Glycerol is hygroscopic. It absorbs moisture from the environment, making the product tougher, too soft, and sticky [18]. This reduces chewing comfort. This result aligns with Barrett et al. [38], who reported that the optimal amount of glycerol can soften protein or polymer matrices, but excessive use can damage the product's structural integrity. Determining the optimal glycerol concentration is essential to balance elasticity, chewiness, and overall eating quality in moringa leaf vegetable leather.

3.5.4 Aroma

The aroma score of moringa leaf vegetable leather was 7.60±1.40[bc]. This shows that panelists accepted the aroma well. Glycerol did not change the aroma because it is odorless, neutral, and lacks aromatic character that could interact with volatile compounds. As an alcohol with three hydroxyl groups, glycerol acts mainly as a plasticizer and does not contribute volatile components to food. Changes in glycerol concentration did not affect the product's aroma perception [39].

The final aroma of moringa leaf vegetable leather was driven by the natural volatile compounds of the leaves. Many of these compounds decreased during blanching and drying. Both heat-based processes triggered evaporation and degradation of volatiles that normally give moringa leaves their characteristic green or grassy aroma. The finished product had a neutral and mild aroma. This improved panelist acceptance by reducing the strong notes that often lead to rejection of leaf-based products.

Table 3. Sensory Characteristics of Moringa Leaf Vegetable Leather under the Optimum Condition

Parameter	Score
Colour	6.73±1.14[a]
Taste	7.40±1.33[b]
Texture	7.40±1.61[a]
Aroma	7.60±1.40[bc]
Interval of confidence	$7.07 < \mu < 7.49$

4 Conclusion

This study successfully formulated and optimized moringa leaf vegetable leather by adjusting glycerol concentration and drying temperature using Response Surface Methodology. The optimization identified a glycerol concentration of 3.715% and a drying temperature of 48.506 °C as the best processing conditions. These conditions produced stable physicochemical properties, with a moisture content of 12.98%, an ash content of 6.40%, a crude fiber content of 4.80%, and a solubility of 68.62%. The bioactive properties were maintained, as indicated by an IC_{50} value of 1920.79 ppm. Sensory evaluation showed good acceptance, with panelist preference scores falling within the confidence interval of $7.07 < \mu < 7.49$ for color, taste, texture, and aroma. The close agreement between predicted and verified values confirmed that the RSM model accurately described the process interactions and could be reliably reproduced. These optimal conditions can serve as a formulation reference for the development of functional moringa leaf products at an industrial scale. The product offers nutritional value and stable physicochemical characteristics. Future studies are recommended to explore the utilization of moringa leaf processing residues or other parts of the moringa plant, such as pods or seeds, as alternative sources of bioactive compounds to improve sustainability and support product diversification. Furthermore, research focusing on application aspects, including consumption methods, shelf-life stability, and the bioavailability of antioxidant compounds, is necessary to strengthen the development of moringa leaf vegetable leather as a functional food suitable for regular consumption.

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