iJRASET

International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 Issue: IV Month of publication: April 2026

DOI: https://doi.org/10.22214/ijraset.2026.80326

www.ijraset.com

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

Development of Functional Noodles Using Plant-Based Ingredients

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Abstract: The formulation and quality of noodles made with oat flour and pumpkin powder were investigated for the health benefits and functionality of the final product. Previous research has shown that the addition of pumpkin increases the content of β-carotene and dietary fibre, thereby improving the nutritional value of the noodles. Response Surface Methodology (RSM) has been widely used to determine the optimal ingredient ratio while maintaining product quality. The final optimised formulation contained higher concentrations of all three ingredients, resulting in higher β-carotene, β-glucan, and total dietary fibre than those produced with pumpkin-based cereals. The inclusion of pumpkin and oat flours also affected the cooking quality parameters, including water absorption and cooking loss. Similar results were noted in types of noodles produced from various composite flour blends. The overall findings of the taste test indicated that the noodles were well received and had good acceptability up to medium levels of pumpkin when evaluated by consumer taste testers; the results of the microbiological analyses indicated that dried noodle samples remained safe for consumption after a 3-month storage period. It appears that the combination of pumpkin and oat flour can provide a healthier noodle option for the commercial production of those products.
Keywords: Pumpkin powder, Oat flour, Functional noodles, Response Surface Methodology, Dietary fibre.

I. INTRODUCTION

Functional foods have emerged as an incredibly fast-growing segment of the global food industry as consumers become increasingly aware of the link between dietary patterns and long-term health outcomes [1]. A definition given to functional foods is that they provide physiological advantages beyond basic nutrition, with the potential to lower the incidence of disease when consumed on a regular basis as part of an overall balanced diet. Functional foods are designed for everyday use in our diets and are distinguished by their inability to be used for medicinal purposes compared to nutraceuticals. Poor nutritional habits and low fibre consumption have been related to the global growth of chronic non-communicable diseases (NCDs) such as Type 2 Diabetes Mellitus and cardiovascular disease [2]. The global evidence to support the strategy of increasing dietary fibre consumption as a key nutritional approach to preventing and managing metabolic disorders is well established [3]. Further, recent epidemiological data confirm that increased consumption of cereal-derived dietary fibre is significantly associated with improving glycemic control and decreasing the risk of Type 2 Diabetes Mellitus [4]. Recently, soluble dietary fibres (e.g., β-glucans) have attracted significant scientific attention due to their ability to lower cholesterol levels and regulate blood glucose and insulin responses [5], [6]. Fortifying noodles with nutrient-dense ingredients such as pumpkin powder and oat flour is a potential strategy for enhancing dietary fibre, β-carotene, and β-glucan content while improving overall nutritional quality.

The inclusion of nutritionally superior ingredients in cereal-based products has received considerable interest in functional food development. Pumpkin flour contains moisture (6–8%), protein (7–9%), fat (<1%), ash (2–3%), and total dietary fibre (25–30%), making it a valuable ingredient for nutritional enrichment [7].

The addition of pumpkin flour alters dough characteristics by partially replacing gluten. Studies have shown increased water absorption, longer dough development time, and reduced dough stability due to gluten dilution and interference with the protein matrix [8]. Pumpkin flour improves nutritional quality but excessive incorporation negatively affects texture and acceptability [9]. High levels (>20–25%) may reduce firmness, elasticity, and structural integrity due to disruption of the gluten-starch matrix [10]. Optimal incorporation levels (5–15%) maintain sensory quality while enhancing nutrition [11]. Cooking quality is also affected, with increased fibre leading to higher cooking loss and reduced product density at higher substitution levels [12]. However, controlled substitution levels can improve functionality while maintaining acceptable cooking quality [13]. This study aims to develop functional noodles using pumpkin and oat flour at controlled substitution levels (5–10%) to achieve a balance between nutritional enhancement and technological stability. Pumpkin provides β-carotene and dietary fibre, while oat flour contributes β-glucan with cholesterol-lowering and glycemic-regulating properties [5].

II. MATERIALS AND METHODS

The experimental phase of the project took place in the Food Processing Laboratory of the Department of Food Technology under controlled conditions. The noodle formulation was made with refined wheat flour (maida) as the primary base ingredient due to its ability to develop gluten and gel together while also exhibiting good structural properties [14]. Oat flour that was approximately 10% moisture was added as a functional ingredient because of the high β-glucan and soluble dietary fibre levels that it has [15]. Pumpkin (*Cucurbita maxima*) is believed to have originated in Central and South America. It is widely grown in tropical, subtropical, and temperate regions around the world. This plant belongs to the Cucurbitaceae family. Pumpkins are creeping plants valued for their edible fruits, seeds, and flowers. People consume them in both fresh and processed forms. Because they adapt well to different climates and can produce high yields, pumpkins are important for food security and nutrition, especially in developing countries [16], [17].

Pumpkin is known worldwide as a significant vegetable crop due to its nutritional value, economic benefits, and availability. It is a great source of β-carotene, dietary fiber, vitamins, minerals, and bioactive compounds [18], [19]. Many varieties of pumpkin are grown globally, each differing in size, color, shape, and chemical makeup [20]. Pumpkin flour was produced from mature *Cucurbita maxima*, which were purchased locally in India. The pumpkin is a source of high amounts of dietary fibre and β-carotene, thus providing an excellent supplement for the enrichment of functional cereal products [21].

Oat flour was made from whole grain *Avena sativa L.*, a major cereal grain that is widely grown and contains high levels of β-glucan and soluble dietary fibres [15].

Refined wheat flour has been chosen as a suitable primary base ingredient mainly because of its gluten forming characteristics and structure [22]. Xanthan gum was included in the noodle formulation to stabilise and thicken the dough while improving handling characteristics [23]. Xanthan gum is a high molecular weight exopolysaccharide produced by fermentation [24]. It enhances viscosity and improves texture [25]. In composite cereal products, xanthan gum improves elasticity, hydration, and reduces cooking loss [26].

A. Preparation Of Pumpkin Flour

Pumpkin (*Cucurbita maxima*) at the ripened stage was procured from a local market in Coimbatore, Tamil Nadu. The freshly harvested pumpkins were washed thoroughly to remove dirt and other foreign objects. The skins and the seeds were removed manually, and the pumpkin flesh was cut into long slices (approximately 500 ± 20 mm) and thin sections (approximately 1.5 ± 0.5 mm) to ensure uniform drying.

The cut pumpkin pieces were blanched for 5 minutes in 0.1% potassium metabisulphite (KMS) solution to prevent enzymatic browning and preserve colour. KMS acts as an effective anti-browning and antioxidant agent by reducing polyphenol oxidase activity and protecting carotenoids from oxidative degradation, thereby improving product quality and stability [27], [28].

After blanching, the slices were drained and air-dried at room temperature for 30 minutes to remove excess surface moisture. Subsequently, the pumpkin pieces were dried in a dehydrator at 60 °C until a constant weight was achieved. Controlled drying at moderate temperatures is essential for preserving carotenoids and minimizing nutrient loss [29].

The dried pumpkin slices were then ground into fine flour and sieved through a 60 µm mesh to obtain uniform particle size. The flour was packed in airtight polyethylene zip-lock bags and stored at ambient conditions until further use [30].

Fig.1 Pumpkin flour

B. Xanthun Gum

Xanthan gum is a high-molecular-weight polysaccharide produced by fermenting carbohydrates using *Xanthomonas campestris*. It is widely used in food products as a stabilizer, thickener, and emulsifier due to its strong water-binding capacity and ability to enhance viscosity [31].

It improves the functional characteristics of composite flour systems by making the dough more consistent and stable. Xanthan gum also exhibits pseudoplastic behavior, maintaining high viscosity at low shear rates while flowing easily during mixing or extrusion, making it highly suitable for noodle processing [31]. Furthermore, it enhances dough handling properties by increasing viscosity and forming a stable network structure [32]. Xanthan gum is particularly important in composite flours made from non-gluten ingredients such as pumpkin and oat flour, as it improves dough elasticity and water-binding capacity. It also contributes to increased noodle firmness and reduced cooking loss [33]. Additionally, xanthan gum ensures uniform mixing and prevents phase separation of ingredients. It is effective even at low concentrations (0.5–1 g per 100 g), providing the desired functional properties without negatively affecting sensory quality. Therefore, it plays a crucial role as a hydrocolloid in improving dough structure, stability, and overall product quality in composite noodle formulation

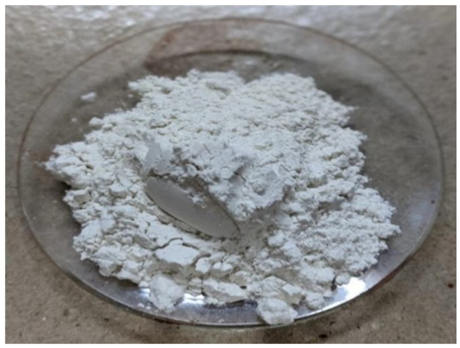

Fig.2 Xanthan Gum

C. Formulation For Composite (Pumpkin And Oats) Flour

Pumpkin flour (5–15%) and oat flour (5–10%) were used as partial replacements for refined wheat flour in the preparation of noodles, with the remaining portion consisting of maida.

Std	Run	Space Type	Factor 1 A: OF	Factor 2 B: PF	Response 1 Cooking Time (mins)	Response 2 Cooking loss (%)	Response 3 Water Absorption (%)	Response 4 Swelling index (%)
11	1	Center	10	10	7.91	7.7	113	179.3
8	2	Axial	10	17.07	7.96	5.9	117.8	177.5
1	3	Factorial	5	5	8.03	10.3	126.9	180.6
5	4	Axial	2.9	10	7.84	8.61	121.6	174.6
3	5	Factorial	5	15	8.01	5.9	118.2	171.3
7	6	Axial	10	2.9	7.75	9.12	139.5	186.2
10	7	Center	10	10	8.04	7.28	115.2	179.8
13	8	Center	10	10	7.66	7.32	114.9	181.5
6	9	Axial	17.07	10	7.93	6.26	126.5	185.71
4	10	Factorial	15	15	8.1	6.9	118.6	185.48
12	11	Center	10	10	7.98	7.8	115.2	180.1
2	12	Factorial	15	5	7.35	6.6	136.5	190.6
9	13	Center	10	10	8.06	7.96	114.6	183.2

Table 1 Response Surface Methodology for Pumpkin and Oats Noodles

The levels of substitution were selected based on previous studies, which reported that moderate incorporation improves the nutritional properties of noodles while maintaining acceptable technological and sensory characteristics [11], [21]. Before dough preparation, all dry ingredients were thoroughly mixed to ensure uniform distribution. Water was then gradually added until a suitable dough consistency was achieved for kneading and shaping. The incorporation of oat and pumpkin flours is intended to enhance the nutritional profile of noodles by increasing total dietary fibre, β-carotene, and β-glucan content, while maintaining processing suitability and overall product quality [5], [7], [15].

D. Extrusion Process

Pumpkin flour and oat flour were incorporated into refined wheat flour (maida) to develop the treatment combinations. The dry ingredients were blended thoroughly to ensure uniform distribution of fibre and functional components. Water was gradually added during mixing to achieve proper hydration of each component. Proper mixing is essential for uniform water absorption without excessive mechanical disruption of the gluten matrix [23]. The dough was mixed using a dual shaft counter-rotating mixer equipped with propeller-type blades to prevent lump formation and ensure homogeneous hydration. The design minimized dead zones, thereby avoiding uneven hydration and localized fermentation. Mixing was continued until a stiff and cohesive dough mass was obtained. Controlled mixing is crucial to prevent structural breakdown of the gluten network, as excess water absorption and mechanical stress can weaken dough structure [32]. The mixing process was carried out at a controlled temperature (≤ 55 °C) to prevent premature protein denaturation. Exposure of gluten proteins to temperatures above 60–70 °C may lead to coagulation, reducing extensibility and adversely affecting dough handling and final noodle texture [34].

After mixing, the dough was transferred to a single screw extruder for shaping. The extrusion process was performed at an intermediate screw speed of approximately 30 rpm. To minimize heat generation due to shear forces, the barrel temperature was maintained around 45 °C using circulating cooling water (19–25 °C) [35]. The extruded noodle strands were cut into uniform lengths using rotating knives positioned below the die. The cutting speed was maintained constant to ensure uniform strand length and consistent flow rate. The noodles were then dried under controlled conditions until the desired moisture level suitable for storage was achieved. Finally, the dried samples were packed in airtight containers and stored at ambient conditions for further physicochemical, sensory, and nutritional analysis. The incorporation of pumpkin and oat flour during processing enhances the dietary fibre, β-carotene, and β-glucan content while maintaining acceptable protein levels and product quality [5], [7], [15].

Fig.3 Pumpkin and Oats Noodles

III. RESULT AND DISCUSSION

One of the most important components of scientific studies is selecting an appropriate statistical method to minimize experimental error and ensure accurate interpretation of results. The choice of statistical tools depends on the nature and distribution of the data being analyzed [36]**.** In the present study, Response Surface Methodology (RSM) and ANOVA were used to evaluate the effect of different levels of pumpkin powder (5–15%) and oat flour (5–15%) on noodle quality characteristics. The control sample (100% refined wheat flour) exhibited superior cooking stability due to the formation of a strong gluten network. The incorporation of pumpkin powder altered cooking properties, as it lacks gluten-forming ability and has different water absorption characteristics. As the level of pumpkin powder increased, cooking loss also increased due to gluten dilution and the leaching of soluble solids into the cooking water. Due to the high β-glucan and dietary fibre content of oat flour and its strong water absorption capacity, its addition improved cooking stability despite interfering with gluten network formation and starch–protein interactions [12], [15]**.** Sensory evaluation indicated that noodles with moderate incorporation levels (5–10%) of pumpkin and oat flour showed high overall acceptability, balancing improved nutrition with desirable sensory attributes [11], [21]**.**

A. Estimation Of Β-Carotene

To determine the β-carotene content of the developed pumpkin–oat-enriched noodles, a liquid chromatography method was employed based on validated analytical procedures [37]. Approximately 0.5 g of the ground sample was accurately weighed and extracted using an appropriate solvent under controlled conditions to prevent light- and oxygen-induced degradation of carotenoids. The sample was mixed with solvent and stirred magnetically at room temperature for 30 minutes, followed by centrifugation to separate the supernatant. The extraction process was repeated until the residue became colourless, ensuring complete recovery of β-carotene. The collected supernatants were pooled and made up to a final volume of 50 mL using the extraction solvent. The entire procedure was carried out under dark conditions to minimize carotenoid degradation during analysis [38]. The absorbance of the extract was measured at the characteristic wavelength of β-carotene, and the concentration was calculated using standard extinction coefficients, expressed as mg per 100 g of dry sample [39].

This method is widely recognized for carotenoid estimation in cereal-based food systems due to its high sensitivity, accuracy, and reproducibility.

B. Proximate Analysis For Noodles

1) Determination Of Moisture Content

In order to evaluate product stability and shelf-life characteristics, the moisture content of the developed pumpkin–oat–enriched noodle samples was determined. Moisture analysis was conducted in accordance with the standard methods prescribed by the Association of Official Analytical Chemists [40]. Approximately 1 g of finely ground noodle sample was evenly spread on the heating pan of an MX-50 Moisture Analyzer to ensure uniform drying. The temperature was maintained at 140 °C, and the sample was dried for about 5.8 minutes until a constant weight was achieved. The moisture content was automatically calculated and expressed as a percentage (%) on a wet basis. Moisture determination is a critical factor influencing fibre-enriched noodle formulations, as variations in dietary fibre content from pumpkin and oat flour affect water-holding capacity compared to refined wheat flour [41]. Maintaining optimal moisture levels is essential for product quality, storage stability, and prevention of microbial growth [42].

Table 2. Determination of Moisture Content of Noodles

Storage Period (Days)	Control (%)	S4 (%)	Acceptable Limit
0	10.4	10.9	≤ 12 %
30	10.7	11.2	≤ 12 %
60	11.0	11.5	≤ 12 %
90	11.3	11.8	≤ 12 %

2) Determination Of Dietary Fiber (%)

Total dietary fibre (TDF) was determined using the AOAC enzymatic–gravimetric method [40]. Moisture- and fat-free samples were treated sequentially with α-amylase, protease, and amyloglucosidase to remove starch and protein components.

Soluble fibre was precipitated using 78% ethanol, and the residue was filtered, washed with ethanol and acetone, oven-dried, weighed, and ashed. TDF was calculated gravimetrically and expressed as a percentage on a dry weight basis. This analysis was conducted to evaluate fibre enhancement due to the incorporation of pumpkin and oat flour [41].

3) Determination Of Ash Content (%)

Ash content was determined using the standard dry ashing method as per AOAC guidelines [40]. Approximately 5 g of ground sample was placed in a pre-weighed silica crucible, charred, and incinerated in a muffle furnace at 500 °C until complete ash formation.

The crucible was cooled in a desiccator and weighed, and ash content was expressed as a percentage of the original sample weight. This parameter indicates the mineral contribution from pumpkin and oat flour [41].

C. Scanning Electron Microscope

Scanning Electron Microscopy (SEM) was used to study the microstructural characteristics of the developed pumpkin-enriched noodle samples. The samples were dried, cut into small pieces, and mounted on aluminium stubs using conductive carbon tape. They were then coated with a thin layer of gold to enhance electrical conductivity and improve image clarity [43].

The samples were examined using SEM at an accelerating voltage of 5–15 kV to observe surface morphology and internal structure [44]. Micrographs at different magnifications were used to analyze the distribution and interaction of pumpkin flour, oat components, and the wheat starch–protein matrix.

SEM analysis also provided insights into the structural network formed due to xanthan gum, which enhances binding, structural integrity, and texture of the noodles [45]. This microstructural evaluation helps in understanding the effect of composite flour incorporation on product quality.

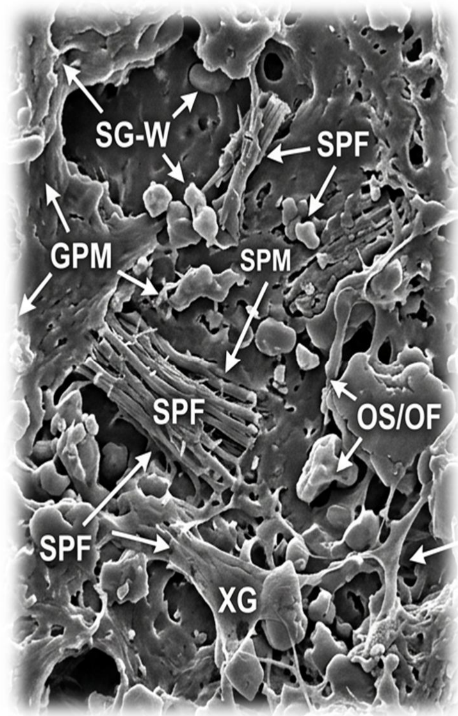

Fig.4 SEM Image of pumpkin Oats Noodles

D. Texture Profile Analysis

Texture Profile Analysis (TPA) was conducted to evaluate the textural properties of the pumpkin-enriched noodle samples. In this method, cooked noodle samples are subjected to two consecutive compression cycles using a texture analyser. The resulting force–time curve is used to determine various textural parameters such as hardness, cohesiveness, springiness, gumminess, and chewiness [46].

1) Hardness: This measures the maximum force needed to compress the noodle sample during the first cycle. It shows the firmness of the noodle and is a significant quality factor that impacts consumer acceptance.
2) Cohesiveness: This indicates how well the noodle can handle a second compression compared to the first one. It reflects the strength of the starch and protein structure formed during noodle preparation.
3) Springiness: This describes how well the noodle returns to its original shape after the compressive force is removed. Higher springiness means better elasticity and flexibility in the noodle structure.
4) Gumminess: This measures the energy needed to break down the noodle sample for swallowing. It is calculated as the product of hardness and cohesiveness and indicates how compact the noodle matrix is.
5) Chewiness: This refers to the energy needed to chew the noodle until it is suitable for swallowing. It is calculated from gumminess and springiness and reflects the overall eating quality of the noodle.

Table. 3 Tabulation for Texture Profile Analysis

Sample	Hardness (N)	Springiness	Cohesiveness	Gumminess (N)	Chewiness (N)
Control	5.42 ± 0.18[a]	0.91 ± 0.02[a]	0.62 ± 0.02[a]	3.36 ± 0.11[a]	3.06 ± 0.12[a]
S1	5.68 ± 0.17[b]	0.90 ± 0.02[a]	0.61 ± 0.01[a]	3.47 ± 0.10[b]	3.12 ± 0.11[b]
S2	5.83 ± 0.16[b]	0.89 ± 0.02[ab]	0.60 ± 0.02[b]	3.50 ± 0.09[b]	3.11 ± 0.10[b]
S3	6.05 ± 0.19[c]	0.88 ± 0.02[b]	0.59 ± 0.01[b]	3.57 ± 0.10[c]	3.14 ± 0.09[b]
S4	6.28 ± 0.20[c]	0.87 ± 0.02[b]	0.58 ± 0.02[b]	3.64 ± 0.11[c]	3.17 ± 0.10[c]
S5	6.47 ± 0.21[d]	0.86 ± 0.02[c]	0.57 ± 0.02[c]	3.69 ± 0.12[c]	3.17 ± 0.11[c]
S6	6.63 ± 0.22[d]	0.85 ± 0.02[c]	0.56 ± 0.02[c]	3.71 ± 0.13[c]	3.15 ± 0.12[c]

These textural parameters provide useful information about the firmness, elasticity, and structural stability of pumpkin-enriched noodles. They help assess how the combination of ingredients affects noodle quality [47]. Texture Profile Analysis evaluates the mechanical and sensory textural attributes of noodles, such as hardness, springiness, cohesiveness, gumminess, and chewiness. These parameters indicate the structural strength and eating quality of noodles prepared from composite flour.

Sample 4 exhibited balanced textural properties with moderate hardness, good springiness, and acceptable chewiness. These characteristics indicate desirable firmness and elasticity suitable for noodle products while still benefiting from the nutritional contribution of pumpkin and oats flour. Texture profile analysis revealed that the incorporation of pumpkin flour and oats flour influenced the structural properties of noodles. The hardness value slightly decreased from control to samples with higher substitution levels due to gluten dilution and fibre incorporation [48]. Springiness values ranged from 0.91 to 0.85, indicating acceptable elasticity. The presence of xanthan gum helped maintain structural resilience by improving water retention and dough cohesion [49].

E. Storage And Shelf Life Studies Of Control And Best Composite Noodle (S4)

The storage stability of the best composite noodle sample (S4) was tested for 90 days at room temperature (27 ± 2 °C) using polypropylene packaging. During this time, free fatty acid (FFA) content was measured as an indicator of lipid degradation. The gradual increase in FFA may be attributed to lipid hydrolysis during storage; however, values remained within acceptable limits, indicating good product stability [50]. Packaging in polypropylene helped reduce moisture absorption and oxidative deterioration, thereby maintaining product quality.

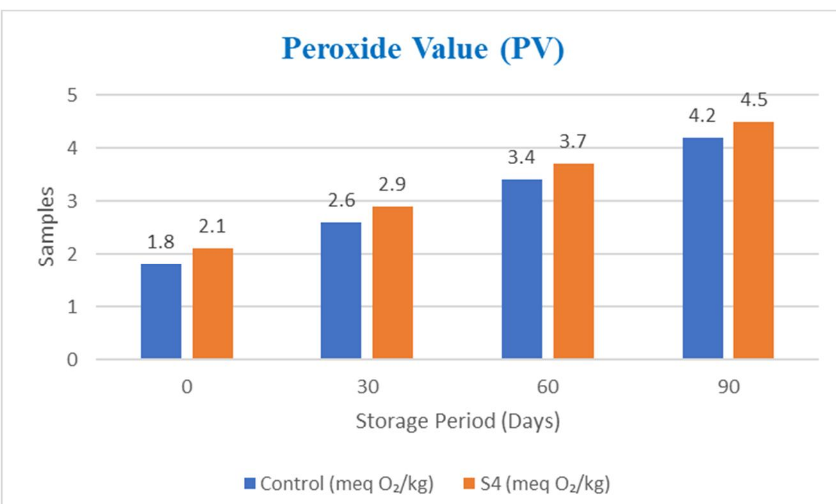

Fig.5 Peroxide Value of Pumpkin and Oats Noodles

F. Microbiological Analysis

Total Plate Count (Tpc)

Microbial quality and storage stability were assessed by determining total plate count. One gram of sample was aseptically mixed with sterile peptone water and serially diluted (10^{-1} to 10^{-4}). Aliquots were plated on Plate Count Agar and incubated at 30 °C for 48–72 hours. Colonies were counted and expressed as CFU/g [51].

Table. 4 Total Plate Count of Pumpkin and Oats Noodles

Days	Control (log CFU/g)	S4 (log CFU/g)	Acceptable Limit
0	1.8	1.9	≤ 5 log CFU/g
30	2.3	2.4	≤ 5 log CFU/g
60	2.8	2.9	≤ 5 log CFU/g
90	3.2	3.3	≤ 5 log CFU/g

Microbial counts increased slightly during storage but remained well below the permissible limit of 5 log CFU/g, indicating microbiological safety.

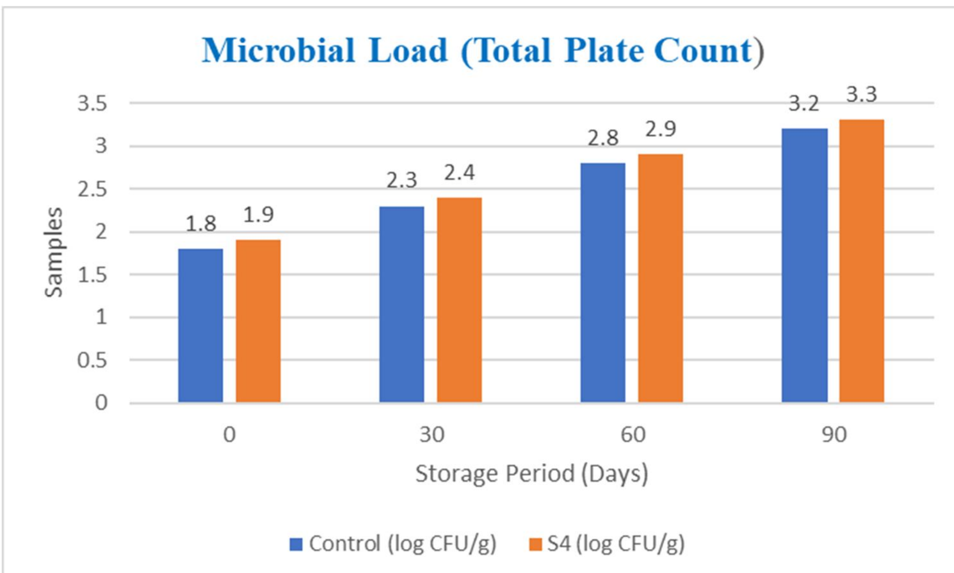

Fig.6 Microbial Load of Pumpkin and Oats Noodles

IV. CONCLUSION

The current study very successfully developed/optimised pumpkin/oat-enriched noodles using a Response Surface Methodology (RSM) to improve their health and functionality while ensuring they met adequate technological and sensory quality levels. The results showed the addition of 5% to 15% pumpkin powder and/or 5% to 15% of oat powder greatly increased nutritional content (increased β-carotene, dietary fibre, resistant starch, and β-glucan properties) in the noodle products, with oat powder adding β-glucans; both additives providing some cardiovascular health benefits, while also improving the amount of provitamin A and the overall antioxidant properties of the noodles. The optimal RSM formulation created noodles with 15% oat powder and 5% pumpkin powder for the highest desirability value (0.884) to provide a balance of cooking performance and sensory acceptability. Although an increase in pumpkin powder improved nutritional value, inclusion levels above 10%–15% were found to cause small negative changes in smell and taste due to unique aromatic compounds in the pumpkin powder. The volume of water absorbed, cooking time required, swelling index, and total amount of product retained (cooking loss) were also affected by both powders.

The addition of pumpkin and oat powders resulted in gluten dilution and modification of starch-protein interactions, affecting noodle hydration characteristics. Moderate incorporation of the two powders produced noodles with good structure and acceptable cooking behaviour. The texture values of the noodles decreased somewhat with the increased level of either powder. Overall, noodles produced with a high percentage of substitution of either powder are generally softer and may be consumed by a larger consumer group. The microscopic counts, in addition to the measured soluble solids (TSS), of the optimal RSM noodles were favourable and within acceptable limits.

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