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Physicochemical and nutritional properties of pasta fortified with carrot leaf extract

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Abstract

This study aimed to develop a nutritious pasta product by incorporating carrot leaves (*Daucus carota* L.) into semolina flour formulations at concentrations of 0%, 5%, 10%, and 15%. Carrot leaves, often considered agricultural waste, are rich in dietary fiber, antioxidants, and chlorophyll. The physicochemical properties of the resulting pasta, such as moisture, ash, protein, fat, carbohydrate content, cooking time, cooking loss, water absorption, and swelling index, were evaluated, alongside sensory attributes such as color, aroma, texture, and taste. Results showed that increasing carrot leaf concentration significantly influenced nutritional content and physical characteristics. Pasta with 10% carrot leaf powder yielded the most acceptable results in terms of sensory evaluation while enhancing nutritional value. The findings support the potential of carrot leaves as a functional ingredient in pasta development, contributing to sustainable food innovation and waste reduction.

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1. Introduction

The increasing awareness of health and wellness among consumers has led to a significant rise in demand for functional foods (1). These foods not only provide basic nutrition but also offer additional health benefits, such as disease prevention or enhancement of physical or mental well-being. As modern consumers seek food options that contribute to long-term health while aligning with sustainable and plant-based trends, the development of innovative functional food products has become a priority in the food industry (2).

Among the various plant-based sources, leafy vegetables present remarkable potential as functional ingredients (3). Carrot leaves are a byproduct of carrot harvesting that are usually discarded, while they are rich in phytochemicals, including vitamin A precursors (such as α-carotene and β-carotene), vitamin C, dietary fiber, flavonoids, and polyphenols (4,5). Prior studies have highlighted the antioxidant and anti-inflammatory activities due to the existance of phenolic and flavonoid groups (6–9).

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Pasta, a widely consumed staple food globally, presents an ideal vehicle for the fortification of functional ingredients. Pasta has a simple matrix that can be modified to incorporate vegetables or their extracts, improving both its nutritional and functional value. The incorporation of unconventional plant-based ingredients into pasta formulations aligns with modern consumer preferences and offers a familiar yet enhanced food product (10–13).

Despite the potential of carrot leaves as a functional food ingredient, research on their application in functional food is still limited. Most existing studies focus on the roots of the carrot plant, leaving a research gap concerning the effective utilization of its leaves. Unlike previous studies that mainly focused on carrot roots as functional food ingredients, this study specifically investigates the utilization of carrot leaves, an underutilized agricultural byproduct, as a fortifying agent in pasta formulations. The novelty of this research lies in the integration of carrot leaf powder into semolina-based pasta at different concentrations to simultaneously evaluate nutritional enhancement, cooking quality, physicochemical characteristics, and sensory acceptance. In addition, this study highlights the dual contribution of carrot leaves as a sustainable food ingredient with functional properties and as an approach to reduce agricultural waste, supporting the development of environmentally friendly functional foods.

2. Materials and Methods

The study employed a Completely Randomized Design with 3 replications. The pasta formulation consisted of wheat flour, olive oil, salt, and water. The formulations were enriched with 100%, 75%, 50%, and 25% carrot leaf extract, resulting in 12 sample units. To prepare the pasta, all ingredients were mixed for 5 minutes (Pastamatic 1581, Ariete, Florence, Italy). Twelve types of pasta were prepared for all formulations, then dried at 50°C (14) for 8 hours.

2.1. Chemical Composition Analysis

Product analysis methods referred to the American Association of Cereal Chemists (AACC) methods (15) and methods found in the Association of Official Analytical Chemists (AOAC) (16). Moisture content was determined using an oven method (AACC Method 44-15A). Samples (3 g) were placed in a laboratory dryer and dried at 103°C ± 1°C until constant weight was achieved. After cooling in a desiccator, samples were weighed and the moisture content was calculated. Ash content was determined using AACC Method 08-01. Samples were measured into ash plates at 3 g and placed in a muffle furnace at 550°C. Samples were ashed until light gray or constant weight was obtained (7 hours). After cooling, samples were weighed, and ash content was calculated. Total protein content was determined using the Kjeldahl method (AACC Method 46-08) and Kjeltec 2300 equipment (FOSS, Höganäs, Sweden). Protein content was calculated from total nitrogen content using a conversion factor. Fat content was determined using the Soxhlet method. SoxtecTM8000 with AN 310 application (FOSS, Höganäs, Sweden) and hexane as solvent. Total dietary fiber (TDF), including insoluble dietary fiber (IDF) and soluble dietary fiber (SDF), was determined by enzymatic methods (AACC 32-05, AACC 32-21, AOAC 991.43, and AOAC 985.29). Subsequently, 1 g of dry sample was sequentially digested enzymatically using α-amylase, protease, and amyloglucosidase (Megazyme International Ireland Ltd., Wicklow, Ireland).

2.2. Cooking Quality

Cooking loss, the amount of solid substance lost during boiling, determined by the method in AACC 66-50 (15). Swelling index and water absorption of cooked pasta (17).

2.3. Hardness and Adhesiveness

Hardness and stickiness analysis were conducted using a Texture Analyzer Z010 (Zwick Roell Italia S.r.l., Genoa, Italy) equipped with a stainless-steel cylinder probe (diameter 2 cm). Hardness (average maximum force, N) and stickiness (average negative area, N mm) were tested under the following specifications: initial load 0.3 N; load cell of 1 kN; deformation percentage 25%; crosshead speed constant at 0.25 mm/s(17).

2.4. Data Analysis

The data analysis began with a normality assessment using the Kolmogorov-Smirnov test. For datasets that met the normality assumption, a Two-way ANOVA followed by Tukey's post-hoc test was applied to evaluate statistical differences. For the non-normal data, Friedman's non-parametric test was utilised, and if the data were significant, One-way ANOVA and Tukey's comparison test were performed. All statistical analyses were performed using Minitab version 21. Each data point was collected in triplicate to ensure reliability and accuracy.

3. Results and Discussion

3.1. Proximate Characteristics

Increasing the extract concentration significantly enhances protein and total fiber content, with the highest levels observed at 100% extract. Conversely, carbohydrate content decreases as extract levels rise. Meanwhile, moisture, ash, and fat contents remain relatively stable across all treatments, showing no significant differences. These findings highlight the nutritional benefits of incorporating carrot leaf extract, particularly in boosting protein and fiber content in pasta.

Table 1 presents the proximate composition and total fiber content of pasta with varying concentrations of carrot leaf extract. The moisture content showed no significant difference among treatments, ranging from 0.69% to 1.35%, indicating a low moisture level that favors longer shelf life.

Table 1. Proximate composition and total fiber of carrot leaf pasta.

Carrot Leaf Extract	Water (%)	Ash (%)	Protein (%)	Fat (%)	Carbohydrate (%)	Total Fiber (%)
100%	0.73 ± 0.28^{a}	2.62 ± 0.28^{a}	13.82 ± 0.54^{a}	1.34 ± 0.27^{a}	81.44 ± 0.35^{b}	5.04 ± 0.46^{a}
75%	0.97 ± 0.16^{a}	2.55 ± 0.16^{a}	12.73 ± 0.94^{ab}	1.40 ± 0.35^{a}	82.00 ± 0.86^{ab}	4.41 ± 1.77^{ab}
50%	1.35 ± 0.12^{a}	2.43 ± 0.67^{a}	11.81 ± 0.70^{b}	1.68 ± 0.20^{a}	82.63 ± 0.79^{ab}	2.92 ± 1.51^{ab}
25%	1.30 ± 0.30^{a}	2.21 ± 0.23^{a}	11.79 ± 0.22^{b}	1.93 ± 0.19^{a}	83.40 ± 0.16^{a}	2.79 ± 1.06^{ab}
0%	0.69 ± 0.34^{a}	2.03 ± 0.21^{a}	11.31 ± 0.74^{b}	1.86 ± 0.33^{a}	82.54 ± 0.30^{ab}	0.32 ± 1.65^{b}

Note: All data were normal (p-value >0.150) with the Kolmogorov-Smirnov Test and analyzed using two-way ANOVA with Tukey's comparison test (p-value <0.05).

Ash content did not significantly differ, suggesting that the mineral content remained relatively stable regardless of extract concentration. In contrast, protein content showed a significant increase with the addition of carrot leaf extract, with the 100% extract group showing the highest protein level, while the 0% to 50% groups had significantly lower values.

Fat content did not vary significantly across treatments and remained low overall. Carbohydrate content, calculated by difference, showed significant differences from the 25% extract group had the highest value, while the 100% extract group had the lowest, suggesting that increased extract levels may displace carbohydrate-rich ingredients.

Total fiber content significantly increased with higher concentrations of carrot leaf extract, with the 100% group showing the highest fiber content, and the control (0%) the lowest. These findings indicate that carrot leaf extract contributes notably to enhancing the protein and dietary fiber content of pasta, with minimal effects on fat, ash, and moisture.

Based on the proximate composition of pasta fortified with carrot leaf extract, spinach leaf powder, and *Malva parviflora* (mallow) leaf powder, there are notable differences in nutritional profiles depending on the type of leaf used and concentration levels. The carrot leaf pasta (100% extract) exhibits high carbohydrate content (81.44%) and moderate protein content (13.82%), but relatively low fat (1.34%) and ash (2.62%) levels. Total fiber in this formulation reaches 5.04%, which is higher than the control pasta (0% extract, fiber 0.32%) and comparable to the fiber level in mallow leaf pasta (MLP4, 4.27%), though still lower than the fiber in spinach noodle F2 (8.69%) (18,19).

While the protein content of carrot leaf pasta reaches up to 13.82%, the F2 spinach noodle formulation shows a slightly higher value at 14.22%, and mallow leaf pasta at its highest concentration (MLP4) records the highest protein level at 17.13%. In terms of crude fiber, carrot leaf pasta provides up to 5.04%, which, although lower than the 8.69% found in spinach noodles, still represents a notable improvement compared to the control and offers meaningful dietary fiber enhancement (18,19).

The spinach noodle contains a much lower carbohydrate content (60.09%) than carrot leaf pasta (81.44%) (19). Spinach powder may significantly dilutes starch content more effectively than carrot leaf extract. The fat content across all three formulations is variable—highest in spinach noodles (5.46–5.62%) (19), moderate in mallow pasta (up to 3.58%) (18), and lowest in carrot leaf pasta (1.34–1.93%).

The protein content of carrot leaf pasta, which reaches up to 13.82%, is comparable to that of the F2 spinach noodle (14.22%) and falls within the range of values observed in mallow leaf pasta formulations (10.0%–17.13%). This indicates that carrot leaf extract is also a valuable protein contributor, offering a level of enrichment that is consistent with other leafy fortification sources (18,19).

The water content of carrot leaf pasta ranges from 0.69% to 1.35%, which reflects a drier profile compared to spinach noodles (6.26%–8.21%) and mallow leaf pasta (11.09%–12.25%) (18,19). Although lower, this moisture level is typical for dry pasta products and suggests that carrot leaf pasta maintains good shelf stability while still aligning with acceptable moisture standards in comparable formulations.

While spinach and mallow leaves are often associated with greater enhancements in protein and fiber, carrot leaf extract stands out for its ability to retain higher carbohydrate content, reaching up to 83.40%. This suggests that the incorporation of carrot leaf extract minimally interferes with starch integrity, making it a suitable choice for formulations aimed at maintaining energy-rich profiles. These distinctions highlight the value of selecting fortificants based on the desired nutritional emphasis in pasta or noodle products.

3.2. Cooking Quality

As the concentration of carrot leaf extract increases, both the swelling index and water absorption of the pasta tend to decrease, indicating reduced water uptake and expansion during cooking. In contrast, higher extract levels lead to an increase in cooking loss and hardness, suggesting that the pasta becomes firmer but also loses more solids into the cooking water. Additionally, stickiness values become less negative with greater extract concentrations, reflecting a reduction in surface adhesiveness and an improvement in overall pasta texture.

Table 2 shows the cooking quality parameters of pasta formulated with different concentrations of carrot leaf extract. A significant difference ($p < 0.05$) was observed in all evaluated attributes, demonstrating that carrot leaf extract substantially influences pasta quality. The swelling index decreased with increasing extract concentration. This reduction suggests that the extract limits starch gelatinization and water retention during cooking. Similarly, water absorption declined significantly, likely due to the reduced starch content and increased fiber, which binds water differently.

In terms of cooking loss, a key indicator of pasta integrity, values increased significantly with higher extract levels. The control group showed the lowest loss, while the 100% extract group had the highest, indicating that pasta with more extract tends to lose more solids during cooking, possibly due to weakened gluten or starch networks.

Hardness increased markedly with more extract, indicating firmer pasta structure, likely contributed by the fiber and protein content from the extract. Conversely, stickiness decreased (became more negative) with increasing extract concentration. The highest stickiness (least negative value, i.e., less sticky) was found in the 100% extract group, while the control group had the lowest, indicating that carrot leaf extract reduces surface adhesiveness, possibly due to lower surface starch release and increased fiber content.

Table 2. Cooking quality of carrot leaf pasta.

Carrot Leaf Extract	Swelling index (ml/g)	Cooking Loss (%)	Water Absorption (%)	Hardness (N)	Adhesiveness (N·mm)
100%	49.40 ± 1.97^{d}	13.40 ± 0.17^{a}	58.30 ± 2.20^{d}	538.13 ± 7.05^{a}	-33.75 ± 140.1^{a}
75%	51.70 ± 1.75^{c}	13.30 ± 0.27^{ab}	60.83 ± 1.94^{c}	517.20 ± 7.11^{b}	-176.23 ± 51.6^{ab}
50%	53.53 ± 1.94^{bc}	13.03 ± 0.21^{bc}	63.67 ± 1.93^{b}	494.07 ± 7.78^{c}	-208.50 ± 38.8^{ab}
25%	55.30 ± 1.41^{b}	12.83 ± 0.31^{c}	64.83 ± 1.55^{b}	460.63 ± 6.69^{d}	-298.23 ± 31.8^{b}
0%	60.43 ± 1.08^{a}	11.07 ± 0.21^{d}	68.23 ± 1.03^{a}	409.70 ± 5.29^{e}	-336.50 ± 33.5^{b}

Note: All data were normal (p-value >0.150) with the Kolmogorov-Smirnov Test and analyzed using two-way ANOVA with Tukey's comparison test (p-value <0.05).

Carrot leaf extract pasta showed unique physicochemical traits compared to other leafy green formulations. As the extract concentration increased, it resulted in reduced swelling index, water absorption, and stickiness, alongside higher cooking loss and firmness, indicating a denser, less hydrated pasta texture. In contrast, spinach-based noodles exhibited much higher water absorption (161.26%), lower cooking loss (7.43%), and a lower swelling index (1.85 ml/g), reflecting different hydration and cooking behaviors likely influenced by spinach's soluble fiber and mucilage content (19).

Meanwhile, egg pasta fortified with wild garlic leaves (*Allium ursinum*) also showed a reduction in swelling index (ranging from 2.91 to 2.06 ml/g) and a varied pattern in cooking loss (2.58% to 1.93%) and water absorption (225.50% to 171.08%) (20). This reflects a comparable trend with carrot leaf pasta where leaf content influences water interaction and matrix structure.

In another study using legume flour and mallow leaves, the addition of up to 12% mallow powder resulted in improved weight and volume increases (up to 241.13% and 193%, respectively), and a marked decrease in cooking loss (from 3.89% to 2.32%) (18). Despite different botanical sources, both mallow and carrot leaf pasta exhibited inverse relationships between leaf concentration and cooking loss, though mallow showed stronger water-holding properties.

Carrot leaf extract pasta demonstrated a progressive increase in hardness from 409.70 N (0% extract) to 538.13 N (100% extract), indicating that higher concentrations of carrot leaf extract significantly enhanced the firmness of the pasta. This range is substantially higher than that observed in mallow leaf formulations, where hardness values rose more modestly from 63.5 N (PC) to 85.7 N (MLP4) (18). These results suggest that carrot leaf extract has a more pronounced densifying effect on the pasta matrix, potentially due to its impact on dough structure and reduced water retention.

In terms of adhesiveness, carrot leaf pasta also showed a trend of decreasing stickiness with increased extract concentration. The adhesiveness dropped from –33.75 N·mm at 100% extract to –336.50 N·mm at 0%, suggesting that carrot leaf extract contributes to a less sticky surface texture. Meanwhile, MLP pasta displayed an increase in adhesiveness from 89 (PC) to 375 (MLP4), indicating a more cohesive and possibly gummier texture as more mallow leaf powder was added (18).

Carrot leaf pasta provides unique textural firmness and lower stickiness, distinguishing it from other leafy green pasta such as spinach, wild garlic, or mallow-based formulations, though with relatively higher cooking loss. These differences may be attributed to the distinct fiber types, phenolic content, and interaction between added leaf components and the starch-protein matrix of the pasta.

4. Conclusions

This study demonstrates the novel application of carrot leaves as an underutilized agricultural byproduct in functional pasta development, offering a sustainable approach to enhance nutritional value while maintaining acceptable physicochemical and sensory qualities. The incorporation of carrot leaf extract into pasta formulations significantly enhances its nutritional and functional properties. Increasing concentrations of the extract improved protein and dietary fiber content, while maintaining low levels of fat and moisture, contributing to a more health-oriented product. Although higher concentrations resulted in increased cooking loss and firmness, they also reduced stickiness and water absorption, producing pasta with distinct textural qualities. The 100% carrot leaf extract pasta exhibited the highest nutritional enrichment but showed trade-offs in cooking quality.

These findings highlight carrot leaves as a viable fortifying agent that not only addresses food waste by utilizing an agricultural byproduct but also aligns with consumer demand for functional and sustainable food innovations. Further research into sensory acceptability and bioactive stability is recommended to optimize formulation for commercial applications.

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Author Contributions

T.K conceptualized the study, supervised the research activities, and secured the research funding. I.B performed statistical analyses and contributed substantially to the writing and revision of the discussion section. N.H was responsible for data collection and initial data curation. S.S provided technical expertise in experimental design and methodology development. M.H contributed to the literature review and editing of the manuscript. All authors reviewed and approved the final version of the manuscript.

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Data Availability Statement

Data availability is shown at this link: https://bit.ly/CarrotPasta-UM.

Conflicts of Interest

No conflict of interest was reported by the author(s).

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