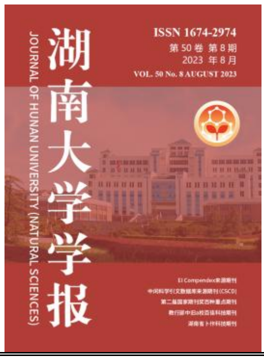

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Effect of Different Functional Ingredients on the Quality of Extruded Phyto-Snacks

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Abstract: Confectionary, biscuits, and savory snacks (including crisps and extruded snacks) are the most commonly consumed foods. Further efforts are required to develop snacks that offer positive health benefits. Possible options include adding ingredients with positive health benefits, such as fruits and vegetables. Researchers have investigated extrusion cooking as a means of creating snacks that fulfill the dietary needs of specific population groups. The aim of this study was to investigate the effect of different functional ingredients on the quality of extruded phyto-snacks. This study investigated the interactions between functional ingredient powders, the extrusion process, nutritional qualities, and antioxidant activities of the resulting product. The exact process conditions, encompassing a speed rate of 400 rpm, moisture content of 15%, and barrel temperatures of 70 and 120°C, were employed to extrude five samples. We evaluated the nutritional properties, including soluble, insoluble, dietary fiber, and carbohydrate content. In addition, we assessed phytochemical composition and antioxidant activities using DPPH and TBARS assays. Adding functional ingredients powder significantly ($P < 0.05$) affects the extrudates' nutrition, phytochemical, and antioxidant activities. The novel functional ingredients were enriched with fiber and antioxidants. Deliver snack products with an equilibrium between nutrition and antioxidants. Further work would investigate the effect of functional ingredient powders and the process conditions on physical properties and sensory preferences while bridging the innovation–health nexus within the snack industry and advancing the frontier of functional food formulations.

Keywords: functional ingredient, extruded phyto-snack, quality.

不同功能成分对植物膨化零食品质的影响

摘要：糖果，饼干和咸味零食（包括薯片和挤压零食）是最常食用的食物。需要进一步努力开发具有积极健康益处的零食。可能的选择包括添加具有积极健康益处的成分，如水果和蔬菜。研究人员已经研究了挤压烹饪作为创造满足特定人群饮食需求的零食的一种手段。本研究的目的是研究不同功能成分对挤压植物零食质量的影响。本研究研究研究研究了功能性成分粉末之间的相互作用，挤出过程，营养品质和所得产品的抗氧化活性。采用精确的工艺条件,包括一分钟的 400 转/分钟的速度，15%的水分含量，以及 70 和 120 摄氏度的桶温，挤出五个样品。我们评估了营养特性，包括可溶性，不溶性，膳食纤维和碳水化合物含量。此外，我们使用 2,2-二苯基-1-吡啶基和硫巴比妥酸反应物质测定评估了植物化学成分和抗氧

化活性。添加功能成分粉末显着（磷<0.05）影响挤出物的营养、植物化学和抗氧化活性。新的功能包括富含纤维和抗氧化剂. 提供营养和抗氧化剂之间平衡的零食产品。进一步的工作将研究功能性成分粉末和工艺条件对物理特性和感官偏好的影响，同时弥合零食行业的创新-健康联系，推进功能性食品配方的前沿.

关键词：功能成分、挤压植物零食、品质。

1. Introduction

In the contemporary food landscape, the consumption of snacks plays a significant role in the daily dietary habits of individuals. With the increasing awareness of the impact of diet on health, there is a growing demand for snack options that satisfy cravings and contribute to overall well-being. In response to this evolving consumer preference, the food industry has been exploring innovative strategies to create palatable snacks and offer nutritional benefits [1].

One approach to address this demand is to incorporate functional ingredients into snack formulations [2]. Functional ingredients are bioactive compounds derived from various natural sources, such as plants, that possess potential health-promoting properties beyond their essential nutritional value. These bioactive compounds, often called phytochemicals, encompass a diverse array of compounds, including polyphenols, flavonoids, carotenoids, and phytosterols, each with unique physiological effects [3]. By harnessing these compounds, snacks can be transformed into vehicles for delivering health-enhancing components, aligning with the shift toward healthier dietary choices [4].

The processing method employed in snack production is crucial in determining the final product's characteristics [5]. Extrusion, a well-established and widely used food processing technique, has gained prominence for its ability to transform raw ingredients into various snack forms with appealing textures and flavors. The extrusion process involves the application of heat, pressure, and mechanical shear forces to raw materials, resulting in a unique combination of textural attributes not easily achievable through other methods [6]. This technique offers the advantage of incorporating various ingredients into a matrix, resulting in snacks with enhanced functional and sensory properties.

This study aimed to investigate the effect of different functional ingredients on the product quality of extruded phytosnacks. These snacks, fortified with phytochemical-rich additives, present an exciting opportunity to provide consumers with an enjoyable snacking experience while delivering bioactive compounds that may contribute to their well-being. By systematically exploring the impact of various functional ingredients on sensory attributes, nutritional composition, and overall product quality, this research contributes to understanding how extrusion was harnessed to create phyto-snacks that bridge the gap between indulgence and health.

In the following sections of this research, we will delve into the methodology used to conduct this investigation, discuss the results obtained, and analyze the implications of our findings for the snack industry and broader dietary trends. Through this research, we endeavor to shed light on the potential of extrusion as a technology to craft snacks that cater to consumers' taste preferences and nutritional needs in an increasingly health-conscious world.

2. Materials and Methods

2.1. Chemical Reagents

Analytical grade methanol was used, and reagents including thiobarbituric acid (TBA), 2,2-diphenyl-1-dicrylhydrazyl (DPPH), and Anthrone were obtained from Sigma. Distilled water was used.

2.2. Functional Ingredients and Formulations

Functional ingredient samples were developed using powdered phytoingredients sourced from fruits and vegetables. Formulations containing a minimum of 42% functional ingredients were prepared for extrusion processing. These formulations blended specific food components, including phyto powder from fruits and vegetables (Fig. 1), binders, defatted soy flour (DFSF), maltodextrin, and rice bran oil.

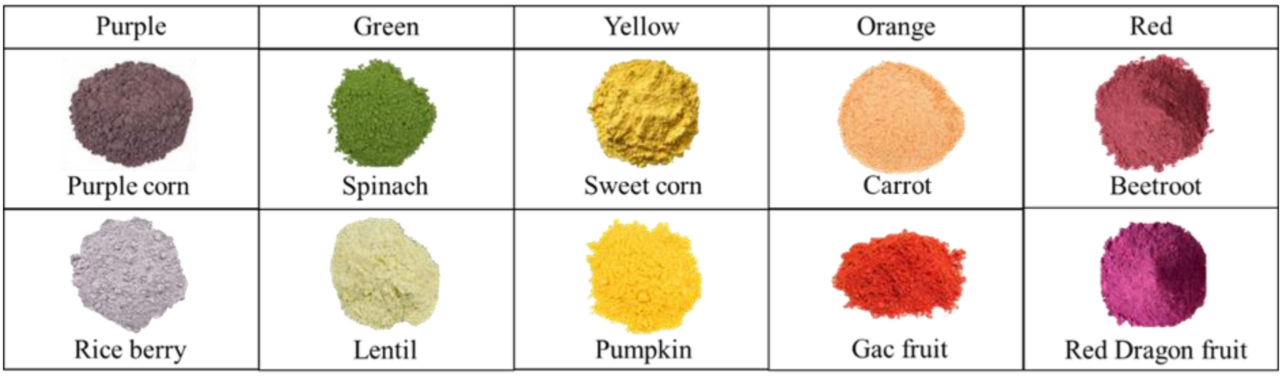

Fig. 1 Phyto ingredient powder from fruits and vegetables

2.3. Extrusion Experiment

Extrusion experiments were conducted using a twin-screw extruder. A twin-screw volumetric feeder introduced the dry mixture into the extruder. The following process conditions were applied: a screw speed of 400 rpm. The barrel was divided into two zones: the first heated to 70°C (from feed entry to midpoint) and the second heated to 120°C (from midpoint to die exit pressure). After extrusion, all samples were cooled for 30 minutes, packaged in aluminum foil bags, and stored at room temperature for later determination.

2.4. Nutritional and Phytochemical Analysis

The soluble, insoluble, and total dietary fiber contents were determined using AOAC methods [7]. The Anthrone method was employed to determine total carbohydrates (TC), and the absorbance was measured at 630 nm on a UV/Vis spectrometer. A glucose calibration curve (10–100 mg/mL) was used alongside the samples to ensure accuracy.

The Folin–Ciocalteu assay accurately determined the total phenolic compounds, with absorbance measured at 765 nm. The flavonoid contents were calculated confidently using gallic acid as a standard. The method involved mixing 1 mL of sample or standard with methanol and 4 mL of diluent, allowing the solution to stand for approximately 15 minutes before measuring absorbance at 280, 320, and 360 nm.

2.5. Determination of Antioxidant Activity

We analyzed the antioxidant activity of the extracts using two different tests. First, we used a microplate reader to assess the DPPH radical-scavenging activities. We calculated the percentage of DPPH discoloration after 1 hour of incubation by measuring the absorbance at 515 nm. Second, we used the TBARS assay to measure the color intensity of malondialdehyde-thiobarbituric acid (MDA-TBA) by its absorbance at 532 nm. The reports are expressed as EC_{50} values.

2.6. Statistical Analysis

Data were analyzed using analysis of variance (ANOVA) followed by Duncan's test. SPSS software was used for statistical analysis at a 95% confidence level.

3. Results and Discussion

3.1. Phytochemical Analysis

The functional ingredient phytochemical composition analysis in this study revealed significant variability in the levels of soluble and insoluble dietary fiber, total dietary fiber, and total carbohydrates (Table 1).

Table 1 Analysis of the nutritional content of extruded phyto-snack (Values bearing different letters in the same column are statistically significant differences ($p < 0.05$) compared by Duncan's test)

Treatment	Functional ingredient (Powder form)	Nutritional content (g/100 g dry weight) (Mean ± SD)			
		Insoluble fiber	Soluble fiber	Total dietary fiber	Total carbohydrates
1	Purple corn and rice berry (PR)	9.97 ± 0.39^{b}	0.63 ± 0.09^{ab}	10.23 ± 0.39^{ab}	70.08 ± 1.28^{a}
2	Spinach and Lentil (SL)	10.81 ± 2.22^{ab}	0.52 ± 0.07^{b}	10.15 ± 2.22^{ab}	69.73 ± 1.16^{ab}
3	Sweet corn and pumpkin (SP)	8.64 ± 0.26^{b}	0.75 ± 0.05^{a}	9.39 ± 0.26^{b}	70.04 ± 0.73^{a}
4	Carrot and Gac fruit (CG)	12.31 ± 2.54^{a}	0.11 ± 0.09^{c}	12.56 ± 2.54^{a}	65.80 ± 0.65^{b}
5	Beetroot and red dragon fruit (BR)	11.12 ± 1.11^{a}	0.27 ± 0.02^{c}	11.39 ± 1.19^{a}	60.15 ± 4.28^{b}

The soluble fiber content within the ingredients exhibited a range of 0.11 ± 0.09 g/100g dw to 0.75 ± 0.05 g/100g dw, whereas the insoluble fiber content ranged from 8.64 ± 0.26 g/100g dw to 12.31 ± 2.54 g/100g dw. Notably, the functional ingredients displayed diverse profiles concerning total fiber content, with values ranging from 9.39 ± 0.26 g/100g dw. to 12.42 ± 2.54 g/100g dw.

After extrusion processing, the structural modifications that likely contributed to the observed increase in total carbohydrates stemmed from cell rupture and heightened porosity of cell walls. These alterations result in an enlarged specific surface area, facilitating the diffusion of solvents within the extrudates and subsequently increasing the availability of these carbohydrates [8]. The potential influence of different food matrices is a plausible explanation for these variations [9]. These disparities underscore the inherent potential for incorporating a spectrum of dietary fibers into extruded phytos-nacks, thereby augmenting their overall nutritional value [10].

3.2. Antioxidant Activity

In Table 2, the total phenolic content exhibited a range of 4.86 ± 0.07 to 9.38 ± 0.01 mg GAE/g, while the flavonols content ranged from 7.59 ± 0.07 to 13.17±0.38 mg QE/g across treatment groups: three # SP, two # SL, one # PR, five # BR, and four # CG.

Table 2 Analysis of the phytochemical and antioxidant properties of extruded phyto-snack

Treatment	**Phenolic compound (Mean ± SD)**		**Antioxidant properties (EC_{50}, mg/mL MetOH extract) (Mean ± SD)**	
	Total Phenolics (mg GAE/g)	**Flavonols (mg QE/g)**	**DPPH assay**	**TBARS assay**
1 # PR	8.12 ± 0.04^{ab}	9.30 ± 0.51^{c}	69.99 ± 1.09^{bc}	6.32 ± 0.15^{b}
2 # SL	6.59 ± 0.01^{b}	7.98 ± 0.09^{d}	60.77 ± 0.87^{c}	4.17 ± 0.07^{c}
3 # SP	4.86 ± 0.07^{c}	7.59 ± 0.07^{d}	59.57 ± 3.01^{c}	3.52 ± 0.34^{c}
4 # CG	9.38 ± 0.01^{a}	13.17 ± 0.38^{a}	86.93 ± 2.79^{a}	7.49 ± 0.29^{b}
5 # BR	9.14 ± 0.51^{a}	10.11 ± 0.17^{b}	74.57 ± 1.83^{b}	9.32 ± 0.51^{a}

Note: Values bearing different letters in the same column are statistically significant differences ($p < 0.05$) compared by Duncan's test.

The outcomes underscore the influence of distinct functional ingredients within the extruded phyto-snack blends, particularly evident in treatment four # CG, which displayed significantly elevated ($p < 0.05$) levels of total phenolic and flavonol content compared with mixes containing carrot and gac fruit. The observed augmentation in these functional constituents results from the influence of extrusion processing, which may facilitate phenolic decarboxylation owing to elevated barrel temperature and heightened moisture content, potentially fostering the polymerization of phenolic compounds and tannins, subsequently contributing to diminished extractability and antioxidant activity [11].

Two distinct in vitro assays were employed to evaluate the antioxidant properties (EC_{50}, mg/mL MetOH extract) of the extruded phyto-snacks (Table 2). The DPPH assay disclosed varying degrees of radical scavenging, underscoring the diverse antioxidant capacities of distinct formulations. Specifically, treatment four # CG exhibited an EC_{50} of 86.93±2.79 mg/mL, while treatment five # BR yielded an EC_{50} of 9.32±0.51 mg/mL MetOH extract, as determined by the DPPH and TBARS assay, respectively. The findings underscore the significant impact of the extruded process and functional components on antioxidant activity, as discerned through distinct assay methodologies. The antioxidant and free radical potentials of functional ingredients in dietary snacks are contingent on the levels and compositions of bioactive compounds [12].

4. Conclusion

In conclusion, this study delved into extruded phyto-snacks enriched with functional ingredients, revealing a comprehensive understanding of their formulation, nutritional composition, and antioxidant potential. Through meticulous analysis, it was evident that incorporating diverse functional ingredients sourced from fruits and vegetables yielded snack formulations with varying soluble and insoluble dietary fiber contents, contributing to their nutritional value. The extrusion process successfully integrated these functional ingredients with carefully selected components, resulting in snack matrices that meet the criteria of both health-enhancing properties and sensory attributes.

The nutritional analyzes highlighted the significant role that functional ingredients play in boosting the soluble and insoluble dietary fiber content of phyto-snacks. These findings cater to the growing consumer demand for fiber-enriched products that contribute to overall well-being. Moreover, the modulation of the total carbohydrate content, influenced by functional ingredients and developed components, showcased the intricate interplay between nutrition and product formulation.

The evaluation of antioxidant activity provided noteworthy insights into the potential health benefits of these phyto-snacks. The DPPH radical-scavenging and TBARS assays collectively illuminated the ability of the snacks to mitigate oxidative stress and lipid oxidation, underpinning their potential as functional food products with antioxidant properties.

This study's implications for product development are substantial. The findings pave the way for snack manufacturers to create products that cater to the contemporary consumer's dual demands for taste satisfaction and health enhancement. By harnessing the diversity of functional ingredients and refining the formulation, snack creators can deliver innovative options that offer enjoyment and contribute to a healthier diet.

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