Sustainable production of gluten free tigernut pasta and analysis of its functional and physicochemical characteristics

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Abstract

The goal of this research was to develop gluten free pasta product by utilizing the Tigernut (TN) tuber waste (generated post milk extraction). A key idea in sustainable and waste minimization applications is waste food valorization. Lab scale pasta extruder machine was used. The TN tuber waste was oven dried and grinded into flour. 100% Semolina flour pasta was control sample. TN flour (10, 30, 50, 70%) was blended with red bean flour (20, 40, 60, 80%), Djulis flour 10%, corn starch 40%, Kappa carrageenan 1.5%, egg 30% and 20% water in the production of TN based pasta. On an evaluation of functional, and physicochemical analysis, the various flour compositions containing tigernut flour exhibited substantial variances from pasta produced with control sample. The ideal texture and consistency of flour was rendered attainable with the utilization of 1.5% kappa carrageenan. The color of the pasta was improved due to incorporation of djulis. The combination of TN flour, red bean flour, and djulis flour enhanced the functional and physicochemical characteristics of gluten free pasta. This research may offer insights into the way to process TN pasta while promoting sustainable production and consumption, which could help ensure food security and accomplish the requirements of a growing demographic.

Keywords: pasta extrusion, tigernut based pasta, gluten free pasta, sustainable production, food security

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1. Introduction

Food preferences have shifted in the modern era, and the accessibility of processed food is ascending. The consumption of vegetables, fruits, and dietary fiber, considered essential components of a balanced diet, is dropping as people's food choices transition and they devour higher-energy foods (Martín-Esparza et al., 2018). Reducing waste and loss of food is vital for minimizing production costs, boosting the effectiveness of the food mechanism, and promoting a sustainable environment. Waste food valorization is a significant notion in sustainable and waste minimization initiatives. We can lessen our influence on our surroundings and develop novel, valuable goods by figuring up creative methods for utilizing waste materials (Socas-Rodríguez et al., 2021). Optimize the amount of energy used for producing of lab-scale pasta and also to reduce the loss of energy amid the cooking and drying processes, use appliances that are energy-efficient, such as pasta machines, induction cookers, or efficient ovens plays an important role in sustainable production of pasta (Bresciani et al., 2022). Developing measures to reduce waste production and encourage waste reduction. For instance, one can minimize waste and improve resource use by repurposing the byproducts of grain processing for other uses like developing novel products or use it as animal feed or compost (Amoriello and Ciccoritti, 2021).

The sustainability of food is the foremost concern for the present as well as the future. The top priorities are the execution of environmentally friendly initiatives and bridging the gap amid the need for growth in the economy and the necessity of safeguarding ecosystems and human well-being. People choose products that are composed of natural ingredients which are usually rich with nutrients and are beneficial to human health. The FAO (Food and Agricultural Organization of the UN) considers pasta to be a model of a sustainable, nutritious, and excellent diet. The majority of developed as well as developing nations utilize wheat for producing a common staple food that's referred to as pasta. Pasta-based foods tend to be unhealthy for individuals with celiac illness. Based on the benefits, the application of rice flour alongside various types of flour in the production of gluten-free products is growing in in favor (Bolarinwa and Oyesiji, 2021). Pasta intake and manufacturing are increasing globally, with an anticipated yearly growth rate of 4.4% from 2019 to 2023 (Saget et al., 2020). Tigernut flour, a typical cereal-based dish that is developed and consumed across the globe, might be added to pasta products to fill the gap while also giving benefits to health. Pasta is also easy to prepare and cost-effective for people (Romano et al., 2021). The extended shelf life, short preparation duration, and numerous shapes and forms of this item are its main advantages. The incorporation of pseudo-cereals, legumes, as well as other additives to multiple cereal basic materials commonly improves the nutritional value and flavor profile of pasta (Sobota et al., 2020).

Tigernut (*Cyperus esculentus* L), often referred to as earth almond, is a smaller root vegetable which is becoming well-known because of the many health advantages it delivers. Tigernuts, tiny tubers with a subtly sweet and nut flavor, are utilized for producing Tigernut (TN) flour. Tigernuts, despite their name, are in fact root vegetables rather than nuts (Maduka and S Ire, 2018). They are used for numerous decades in various dishes and have gained popularity in several parts of the world(Maduka and Ire, 2019). Tigernuts can be valued by identifying and maximizing their value in an array of industries, including food and beverages, the agricultural sector, and alternative healthcare. The commercialization of tigernuts offers prospects for developing novel products, a boost to the economy, and sustainable agriculture as the market for healthy, organic, and plant-based products elevates (Barba et al., 2019). Tigernuts are often dehydrated and eaten as a distinct nutritious snack. They can also be mixed into trail mixes, breakfast cereal, and snack bars. Tigernut flakes or chunks can be used as a garnish for desserts, yogurt, and breakfast cereals (Elizabeth and Tijesuni, 2020). Tigernuts constitute an ideal source of fiber, antioxidants, and micronutrients like manganese, and potassium (Badejo et al., 2020). They serve a purpose for the production of functional food items because of their nutritive characteristics. Tigernut fiber could be retrieved and utilized as a functional component in food products or as a nutritional supplement. We may devour them raw, roast them, or produce flour by grinding them. Tigernut flour has the potential to be utilized in baking as an alternative to wheat flour considering it is gluten-free (Gasparre, 2021). Tigernut milk, a prevalent dairy-free substitute that can be incorporated into cereal, smoothies, and coffee, is produced by combining soaked tigernuts . The gluten-free and diets based on paleo can both benefit from using tigernut flour as a free of grains and gluten-free substitute for conventional flours. When making bread, cakes, and cookies, it often serves as an alternative to wheat flour (Swelam et al., 2021). It's essential to continually keep in consideration that tigernut flour has distinct qualities from wheat flour and can require modifications to other components or baking processes. While using tigernut flour, might have to reduce the usage of additional sweeteners in the method because of the flour's own sweetness (Ani, 2021).

Therefore, taking into consideration the valorization of waste material that generated following the extraction of Tigernut milk from TN tubers can be utilized in the production of pasta. The goal of this research was to develop pasta product by utilizing the TN tuber waste (generated post milk extraction) and to assess its functional and physicochemical characteristics. The research fosters more substantial theoretical progress and practical comprehension of how TN waste could develop via future research on the advantages that novel reuse choices can provide.

2. Materials and Methods

2.1. Procurement of raw material

Tigernut (*Cyperus esculentus* L) tubers were procured from Tigernut Traders Co., Ltd, L'Eliana, Spain. Red bean flour and Djulis were bought from the local market. Other chemicals and materials procured were of analytical grade.

2.2. Flour preparation

A laboratory use grinder (RT-04, Mill Powder Tech Solution, Tainan, Taiwan) was used to ground dry tubers. Afterwards, the TN flour was sealed in a polyethylene bag and stored in a cool, dry environment for subsequent analysis. The raw material composition of TN (10, 30, 50 and 70%), red bean flour (80, 60, 40, 20%) and djulis flour of 10% each was homogenously mixed. The flour was passed through 44 mesh sieve and stored at 4°C till further analysis.

Treatment	Tigernut flour (%)	Red bean flour (%)	Djulis (%)	Egg (%)	Water (%)	K-Carrageenan (%)
T1	Wheat flour 100%	-	-	30	20	1.5
T2	10	80	10	30	20	1.5
T3	30	60	10	30	20	1.5
T4	50	40	10	30	20	1.5
T5	70	20	10	30	20	1.5

2.3. Pasta processing

After initial trials, the formulation was set as a proportion (1.5 g/100 g) of Kappa Carrageenan (Showa Chemical Co. Ltd., Japan) additive in per 100 g of formulation. A fixed amount of egg (30%) and required amount of water according to dough properties was added to each sample. The amount of egg, water and K-Carrageenan were chosen based on the preliminary studies. The condition and moisture content were chosen based on the preliminary studies. Mixed samples were extruded using pasta extruder (La Monferrina, Model P6, Roma, Italy). The pasta samples were dried at 60°C for 4 h in tray dryer and packed in air tight container for further use.

2.4. Functional properties

2.4.1. Optimal cooking time

Cooking time of pasta samples were determined according to method followed by Ciccoritti et al. (2019) with minor modifications. Twenty-five grams of pasta samples were cooked with 250 ml of boiling water for its optimum cooking time. Optimum cooking time was considered when core of the pasta gets completely hydrated.

2.4.2. Cooking loss

For the cooking loss assessed by following the method of Desai et al. (2018) with slight modifications. The cooking water resulted from *WA* determination was placed in glass containers and dried in an oven at 105 °C until dryness. The residue was weighted, three replications being made.

2.4.3. Water absorption index (WAI)

The WAI was determined in triplicate according to the method described by (Giménez et al., 2013). Ten grams of the pasta were boiled in 200 ml of distilled water and after *OCT,* the samples were drained for 3 min and weighed.

2.4.4. Swelling index

The swelling index was determined by using the method described by Ungureanu-Iuga et al. (2020) with some modifications. Pasta samples boiled and weighted for *WA* determination were placed in glass containers, dried at 105 °C for 16 h, cooled and weighted again. Measurements were done in triplicate and the results were calculated as (weight of cooked pasta-weight of pasta after drying)/(weight of pasta after drying).

2.4.5. Oil absorption capacity (OAC)

The method followed by Surasani et al. (2019) was minimally amended to determine the oil absorption capacity (OAC) of the sample. Five grams of flour and 75 mL of oil were mixed and agitated for 30 min and then centrifuged for 10 min at 3000 × g. Afterward, oil was drained while the retained sample was weighed to calculate OAC as shown in the below equation: OAC is calculated using equation (1):

$$\mathrm{OAC} = \left(\frac{\text{Weight of the gel obtained after removal of supernatant (g)}}{\text{Weight of the sample (g)}}\right) \qquad (1)$$

2.5. Color

The color of powdered extrudates was evaluated using a ColorQuest (Hunter-Lab, Reston, Virginia, USA) colorimeter working with xenon lamp illumination and at 8° angle as described by Delić et al. (2023). Prior to taking assessments, the instrument had been set up against a reference white tile. Every sample was analyzed five times after being ground into a fine powder. The values of L* (whiteness/darkness), a* (redness), and b* (yellowness) were averaged respectively to describe the color.

2.6. Texture profile analysis

The method of Kadiri et al. (2020) was amended to assess the hardness, and adhesiveness of the extrudates by using an Instron Universal Testing Instrument (model 5564, Instron Co., Ohio, USA) installed with a 50 N load cell. Fifteen replications of each sample extrudate were analyzed. The sample height was 22 mm, speed was 50 mm/min. The peak force required to cause a 60% deformation and compression head speed of 50 mm has been evaluated. The amount of force required to fully cut an extrudate sample with a double press was noted. The test instrument was connected to a computer, which produced the data gathered throughout each series of readings.

2.7. Total polyphenol content (TPC) and flavonoids (TFC)

The TPC and TFC were calculated by the methods described by Padalino et al. (2019). The TPC and TFC were expressed as milligrams of gallic acid equivalents per gram of dry extract (mg GAE/g DE) and milligrams of quercetin per gram of dry extract (mg QE/g DE) respectively.

2.8. DPPH Antioxidant activity & Reductive potential estimation (RPE)

Antioxidant activity (AOA) was measured using the method described by Padalino et al. (2019) Antioxidant activity was calculated as percent discoloration.

2.9. Statistical analysis

Data were assessed by Duncan's multiple range test using statistical 7 (statistical soft, TULSA, USA) statistical software packages at $p < 0.05$ was used to determine the level of significance. Descriptive statistics like mean and standard deviation were computed. One way analysis of variance (ANOVA) was used to know the mean differences between the different treatments.

3. Results and discussion

3.1. Functional properties

3.1.1. Optimal cooking time of pasta

The enriched pasta resembled refined pasta in physical appearance, without any noticeable bran fragments, and a vibrant pinkish color. The behavior about optimal cooking time for pasta was similar to the control sample pasta. The stage at which the hardness achieved an inflection is regarded as the ideal cooking time. Due to the substantial decrease in hardness, as shown in Table 2, the ideal cooking time for the pasta was 300sec, 320sec, 340sec, 350sec for T2, T3, T4, and T5 respectively. Whereas it took 240 seconds for the control pasta. Despite the cooking times for control and the other pastas were little higher, pasta with 70 % TN was more difficult to prepare than pasta with 50% of TN. In comparison to other pastas, control pasta had a better firmness index. The lower firmness of other pastas could possibly be indicative of the gluten-free network which is congruent with observation made by Ciccoritti et al. (2019).

Table 2 Optimal cooking time of pasta

Treatment	Optimal cooking time (seconds)
T1	240±2.00^{b}
T2	300±3.00^{c}
T3	320±2.00^{a}
T4	340±2.00^{a}
T5	350±3.00^{b}

3.1.2. Cooking loss

In comparison to the control sample, the incorporation of the TN flour and red bean flour as a substitute for semolina prompted a statistically significant reduction in the cooking losses. The cooking loss of the control pasta was found to be 3.30 %. The cooking losses of pasta ranged from 3.70 to 3.75%. It was observed that higher inclusion of pasta with TN (70% compared to 10%) gave higher cooking losses. Dietary fiber from TN's physical characteristics can counteract the effect of starch dilution, which occurs when starch absorbs water, expands, and appears to solubilize when cooked. The amylose particles that are lost in the boiling water are influenced by the fragile binding network. As a result, the use of TN flour in the development of pasta can reduce the water absorption index upon cooking, which pertains to the dilution of starch. Decreased cooking losses are determined by lipid and amylose complexes that have poor water solubility.

Table 3. Cooking loss of pasta

Treatment	Cooking loss (%)
T1	3.30±2.00^{ab}
T2	3.70±1.00^{ac}
T3	3.75±1.50^{c}
T4	3.76±1.00^{b}
T5	3.75±1.30^{a}

3.1.3. Water absorption index

Water absorption index is a measure of the amount of water absorbed by the pasta. Table 4 illustrates that the incorporation of higher amount of TN caused a significant decrease in water absorption index. WAI values ranged from 7.37 −7.98 % for pasta and was 8.66% for control. This may be due to the utilization of TN flour with red bean flour in pasta samples, which reduces starch swelling and pasta water absorption by competing with the starch for water during pasta formation. The decrease in water absorption index could be partly explained by a decrease in swelling index. During pasta formation, TN flour is competing with the starch and this would reduce starch swelling and consequently water absorption of pasta. Similar results were observed in the study conducted by Desai et al. (2018) in which the Fish powder interacted with the starch, reducing starch swelling and, consequently the pasta's water absorption ability. The greater potential of the TN and red bean flour to absorb and maintain water within a strongly formed starch-protein network could be responsible for the higher water absorption index values observed for pasta. The findings of the water absorption in this investigation demonstrated that the starch in the pasta treated with TN and red bean flour might not have gelatinized as much as the control sample while cooking.

Table 4.WAI of pasta

Treatment	WAI (%)
T1	8.66 ± 3.10^{a}
T2	7.98 ± 2.48^{b}
T3	7.43 ± 3.23^{a}
T4	7.46 ± 3.01^{c}
T5	7.37 ± 2.87^{c}

3.1.4. Swelling index

In Table 5, the swelling index of pasta samples is presented. The swelling index of the pasta made with 70 TN was lower than that of the control pasta. The generation of a protein network in the TN enriched pasta might have reduced the amount of water accessible to the starch granules for swelling and gelatinization, which could explain the lower swelling index. The difference in optimal cooking time and swelling index results obtained in the present study and reported in literature could be due to different type and content of ingredient used and different processes used. The differing patterns in swelling and solubility correspond to variations in the forces that bind the starch granules together. The high solubility and low swelling are indicative of weak forces of interaction among the starch granules. This might be explained by the adverse effect that milling inflicted on the TN starch granules (Odey and Lee, 2020). However, some research has shown a significant increase in the swelling index at increasing concentration of dietary fibre and legumes in pasta (Desai et al., 2019).

Table 5. Swelling index of pasta

Treatment	Swelling Index (g/g)
T1	3.04 ± 0.06^{c}
T2	2.98 ± 0.05^{b}
T3	2.76 ± 0.06^{b}
T4	2.75 ± 0.04^{a}
T5	2.76 ± 0.07^{c}

3.1.5. Oil absorption capacity

OAC ability is a key flour quality that stipulates how it could be used in various food compositions along with how effectively it can hold oil, which has an impact on the resulting product's flavor persistence and mouthfeel. A higher proportion of hydrophobic groups than hydrophilic groups on the surface of protein molecules contributes to increased mouthfeel and flavor, and this is associated with high oil absorption capacity (Singh et al., 2023). The propensity of the TN flour to absorb oil falls considerably ($P<0.05$) as proportion of TN increases, from 10%

to 70%. According to this finding, TN flour has a lesser ability to hold onto oil than other flour. Further factors that influence the OAC of flour comprise the size of the flour fragments, the amount of starch, and the presence of nonpolar amino acids. Variability in the existence of non-polar side chains, that might bind the hydrocarbon side chains of the oil, could potentially be utilized to justify variations in the capability of the flours or composites to bind oil. Overall trend of increasing OAC was found due to increase in protein content with increased incorporation level of TN flour.

Table 6. OAC of pasta

Treatment	OAC (g/g)
T1	3.04±0.06^{b}
T2	2.98±0.05^{a}
T3	2.76±0.06^{c}
T4	2.75±0.04^{b}
T5	2.76±0.07^{a}

3.2. Color

The initial aspect that plays a role in a consumer's decision to purchase pasta is color since diverse pasta colors cause varied reactions among distinct consumers. The intrinsic color of the flour, the size of the flour grains, the amount of protein, and enzymatic and non-enzymatic processes may all have an impact on the color of the pasta (Singh et al., 2023). Table 7 depicts the results for pasta's color attributes (L*, a*, b*) as modified by various proportions of TN flour, red bean flour, and djulis flour incorporation. The whiteness of the pasta reduced when the djulis and red bean flour was included, as seen by a declining pattern in the L* value of the pasta. The findings indicated that the L* values (related to brightness) for uncooked pasta dramatically increased from 67.01 to 67.12 with the inclusion of red bean flour at increasing levels. Reduction in the lightness of the pasta, demonstrating that heating caused the pasta to be darker in color than when it was uncooked, which might be attributable to non-enzymatic browning occurrences. The pasta's a* values gradually increased, indicating that their color was closer to red or pinkish. The steady rise in the b* value indicates that the pasta's degree of yellowness increased.

Table 7. Color characteristics of Pasta

Treatment	L*	a*	b*
T1	73.29±1.02^{ab}	2.78±0.80^{c}	10.35±0.32^{a}
T2	67.12±1.25^{a}	3.65±0.37^{b}	11.23±0.28^{b}
T3	67.04±1.16^{ac}	3.79±0.54^{b}	11.72±0.16^{ac}
T4	67.03±1.21^{b}	3.88±0.23^{a}	11.71±0.23^{ab}
T5	67.01±1.31^{c}	3.95±0.33^{c}	11.68±0.51^{b}

3.3. Texture profile analysis

The main indicator for assessing the overall quality of pasta is texture analysis. The key factors affecting a consumer's approval of pasta are its texture and mouthfeel. With the incorporation of TN, red bean, and djulis, the roughness and hardness characteristics of cooked pasta considerably increased. Cohesiveness noticed a decline at a content level of up to 30%. At above 30%, all TPA characteristics gradually increased, with an increase in adhesiveness that was followed by a decline. Incorporating TN flour in modest amounts will often enhance the structural characteristics of pasta to a limited threshold, however using excessive amounts would weaken the protein in noodles, disrupt the network structure, and lower the pasta's quality. Red bean flour can improve the structural properties of noodles to a certain extent (Han et al., 2022). However, the inclusion of 40% red bean flour reduced the hardness when compared to the identical pasta with 60% red bean flour, possibly as a result of an upsurge in dietary fiber content, that might have caused the emergence of crashes or breaks within the red bean strand, weakening the pasta structures. Similar results were reported by Arribas et al. (2020), who discovered that incorporating 10% whole carob fruit into fettuccine reduced the number of breaks that would have occurred as a consequence of the larger amount of dietary fiber.

Table 8. Texture analysis of Pasta

Treatment	Hardness (N)	Adhesiveness (J)
T1	8.05 ± 0.28^{c}	0.22 ± 0.04^{b}
T2	9.89 ± 0.31^{b}	0.23 ± 0.11^{b}
T3	9.95 ± 0.23^{ac}	0.22 ± 0.13^{a}
T4	9.96 ± 0.29^{a}	0.26 ± 0.12^{bc}
T5	10.02 ± 0.42^{c}	0.25 ± 0.15^{ac}

3.4. Total polyphenol content (TPC), flavonoids (TFC), DPPH antioxidant activity & Reductive potential estimation (RPE)

The TPC and TFC investigation indicate that incorporating higher TN flour considerably increased the TPC and TFC pasta (Table 9). The TPC of the other pastas is unaltered by cooking, however, it slightly decreased in the pasta made with 70% TN flour. This might imply that the antioxidant components have not undergone significant change. The propensity is identical for both uncooked and cooked pasta in terms of the antioxidant capacity as determined by DPPH and RPE, with an upsurge in activity that has a direct correlation with the higher TN content. The findings corroborated those of Michalak-Majewska et al. (2020), who found that adding OS powder considerably enhanced the concentration of TPC and TFC. The findings are consistent with earlier research on pasta enhanced with phenolic-rich ingredients, such as chia flour (Aranibar et al., 2018).

Table 9. TPC, TFC, DPPH and FRAP of Pasta

Treatment	TPC (mg GAE/100 g)	TFC (mg QE/100 g)	DPPH (%)	FRAP (mg AAE/100g)
T1	41.34±0.76[a]	40.19±0.12[a]	77.43±1.21[ac]	17.01±0.23[b]
T2	43.56±0.45b[a]	48.33±0.27[ab]	81.20±0.99[bc]	19.44±0.81[bc]
T3	44.12±0.55[a]	48.65±0.23[cd]	82.11±0.73[a]	19.91±0.64[c]
T4	44.97±0.23[c]	48.98±0.47[b]	82.21±0.45[c]	20.12±0.27[c]
T5	45.12±0.97[b]	48.98±0.62[a]	82.45±0.67[ab]	20.11±0.54[a]

4. Conclusion

The core of this work is the production of gluten-free pasta using Tigernut tuber waste that is generated post TN milk extraction. Sustainable food product development can be achieved by utilization of legumes due to their low carbon foodprint. The most crucial step is to minimize TN waste following milk extraction. Producing nutritious and gluten-free pasta has been attempted while taking into consideration factors such as sustainable food product development, waste minimization, and utilization of underutilized TN and djulis. The combination of TN, red bean and djulis improved the physicochemical and functional properties of gluten-free pasta. This study may offer information on how to produce TN pasta while encouraging environmentally friendly production as well as consumption, which might assist in ensuring food security and meeting the dietary requirements of a population that is growing. This study might assist in utilization of TN in producing TN based healthy products.

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