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The quality assessment of starch based noodles enriched with Noui Khuea brown rice starch, physicochemical characteristics and functional properties

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Abstract

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This study aimed to develop starch-based noodles enriched with Noui Khuea (NK) brown rice starch by substituting rice starch at six different levels (0%, 20%, 40%, 60%, 80%, and 100%). The research was designed to investigate how varying proportions of NK brown rice starch influence the physicochemical, functional, and quality characteristics of the noodles. Specifically, the study evaluated parameters such as color, moisture, and water activity (a_w) and viscosity and bulk density. By systematically substituting rice starch with NK brown rice starch, the study sought to determine the optimal substitution level that balances desirable noodle quality with enhanced nutritional value. The physicochemical characteristics and functional properties of the noodle samples were systematically evaluated. Substitution with NK brown rice starch resulted in significant improvements in nutritional and functional properties. At 100% substitution, the noodles exhibited the highest DPPH radical scavenging activity (35.7%), indicating superior antioxidant potential compared to the control (11.18%). Water absorption capacity and swelling index increased from 1.30 to 1.80 g g^{-1} and 5.06 to 6.50 g g^{-1}, respectively, while peak viscosity rose from 225.60 cP in the control to 307.93 cP, reflecting better gelatinization behavior and stability under heat. This research introduces an innovative approach to noodle development by incorporating Noui Khuea brown rice—a local, underutilized rice variety from Southern Thailand—into functional food applications. The study demonstrates how local agricultural resources can be creatively transformed into high-value products with enhanced health benefits, aligning with the principles of Creative Science and sustainable development.

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1. Introduction

For more than half of the world's population, rice is their primary source of nutrition. The major types of rice products include rice paste, rice noodles, and cakes made of rice. Among these, rice noodles are especially significant due to their versatility in culinary applications and cultural relevance in many Asian countries. Rice noodles, which are produced by crushing, fermenting, steaming, and other methods, are quite popular in China because they are easy to make, have a smooth texture, and taste good [1]. The primary factors influencing the quality of rice noodles are the physical and chemical characteristics of the rice flour, which creates a certain network structure [2]. These properties, such as starch composition, amylose-to-amylopectin ratio, and moisture content, influence the noodle's elasticity, cohesiveness, and cooking behavior. Rice noodles are widely recognized as a staple food in East and Southeast Asia, particularly in China, and have gained increasing popularity due to their versatility and cultural significance. The production process typically involves the use of polished rice and encompasses several steps, including soaking, fermentation or non-fermentation, milling, gelatinization, extrusion, retrogradation, and drying. These processes are designed to improve texture, increase shelf life, and enhance the functional quality of the noodles. Rice noodles are commonly classified into three categories based on their moisture content: fresh noodles (with moisture content exceeding 60%), dry noodles (less than 14% moisture), and semi-dried noodles (moisture content between 14% and 60%) [3]. Conventionally produced rice noodles have a fairly low functional value since some of their nutrients are lost and degraded during cooking [4]. On the other hand, rice noodles made completely of rice flour often have worse extensibility,

little nutritional content, and significant boiling losses. The disadvantages include the inability to satisfy the standards for quality rice noodles, which include their nutritional value, light taste, smooth appear, and moderate viscoelasticity [5]. Numerous studies have examined at the variables that impact the quality of rice noodles, including raw ingredients, processing techniques, and additives. A variety of methods have been used to improve rice noodles' quality [6] including the aging of rice [7], modifications to the milling process [8], hydrothermal treatments [9], and the use of additives. According to reports, a combination of rice flour and pea starch has been used to create gluten-free pasta [10]. When more pea starch was included, the finished rice noodles' texture increased firmer, resulting in rice noodles with an appealing texture and minimal cooking losses. It has been shown that adding the right quantity of potato starch to rice noodles will improve their transparency and smoothness, which will improve their texture and cooking efficiency [11]. Although these methods can improve the quality of rice noodles, the issues of damage rate and cooking losses remain difficult to resolve [12].

Recent studies have highlighted the potential of brown rice as a raw material for rice noodles due to its abundance of bioactive compounds such as dietary fiber, phytochemicals, and essential nutrients which are linked to reduced incidences of chronic diseases, including obesity, cardiovascular disease, and type II diabetes [13]. These compounds contribute not only to improved nutritional value but also to the potential development of functional foods that support health and disease prevention. However, the conventional production of rice noodles and other products using native brown rice (NBR) often fails to meet consumer expectations due to the coarse texture, high cooking loss, and poor palatability associated with the presence of rice bran [14]. The fibrous outer layer and high lipid content in the bran often interfere with starch gelatinization, leading to brittle noodle structures and reduced consumer acceptance. Therefore, addressing these limitations is critical to enhancing the usability of brown rice in noodle production.

The objective of this study is to determine the optimum mixing ratio to produce noodle strands from rice flour. Specifically, this research focuses on Noui Khuea (NK) brown rice starch, an underutilized local rice variety from Southern Thailand, consistent with previous findings reported by Chumsri *et al*. [15] NK, characterized as a high-amylose rice, contained greater amounts of protein, minerals, and α-tocopherol compared to the other cultivars. It also exhibited the highest total extractable phenolic content, which corresponded with superior $DPPH^{\bullet}$/ $ABTS^{\bullet+}$ radical scavenging activities, FRAP values, and α-amylase/α-glucosidase inhibitory effects. Moreover, the NK extract demonstrated the strongest ACE-inhibitory activity. Beyond its nutritional attributes, this local rice represents a promising source of bioactive secondary metabolites with potential applications as functional food ingredients in both household and industrial contexts. Therefore, the aim of exploring its functional application in noodle production. Examining the physicochemical characteristics and functional properties of noodle products formulated with different substitution levels of NK brown rice starch was the primary objective of the study. This approach not only supports nutritional improvement but also encourages the creative use of indigenous rice cultivars in food innovation.

2. Materials and Methods

Rice starch preparation

The preparation of Noui Khuea (NK) brown rice starch (*Oryza sativa* L.), a native and underutilized hard rice variety from Southern Thailand, followed the method described by Chumsri *et al*. [16], with slight modifications. A total of 10 kg of NK brown rice was soaked in water at a 1:4 (w v^{-1}) ratio for 6 hours at 4 °C to soften the grains. The soaked rice was then ground into a slurry using a double-disk stone mill. The resulting slurry was transferred to a large cloth bag and subjected to hydraulic pressing for 10 minutes to remove excess water. The wet-milled starch was subsequently dried in a hot-air oven at 60 °C until the moisture content was reduced to approximately 11%.

The dried material was then ground into a fine powder using a Panasonic MK 5087M food processor (Petaling Jaya, Selangor Darul Ehsan, Malaysia), and sieved through a 100-mesh sieve to obtain uniform starch particles. The resulting rice starch flour was stored in ethylene-vinyl alcohol copolymer (EVOH) bags at −20 °C for no longer than one month prior to analysis or use. Rice powder and 0.3% sodium hydroxide were combined in a 1:10 (w v^{-1}) ratio, agitated for 30 minutes, and let to settle overnight at room temperature (27–29 °C) in order to extract rice starch. After the cloudy supernatant was carefully drained, the precipitate was washed with distilled water. To make the supernatant transparent, this washing procedure was repeated three times. After being reconstituted in distilled water, the precipitate was run through a 100-mesh steel sieve. For 12 hours at 40 °C, the resultant filtrate (starch) was allowed to air dried [16].

Determination of physicochemical properties of NK brown rice starch as a partial substitute for rice starch

Color

A portable HunterLab MiniScan/EX spectrophotometer (Hunter Associates Laboratory, Reston, VA, USA) equipped with a D65 illuminant and a 10° standard observer was used to evaluate the surface color of the starch samples. The color was expressed in terms of the CIE Lab^* system, where L^* represents lightness, ranging from 0 (black) to 100 (white); a^* denotes the red–green axis, with positive values indicating redness and negative values indicating greenness; while b^* corresponds to the yellow–blue axis, where positive values indicate yellowness and negative values indicate blueness. The instrument was calibrated using both white and black standards prior to

each measurement to ensure accuracy and reproducibility [17]. Color measurement is a crucial quality parameter, especially in food products, as it influences consumer perception and acceptance. Changes in L^*, a^*, and b^* values provide insights into the effects of brown rice starch substitution on the visual appearance of the final noodle product. Higher substitution levels typically result in lower L^* values due to the inherent darker pigmentation of brown rice, while a^* and b^* values may shift depending on the presence of pigments such as anthocyanins and phenolic compounds. These color variations can also reflect compositional differences, including fiber and phytochemical content, between NK brown rice starch and conventional white rice flour.

Moisture content and Water Activity (a_w)

The moisture content of the noodles was determined following the standardized method described in A.O.A.C [18], which involves drying the sample to a constant weight to accurately quantify the amount of water present. This measurement is crucial for assessing the quality, shelf life, and texture of the noodles. Water activity (a_w), an important parameter indicating the availability of free water for microbial growth and chemical reactions, was measured using a Decagon AquaLab meter (Pullman, WA, USA). Prior to measurement, the device was carefully calibrated using a saturated potassium acetate solution to ensure accuracy. The a_w values provide insight into the product's stability and safety during storage.

Viscosity

The apparent viscosity of the starch samples was determined using a Brookfield viscometer (AMETEK, Model DVNext). A 250 mL beaker (7 cm in diameter and 9 cm in height) were filled with the starch sample, and the temperature were carefully adjusted to 20°C to ensure consistency during measurement. Spindle No. 6 was then immersed into the sample and rotated at a speed of 30 revolutions per minute (RPM). To allow the system to reach thermal equilibrium and to minimize the influence of immediate time-dependent changes in viscosity (such as shear thinning or thickening effects), the measurement was recorded after a stabilization period of two minutes [19]. This procedure ensured accurate and reproducible viscosity data reflective of the starch's rheological properties under controlled conditions.

Bulk density

Bulk density was determined using the mass-to-volume ratio method. A plastic container or measuring cylinder with a known volume and constant weight was used. The grain sample was carefully poured into the container until it reached a consistent level. Excess sample was then gently leveled off with a straight edge to ensure a flat surface. The mass of the filled container was measured, and the bulk density was calculated by dividing the mass of the grain by the volume of the container [20].

Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC)

Water Absorption Capacity (WAC) and Oil Absorption Capacity (OAC) were determined by mixing 2.5 g of the sample (dry weight basis) with 20 mL of distilled water for WAC or mustard oil for OAC. The mixtures were agitated continuously for 30 minutes at 25 °C to ensure thorough interaction between the sample and the liquid. After agitation, the slurries were centrifuged at 3000 × g for 10 minutes to separate the absorbed liquid from the unbound phase. The supernatant was carefully decanted, and the weight increase of the sample was measured. WAC and OAC values were then calculated as the amount of water or oil absorbed per gram of the dry sample and expressed in units of grams per gram (g g^{-1}).
These parameters provide important information on the functional properties of the sample related to hydration and fat-binding capacity [21].

Swelling and Solubility Indices

Starch samples (0.2 g, dry weight basis) were placed in pre-weighed centrifuge tubes and combined with 10 mL of distilled water. The suspensions were incubated in a water bath at four different temperatures 60, 70, 80, and 90 °C for 30 minutes. During incubation, the suspensions were vigorously mixed every five minutes to ensure uniform dispersion and hydration. After incubation, the samples were cooled to room temperature before centrifugation at 5000 × g for 15 minutes. The supernatant was carefully decanted into pre-weighed moisture cans. The swelling index was calculated based on the weight gain of the sediment in the centrifuge tubes, expressed as grams of swollen starch per gram of dry sample (g g^{-1}). The solubility index was determined by dividing the weight of soluble material in the supernatant by the initial dry sample weight, also expressed in g g^{-1}. These indices provide insights into the hydration behavior and solubility characteristics of the starch under varying thermal conditions [21].

Light transmittance (LT)

A 1% (w v^{-1}) aqueous starch solution was prepared and heated at 90 °C for 30 minutes in a CinaW350 Memmert water bath (Schwabach, Germany) with continuous stirring at 75 rpm to ensure complete gelatinization. After heating, the suspension was cooled to 30 °C and held for one hour to stabilize. The light transmittance of the starch solution was measured using a UV spectrophotometer (Shimadzu, MD, USA) at a wavelength of 640 nm. Measurements were taken every 24 hours against a distilled water blank while

the samples were stored at 4°C in a refrigerator for up to 120 hours. Monitoring light transmittance over time provides insight into the clarity and stability of the starch gel during refrigerated storage [21].

DPPH assay

The antioxidant activity of the starch samples was evaluated using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging method, following the procedure described in Chumsri *et al*. [15]. In brief, 5 mL of a 60 mM DPPH solution prepared in methanol was added to 5 mL of a starch solution (1 mg mL^{-1}) dissolved in double-deionized water. After incubation of the mixture in the dark at room temperature for 30 minutes, the absorbance was measured at 517 nm with a UV-Vis spectrophotometer, using methanol as the blank to correct for background absorbance.

Table 1 Ratio of NK brown rice starch in substituting some rice flour

Samples	0%	20%	40%	60%	80%	100%
Noui Khuea Starch (g)	0	20	40	60	80	100
Rice Flour (g)	100	80	60	40	20	0
Tapioca Starch (g)	25	25	25	25	25	25
Water (g)	250	250	250	250	250	250

The percentage of DPPH radical inhibition, indicating the scavenging activity of the sample, was calculated using the formula:

DPPH inhibition (%) = ((A0-A1) /A0) × 100

Where *A*0 is the absorbance of the control (methanol + DPPH solution) and A1 is the absorbance of the sample mixture.

Preparation and characterization of noodle samples

Table 1 shows the ratios of NK brown rice starch used to partially substitute rice flour. NK brown rice starch replaced rice flour at concentrations of 0%, 20%, 40%, 60%, 80%, and 100% by weight relative to the rice flour. For each formulation, 25 g of tapioca starch and 250 mL of water were added into a beaker and mixed thoroughly to prepare the rice flour dough. The batter was allowed to rest for approximately 10 minutes to enable full water absorption by the flour. A large pot was filled with water and brought to a boil. A flat tray or square pan that fits inside the steamer was lightly greased with oil and placed over the boiling water. To steam the noodles, a thin layer of batter was poured onto the greased tray, just enough to cover the surface evenly. The tray was covered with a lid, and the batter was steamed for about 2 minutes or until the noodle sheet was cooked and translucent.

The cooked noodle sheet was carefully lifted from the tray using a spatula or scraper, placed on a cooling rack or flat surface, and lightly brushed with oil to prevent sticking. This steaming and oiling process was repeated with the remaining batter, ensuring the batter was stirred before each pour to prevent flour sedimentation. After cooling, the noodle sheets were stacked and cut into 1-inch-wide strips to form the characteristic "sen yai" wide rice noodles. The rice noodle samples were labeled according to their NK brown rice starch substitution levels as 0% NK, 20% NK, 40% NK, 60% NK, 80% NK, and 100% NK, respectively. The procedure for preparing the wide rice noodles is illustrated in Fig. 1

Determination of color

The surface color of the samples was measured using a portable Hunterlab Miniscan/EX colorimeter (Hunter Associates Laboratory, Reston, VA, USA) under illuminant D65 and with a 10° standard observer. The color parameters recorded included L^* (lightness), a^* (redness to greenness), and b^* (yellowness to blueness). The instrument was calibrated prior to measurements using standard white and black reference tiles [18].

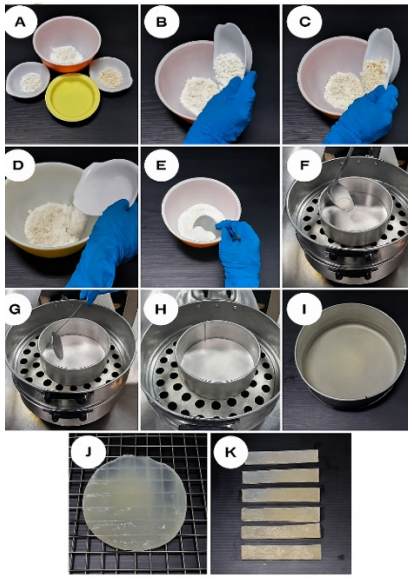

Fig. 1 Preparation Steps for Noodles from NK brown rice starch. Noodle ingredients (A); add tapioca starch into the mixture (B); gradually add NK brown rice starch (C); add water into the mixture (D); a starch slurry (E); ladle the starch slurry into the steaming tray (F); spread the starch solution evenly in the tray (G); the batter was steamed for about 2 minutes (H); once cooked, remove it from the tray and let it cool (I); apply a thin layer of oil on the rice noodle sheet (J) and slice into noodles about 2 inches in width (K).

Determination of moisture content and a_w

The moisture content of the noodles was determined following the method described in [18]. Water activity (a_w) was measured using a Decagon AquaLab meter (Pullman, WA, USA), which was calibrated with a saturated potassium acetate solution to ensure accuracy.

Determination of textural

Texture Analysis: Rice noodle samples were placed on the flat metal base of a texture analyzer (TA-XT Plus, Stable Micro Systems, Godalming, UK). The samples were compressed twice using a P/35 cylindrical probe at a test speed of 1.0 mm s^{-1}. A compression ratio of 70% was applied with a trigger force set at 5.0 g. Hardness and adhesiveness were determined by averaging ten replicate measurements for each sample.

Tensile Strength: For tensile testing, a 10-cm-long strip of rice noodle was secured between two parallel friction wheels to prevent slippage. The upper wheel stretched the noodle vertically at a speed of 10.0 mm/s until breakage occurred, ensuring the noodle remained taut throughout the test. Ten parallel tests were conducted per sample. Tensile strength and deformation at maximum load were recorded, and the average values were calculated after excluding the highest and lowest measurements [19].

Statistical analysis

Three independent duplicates of the studies were carried out using a completely randomized design (CRD). The results were presented in the form of mean ± SD. At $p < 0.05$, statistical significance was taken into account. Analysis of variance (ANOVA) and Duncan's multiple range test were used to examine mean differences. SPSS for Windows, Version 17.0 (SPSS Inc., Chicago, IL, USA), was used to analyze the data.

3. Result and discussion

Physicochemical characteristics of NK brown rice starch that partially replaces rice starch

Table 2 presents the physicochemical properties of rice flour samples partially substituted with NK brown rice starch at various levels. The results showed that the addition of NK brown rice starch significantly affected all measured color attributes (L^*, a^*, b^*), moisture content, water activity (a_w), and viscosity. Specifically, values of L^* (lightness), a^* (redness/greenness), b^* (yellowness/blueness), moisture content, and Water activity (a_w) consistently increased as the level of NK brown rice starch substitution increased. Conversely, bulk density did not show a significant change with increasing NK brown rice starch content, and no notable differences were observed between the substituted samples.

NK brown rice starch, having a light brown color compared to the white rice flour, led to a decrease in L^* values with higher substitution levels—from 94.12 in the control (0% NK) to 89.88 in the 100% NK sample. Among the tested formulations, the 100% NK brown rice starch sample exhibited the highest moisture content (10.28 g 100^{-1} g^{-1}) and a_w (0.57), whereas the control had the lowest moisture (8.93 g 100^{-1} g^{-1}) and a_w (0.53). These moisture values align with findings by Chokchaithanawiwat *et al*. [22], who reported moisture contents of 9.24 g 100^{-1} g^{-1} for wheat flour and 9.67 g 100^{-1} g^{-1} for riceberry flour. Furthermore, increasing NK brown rice starch substitution significantly raised the viscosity of the starch slurry ($p < 0.05$). This behavior is attributed to the gelatinization characteristics of NK brown rice starch, where heating in excess water disrupts the crystalline structure of starch granules. Specifically, the crystalline regions relax and the hydrogen bonds between amylose and amylopectin weaken, allowing water molecules to penetrate the granules, causing swelling and eventual disintegration. These structural changes influence the viscosity and gelatinization behavior of the starch [23]. The observed increase in viscosity with higher NK brown rice starch content indicates improved resistance to heat and shear compared to standard rice starch, making it suitable as a thickening agent in thermally processed foods. Additionally, NK brown rice starch tends to retrograde more rapidly and easily than starches with higher amylopectin content due to its elevated amylose level.

Bulk density

The bulk density and porosity of rice flour samples with various ratios of NK brown rice starch substitution are presented in Table 2. No significant differences ($p \geq 0.05$) in bulk density were observed among the samples. The bulk density values ranged from 0.70 to 0.71 g mL^{-1}, consistent with previous findings reported by Deka, and Sit [20]. For comparison, raw rice grain bulk density typically varies between 0.57 and 0.86 g mL^{-1}. Among different rice varieties, Aijong rice exhibited the highest bulk density at 0.86 g mL^{-1}, while Bhogali rice showed the lowest at 0.57 g mL^{-1}. This variation is attributed to differences in grain shape, as Aijong rice possesses higher sphericity, and bulk density tends to increase with the roundness of the grains.

Water Absorption Capacity (WAC), Oil Absorption Capacity (OAC), Swelling Index, Solubility Index, and Light Transmittance (LT)

The WAC and OAC of NK brown rice starch partially substituting rice flour are presented in Table 3. Both water absorption and oil absorption values increased significantly ($p < 0.05$) with higher proportions of NK brown rice starch replacing white rice flour. The substitution also significantly affected swelling index, solubility index, and light transmittance (LT) ($p < 0.05$). Samples containing 100% NK brown rice starch exhibited the highest values

for WAC (1.80 g g^{-1}), swelling index (6.50 g g^{-1}), and solubility index (0.59 g g^{-1}). In contrast, the highest OAC was observed in the sample with 0% NK substitution. The decrease in OAC with increasing NK starch content may be attributed to the formation of amylose–amylose and/or amylose–amylopectin complexes at high temperatures, which reduce the starch's capacity to bind oil.

When starch is heated in an excess of water, its crystalline regions are disrupted, enabling water molecules to form hydrogen bonds with the hydroxyl groups present in amylose and amylopectin. This interaction results in the swelling of starch granules and enhances their solubility. During heating, the granules absorb large amounts of water and expand, while some polysaccharide chains leach into the surrounding solution at elevated temperatures. Solubility at a given temperature correlates with the proportion of leached amylose and amylopectin, while swelling power indicates the volume of water absorbed per gram of starch at that temperature [24]. According to Lucisano *et al*. [25], the functional properties of starch greatly influence the behavior of starch noodles, as starch forms the structural network during processing, especially under various heating conditions. Water absorption has been linked to the degree of starch degradation and granule instability. Other components within NK brown rice starch may also affect cooking quality [16]. Table 3 also shows the effect of cold storage on the LT of starch pastes. LT is an indicator of starch paste clarity and relates to the retrogradation process. Over 120 hours of storage at 4°C, the light transmittance of all starch samples decreased significantly ($p < 0.05$), indicating progressive retrogradation.

Free radical scavenging activity

The DPPH radical scavenging activity of NK brown rice starch, which partially substitutes rice starch, is presented in Table 3. The radical inhibition capacity is attributed to the hydroxyl groups present in starch molecules as well as phenolic compounds [16]. NK brown rice starch exhibited significantly higher DPPH scavenging activity ($p < 0.05$) compared to the control sample containing 0% NK substitution. The highest DPPH radical scavenging activity was observed in the 100% NK brown rice starch sample, with 35.7% inhibition ($p < 0.05$), followed by the 80% substitution level at 22.42%. In contrast, the control sample showed a much lower activity of 11.18%. This increase in antioxidant activity strongly correlates with the phenolic content of the NK brown rice starch complexes.

Table 2 The physicochemical of NK brown rice starch that partially replaces rice starch.

Parameter	Level of NK (%, w w^{-1})					
	0%	20%	40%	60%	80%	100%
L^*	94.12±0.07^a	92.77±0.10^b	91.93±0.20^c	91.17±0.23^d	90.53±0.18^e	89.88±0.25^f
a^*	-0.10±1.70^f	0.13±0.01^e	0.25±0.01^d	0.36±0.01^c	0.45±0.01^b	0.52±0.02^a
b^*	3.62±0.06^f	4.64±0.07^e	5.49±0.05^d	6.19±0.13^c	6.72±0.16^b	7.15±0.23^a
Moisture (%)	8.93±0.35^c	9.36±0.36^{bc}	9.62±0.32^{abc}	9.77±0.42^{ab}	9.80±0.46^{ab}	10.28±0.65^a
a_w	0.53±0.01^b	0.55±0.01^a	0.54±0.02^{ab}	0.51±0.00^c	0.55±0.00^{ab}	0.57±0.01^a
Peak Viscosity (cP)	225.60±0.52^f	254.37±0.46^e	274.80±0.96^d	284.03±0.90^c	298.03±0.80^b	307.93±0.45^a
Bulk density (g mL^{-1})	0.71±0.04^{ns}	0.72±0.02^{ns}	0.71±0.01^{ns}	0.71±0.00^{ns}	0.70±0.01^{ns}	0.70±0.01^{ns}

Noted: Values from triplicate calculations are shown as mean ± standard deviation (SD). Significant differences ($p < 0.05$) are indicated by different letters in the same row.

Color, Moisture, and Water Activity (a_w)

Fig. 2 presents the visual appearance of rice noodles prepared with varying ratios of NK brown rice starch. Color is a key sensory attribute that influences consumer perception and acceptance of food products. In this study, the incorporation of NK brown rice starch notably altered the color characteristics of the noodles, with increased substitution resulting in a visibly darker appearance. Table 4 summarizes the color parameters (L^*, a^*, b^*), moisture content, and a_w of the noodle samples. As the level of NK brown rice starch increased, a significant decrease ($p < 0.05$) in both L^* (lightness) and a^* (red-green axis) values was observed. This indicates that the noodles became darker and less red/green in hue. In contrast, b^* values (yellow-blue axis), moisture content, and Aw all showed a statistically significant increase with higher NK starch ratios.

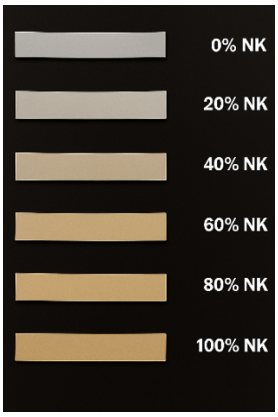

Fig. 2 The appearance of noodles produced with different ratios of NK brown rice starch.

A noticeable change in noodle color was first evident at the 20% NK substitution level, and this trend became more pronounced with higher substitution levels. The decrease in L^* value is attributed to the naturally darker, yellowish color of NK brown rice starch, which reduced the lightness of the noodle samples. The rise in b^* values reflects enhanced yellowness, consistent with the intrinsic color of NK brown rice. The negative shift in a^* values may be explained by the dominance of yellow tones, which diminished the perception of redness or greenness. Regarding moisture and a_w, noodles without NK brown rice starch (0% NK) had the lowest values—60.17 g 100^{-1} g^{-1} for moisture content and 0.96 for a_w. In contrast, noodles made with 100% NK brown rice starch exhibited the highest moisture content (68.82 g 100^{-1} g^{-1}) and a_w (0.99). This increase is likely due to the higher water-binding capacity of NK brown rice starch, which retains more moisture in the noodle matrix.

Table 3 The functional properties of NK brown rice starch that partially replaces rice flour.

Parameter	Level of NK (%, w w^{-1})					
	0%	20%	40%	60%	80%	100%
Water absorption capacity (g g^{-1})	1.30±0.69^{c}	1.55±0.03^{b}	1.58±0.12^{b}	1.55±0.04^{b}	1.72±0.27^{a}	1.80±0.02^{a}
Oil absorption capacity (g g^{-1})	2.09±0.01^{a}	2.04±0.03^{ab}	2.02±0.06^{b}	1.98±0.05^{b}	1.91±0.02^{c}	1.88±0.01^{c}
Swelling index (g g^{-1})						
60 ºC	0.70±0.05^{f}	0.92±0.06^{e}	1.14±0.07^{d}	1.23±0.02^{c}	1.50±0.07^{b}	1.70±0.02^{a}
70 ºC	1.45±0.03^{f}	1.56±0.03^{e}	1.63±0.04^{d}	1.74±0.05^{c}	1.97±0.05^{b}	2.14±0.03^{a}
80 ºC	2.92±0.06^{f}	3.04±0.02^{e}	3.17±0.05^{d}	3.49±0.05^{c}	3.79±0.10^{b}	4.42±0.05^{a}
90 ºC	5.06±0.01^{f}	5.86±0.04^{e}	6.05±0.03^{d}	6.20±0.02^{c}	6.33±0.05^{b}	6.50±0.04^{a}
Solubility index (g g^{-1})						
60 ºC	0.38±0.01^{f}	0.42±0.01^{e}	0.45±0.01^{d}	0.49±0.02^{c}	0.52±0.01^{b}	0.56±0.01^{a}
70 ºC	0.44±0.01^{e}	0.47±0.01^{d}	0.52±0.01^{c}	0.54±0.01^{b}	0.55±0.01^{b}	0.58±0.01^{a}
80 ºC	0.37±0.02^{f}	0.43±0.02^{e}	0.48±0.02^{d}	0.52±0.01^{c}	0.54±0.01^{b}	0.57±0.01^{a}
90 ºC	0.31±0.01^{f}	0.35±0.03^{e}	0.47±0.01^{d}	0.51±0.01^{c}	0.55±0.02^{b}	0.59±0.01^{a}
Light transmittance (%)						
0h	2.81±0.08^{f}	3.84±0.06^{e}	4.20±0.01^{d}	4.67±0.11^{c}	4.88±0.10^{b}	5.69±0.06^{a}
24h	1.86±0.04^{f}	2.18±0.07^{e}	2.89±0.01^{d}	3.13±0.04^{c}	3.22±0.03^{b}	3.71±0.06^{a}
48h	1.51±0.03^{f}	1.75±0.05^{e}	1.95±0.06^{d}	2.18±0.04^{c}	2.51±0.03^{b}	2.70±0.02^{a}
72h	1.10±0.01^{f}	1.19±0.01^{e}	1.30±0.02^{d}	1.45±0.03^{c}	1.59±0.05^{b}	1.97±0.02^{a}
96h	0.18±0.01^{f}	0.27±0.02^{e}	0.36±0.03^{d}	0.47±0.02^{c}	0.57±0.01^{b}	0.62±0.02^{a}
120h	0.06±0.02^{d}	0.08±0.01^{d}	0.12±0.01^{c}	0.12±0.01^{c}	0.15±0.03^{b}	0.22±0.01^{a}
In vitro bioactivity						
DPPH radical scavenging activity (%)	11.18±0.08^{f}	14.33±0.24^{e}	16.22±0.08^{d}	20.18±0.10^{c}	22.42±0.34^{b}	35.7±0.46^{a}

Noted: Values from triplicate calculations are shown as mean ± standard deviation (SD). Significant differences ($p < 0.05$) are indicated by different letters in the same row.

Table 4 The physical value of large noodle products made from NK brown rice starch, which partially replaces rice flour.

Parameter	Level of NK (%, w w^{-1})					
	0%	20%	40%	60%	80%	100%
L^*	61.24±0.53^{b}	65.40±1.14^{a}	65.54±1.80^{a}	63.26±0.71^{ab}	62.66±3.54^{ab}	62.02±0.35^{b}
a^*	-1.34±0.03^{ab}	-1.56±0.17^{bc}	-1.27±0.22^{ab}	-1.70±0.06^{c}	-1.05±0.04^{a}	-1.25±0.26^{a}
b^*	0.82±0.22^{c}	1.03±1.95^{d}	3.85±1.43^{bc}	1.90±0.99^{cd}	7.14±0.17^{a}	5.32±1.55^{ab}
Moisture (%)	60.17±0.02^{e}	62.95±0.07^{d}	64.54±0.04^{c}	65.79±0.17^{b}	65.97±0.23^{b}	68.82±0.09^{a}
a_w	0.96±0.00^{b}	0.97±0.00^{b}	0.97±0.00^{b}	0.99±0.01^{a}	0.99±0.00^{a}	0.99±0.00^{a}

Noted: Values from triplicate calculations are shown as mean ± standard deviation (SD). Significant differences ($p < 0.05$) are indicated by different letters in the same row.

Texture characteristics of rice noodles

Table 5 presents the textural properties of wide rice noodles prepared with varying ratios of NK brown rice starch. Significant differences were observed in both peak load and deformation at peak load among the different formulations. Textural qualities such as chewiness and elasticity are critical for consumer acceptance of rice noodles. The noodles prepared with 100% NK brown rice starch exhibited the highest peak load (93.33 gf) and the greatest deformation at peak load (29.57 mm), indicating superior elasticity and structural integrity. This enhancement in texture is attributed to the strengthening of the gel network structure in the cooked noodles, resulting from the increased viscoelasticity provided by the NK brown rice starch. These findings are in agreement with those reported by Liu *et al*. [26].

In contrast, the control noodles (0% NK) had the lowest peak load (56.33 gf), suggesting a weaker internal structure. According to Chumsri *et al*. [15], NK brown rice starch contains approximately 25.2% amylose. During heating, short amylose chains produced via partial hydrolysis tend to dissociate and diffuse out of the

granules, weakening the internal structure and contributing to increased hardness and reduced elasticity [27]. Brown rice generally contains higher amylose content than white rice, which leads to lower viscosity because amylose restricts starch granule swelling. In addition, it reduces elasticity since the gel structure becomes firmer and more brittle [28]. Moreover, as the proportion of NK brown rice starch increased, it likely influenced the short-to-long chain ratio of amylopectin, contributing to a reduction in adhesiveness [29]. This reduction in adhesiveness may also be accompanied by a decline in springiness, potentially due to starch retrogradation and moisture loss during noodle processing. These changes lead to the shrinkage and densification of the starch matrix, further impacting noodle texture [1].

Table 5 Texture properties of NK brown rice noodles.

Parameter	Level of NK (%, w w^{-1})					
	0%	20%	40%	60%	80%	100%
Peak load (gf)	56.33±0.57^{f}	59.33±0.57^{e}	83.67±1.53^{d}	87.67±1.15^{c}	92.33±1.53^{b}	97.33±1.15^{a}
Deformation at peak load (mm)	10.35±0.25^{f}	14.44±0.91^{e}	17.56±0.49^{d}	21.66±0.98^{c}	25.80±0.51^{b}	29.57±0.43^{a}

Noted: Values from triplicate calculations are shown as mean ± standard deviation (SD). Significant differences ($p < 0.05$) are indicated by different letters in the same row.

4. Conclusion

This study demonstrates the innovative potential of NK brown rice starch as a value-added local ingredient for enhancing the quality of wide rice noodles. As the proportion of NK brown rice starch increased, key functional and physicochemical properties—such as moisture content, water activity (a_w), viscosity, WAC, OAC, swelling index, solubility index, and light transmittance (LT)—improved significantly ($p < 0.05$). These improvements indicate that NK starch can effectively contribute to better texture, structure, and storage stability of noodle products. Importantly, the use of NK brown rice starch aligns with the principles of Creative Science by applying scientific knowledge to creatively transform underutilized local resources into high-value food products. This approach not only enhances food innovation but also supports grassroots economic development by increasing the market value of indigenous rice varieties cultivated in local communities. Future research should focus on starch modification techniques to further improve product performance and expand its commercial potential, particularly in community-based agro-industrial systems that drive sustainable rural economies.

5. Suggestions

Additional studies could examine the nutritional benefits of Noui Khuea brown rice starch-enriched noodles, particularly in terms of dietary fiber and glycemic index. It is recommended to investigate the shelf life and storage stability of the enriched starch-based noodles under various packaging and environmental conditions.

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7. Declaration of generative AI in scientific writing

The use of a generative AI tool in this study was limited to facilitating literature searches and enhancing grammatical accuracy and linguistic clarity.

8. CRediT author statement

Nounhong Kaewnak: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Software, Writing original draft, Writing review & editing.

Paramee Chumsri: Conceptualization, Methodology, Validation, Resources, Funding acquisition, Supervision, Project administration, Writing original draft, Writing review & editing. All authors reviewed the manuscript.

9. Research involving human and animals rights

Not applicable

10. Ethics Approval and Consent to Participate

Not applicable

11. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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