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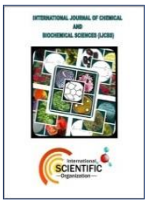

Enhancing Wet Starch Noodle Properties: Investigating the Impact of Acetylated and Ozonized Sago (*Metroxylon sago Rottb.)* Starch

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Abstract

This study explores the impact of ozonation and acetylation on sago starch, targeting improvements in noodle production. Functional properties were examined, including water content, water absorption index (WAI), water solubility index (WSI), and amylose content. Ozonation generally decreased water absorption (from 18.32% in native sago (NS) to 18.29% in ozonated sago (OS)) and solubility (from 12.39% in NS to 15.2% in OS). Conversely, acetylation increased solubility (from 19.04% in acetylated sago (AS) to 17.55% in ozonated-acetylated sago (OAS)). Modifications reduced amylose content (from 31.67% in NS to 23.13% in AS), impacting noodle texture and physiochemical properties. Modified sago starch noodles cooked faster but absorbed less water, resulting in higher cooking loss. For instance, cooking time decreased from 5 minutes (NS) to 6 minutes (AS), while water absorption decreased from 90.22% (NS) to 75.42% (AS). Additionally, cooking loss increased from 19.39% (NS) to 12.04% (AS). Pasting properties were affected, with increases observed in trough viscosity (TV), breakdown (BV), and final viscosity (FV). For instance, TV increased to 2758.5 RVU in OAS compared to 1903 RVU in AS. Modified sago starch noodles showed faster cooking times, lower water absorption, and higher cooking loss. Texture profile analysis (TPA) indicated softer textures for modified noodles, possibly due to enhanced expansion after modification.

Keywords: sago starch; ozonation; acetylation; wet starch noodle; texture properties

Full length article **Corresponding Author*, e-mail: siswo.sumardiono@che.undip.ac.id Doi # https://doi.org/10.62877/18-IJCBS-24-25-19-18

1. Introduction

Apart from noodles made from wheat flour, various types are available in society, such as corn noodles, vermicelli, and cassava noodles [1]. However, the popularity of wheat noodles is very high [2]. One of the reasons why wheat noodles are more popular than starch-based noodles is the superior texture properties of the wheat noodle products. Research by Ahmed et al. (2015) revealed that texture was the most important characteristic in accepting noodle products [3]. Criticism toward wheat noodles often revolves around their gluten content, presenting difficulties for those with gluten-related conditions, like celiac disease or gluten sensitivity [4].

Starch noodles, which encompass a variety of starch sources such as rice, tapioca, or mung bean starch, occupy a niche position within specific culinary traditions. While starch noodles exhibit unique textures and flavor profiles, they often lack the gluten content inherent in wheat noodles, resulting in a softer and more delicate mouthfeel. Despite their distinct characteristics, starch noodles may need more versatility and acceptance among consumers accustomed to the firmness and chewiness associated with wheat-based counterparts [1,5]. Noodles from alternative starch sources offer an enticing choice as a sustainable and gluten-free option. A study conducted by Wahjuningsih et al. (2019) highlights the nutritional advantages and sensory properties of starch noodles, underscoring their potential to rival wheat noodles in terms of consumer acceptance and market share [2]. The study underscores the importance of sensory attributes such as texture, color, and flavor in driving consumer preference for starch noodles, emphasizing the need for product development strategies that prioritize sensory optimization [6,7].

Sago is an endemic plant in several Southeast Asian countries [8-10]. This plant has good resistance and adaptation to tropical environmental conditions and peatlands [11]. Sago, derived from the pith of tropical palm trees, has emerged as a promising alternative for gluten-free noodle production. Studies by Hirao et al. (2021) and Šárka et al. (2023) have revealed the potential of sago starch in food applications, owing to its unique properties such as excellent gelling ability and neutral taste profile [12,13]. While sago starch shows promise, it also possesses inherent weaknesses, such as poor textural properties, which may limit its application in noodle production. However, modifications targeting the starch specifications can effectively address these weaknesses. Modifying starch properties aims to increase functionality and improve quality, making it suitable for application for a product [14-17].

Ozonation, a novel approach in starch modification, involves the treatment of starch granules with ozone gas to induce structural changes and improve functional propertiesh', including increased solubility [18,19]. Previous studies have elucidated the effects of ozonation on starch [19] and improved gelation characteristics. Despite its advantages, ozonated starch may exhibit limitations, such as insufficient texture and structural integrity improvement. Acetylation entails incorporating acetyl groups into starch molecules, altering their physicochemical properties [20,21]. Extensive research by Lin et al. (2019) revealed that acetylated corn starch enhanced the brightness of noodles while diminishing their chewiness, adhesion, and hardness [22,23]. Changes in pasting properties such as PT, PV, BD, SB, and final viscosity (FV) decreased [24]. Dual modification with acetylation emerges as a viable strategy to address these shortcomings. While ozonation enhances solubility and gelation, acetylation further modifies the starch matrix to impart desirable rheological properties and enhance overall noodle quality.

Although much research exists on individual starch modification techniques, the synergistic combination of ozonation technology and acetylation of sago starch for noodle production has yet to be widely explored. This new approach has the potential to overcome the limitations of native sago starch and produce noodles with superior texture, taste, and sensory experience. This research explores the effect of various modification methods, i.e., ozonation, acetylation, and their combination, on the physicochemical properties of sago starch and its application in noodles production. This research seeks to contribute to the development of innovative gluten-free noodle products from local starch sources that meet consumer expectations for sensory attributes that are competitive with wheat noodles.

2. Materials and methods

Experimental material

The study utilized sago starch sourced from Kekal Jaya Sentosa, Ltd. in Palembang, Indonesia. Oxygen gas (≥99.90% w/w) was procured from Aneka Mega Energi, Ltd., Semarang, Indonesia. Glacial acetic acid (analytical grade, ≥99.90% w/w) was also obtained from Merck KGaA. (Darmstadt, Germany).

Ozonation of sago starch (for Oz)

Ozonation of sago starch was performed by adapting the method from the previous study by Çatal & İbanoğlu (2014) with some adjustments. Initially, a suspension of sago starch (S) was prepared by mixing 280 g of sago starch with water (35 wt.%). Then, NaOH 0.1 M was slowly added to the suspension until reaching a pH of 9.5. The mixture was stirred using Overhead Stirrers at 300 rpm for 10 minutes. Then, ozone gas was injected into the suspension at a dosing concentration of 0.69 mL/minute for 10 minutes. The suspension was then washed until a neutral pH was achieved through decantation. The slurry was air-dried at room temperature for 24 hours, producing ozonated sago starch (OS). The exact process was followed for the production of acetylated-ozonated (OAS) starch, but sago starch (S) was substituted with acetylated sago starch (AS) [25].

Acetylation of sago starch (for Oz-As)

The acetylation process followed the previous method reported by Rahim et al. (2022) with slight modifications. A suspension of sago starch (S) was prepared by mixing 280 g of sago starch with water (35 wt.%). NaOH solution (0.1 M) was gradually added to the suspension until reaching a pH of 8.5. The mixture was stirred using an Overhead Stirrer at 300 rpm for 10 minutes. Acetic acid glacial (6 g/100 g starch) was added and stirred with the Overhead Stirrer for 60 minutes. To adjust the pH to 5.5, 1 M HCl was added dropwise. After filtering and washing the slurry, the starch slurry was dried in an aerating oven at room temperature. The resulting product was acetylated sago starch (AS). The production process for OAS remained identical, except that sago starch (S) was substituted with ozonated sago starch [26].

Functional properties

The functional properties of modified sago starch consist of water content, WSI, WAI, and apparent amylose content. Water content analysis followed the standard method from AOAC 925.10-1995 [27]. WSI and WAI analyses were carried out using the research of Castanha et al. (2019) [28].

Determination of amylose contents in samples was carried out using spectrophotometric analysis. The absorbance of the resulting solution was determined using a spectrophotometer set to a wavelength of 620 nm. The amylose concentration was determined by plotting the obtained absorbance in a calibration curve of the amylose standard solution [29].

Pasting properties

The gelatinization characteristics of wheat flour, native sago starch, and modified sago starch were assessed using the Rapid Visco Analyzer (RVA, Brand, Type, Country) 4500 by Perten Instruments, employing the noodle method. Approximately ±3.0 g of each sample (based on dry weight) was measured and placed into an RVA container, adding approximately ±25 g of distilled water. The RVA measurements involved heating and cooling phases with constant stirring at 160 rpm. During the heating phase, the starch suspension was gradually heated from 60 to 95°C at a rate of 6°C per minute and held at that temperature for 4 minutes [30].

Cooking performance

The cooking performance of the produced noodles was evaluated in terms of cooking time and cooking loss. The cooking time was determined by observing the disappearance of opacity in the center of the noodles [31], and the cooking loss of noodle samples was determined based on the method of Hu et al. (2022) [5]. The water absorption index (WAI) was determined by calculating the weight gain ratio based on raw noodle solids [32]. Noodle color analysis was carried out by adopting the color measurement and expression system by the International Commission on Illumination (CIE) in 1976 using L*, a*, and b* [33].

Texture Properties

The texture properties analysis (TPA) was conducted using the TA-XT Plus type texture analyzer (Stable Micro Systems, UK). For this analysis, three strands of cooked noodles were arranged parallel on a flat metal plate. Various texture parameters were evaluated, including hardness, adhesiveness, springiness, cohesiveness, gumminess, chewiness, and resilience. The experimental settings were configured as follows: pretest speed: 1 mm/s, test speed: 1 mm/s, post-test speed: 1 mm/s, compression rate: 60%, and a time interval of 1 s between two consecutive compression tests [34].

Statistical analysis

The statistical analysis was performed using the SPSS 26 software. All data underwent normality testing, and if found to be normally distributed, treatments were compared utilizing one-way ANOVA followed by the Tukey HSD test. Samples bearing the same letter designation were regarded as not significantly different, while those with distinct letter designations were considered significantly different, as outlined by Xu et al. (2020) [35].

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3. Results and Discussions

Functional properties

The water contents of W, OS, AOS, and AS did not exhibit significant differences between samples (ANOVA, $p > 0.05$), except for NS, which showed significant differences compared to other samples ($p < 0.05$). The water content influences the texture properties of food while also affecting microbial growth, shelf life, and cooking times. Controlling water content is essential for maintaining food quality, safety, and nutritional benefits [36-38]. All modified sago starch, whether processed through a single-step or dual-step method, possesses a moisture level within the permissible range stipulated by the Codex Alimentarius Commission regulations, which is not more than 14%. Tiwari and Agrawal (2018) also revealed water content changes in food products resulting from ozonation treatment, attributing this alteration to molecular changes induced by ozone treatment [39].

Statistically, the WAI value shows a significant difference between samples (ANOVA, $p < 0.05$), with the WAI value of sample W being the lowest. In contrast, both NS and OS showed the highest results. The WAI value for OS and AS samples indicated the median value. The WSI analysis between samples showed significant differences (ANOVA, $p <0.05$). The highest and lowest WSI values belonged to the samples of the AS (19.04 ± 0.21) and NS (12.39 ± 0.25). Modifying sago starch (OS, OAS, AS) increased the WSI value. Carbonyl and carboxyl groups formed due to the oxidation process with ozone enhance the affinity towards water molecules [40,41]. The presence of acetyl groups can also interact positively with water [42]. Wheat flour has a lower WAI value than native sago starch (NS) and modified sago starch (OS, OAS, AS). Ozonation did not significantly reduce the WAI value of sago starch. This phenomenon is in line with research conducted by Vanier et al. (2017), which revealed that the WAI of sago starch decreased due to ozonation. The oxidation mainly occurs in hydroxyl groups at the C-2, C-3, and C-6 positions [43]. The results of Maqbool et al. (2024) research indicate that oxidation through ozone exposure generates carboxyl groups in starch, leading to an increase in the WAI of the starch [44]. Similarly, studies on starch acetate (AS) have shown increased water absorption due to modification of molecular interactions and gel formation [45]. The AOS sample has a WAI value between the NS and W samples.

Ozonation and acetylation can disrupt the molecular structure of starch and protein, thereby increasing their solubility in water [46,47]. Ozonation can increase the solubility of starch-based materials in water by breaking molecular bonds and increasing accessibility to water molecules [48]. The ozonation process increases carbonyl and carboxyl levels. The increased carbonyl and carboxyl content affects the hydrophilicity of starch [49]. Similarly, studies on acetylated starch have demonstrated increased water solubility due to modification of molecular interactions and structural properties [50]. According to Renzetti et al. (2021), water hydration also widens the distance between the crystalline areas so that water can enter and bind with the polymer to form hydrogen bonds. Increased hydrogen bonding between water and polymer leads to increased solubility of starch [51].

The amylose content showed significant differences between samples (ANOVA, $p <0.05$), except for the WS and OAS samples, which were not significantly different between the two. There were decreasing amylose levels in all samples of modified sago starch (OS, OAS, AS) compared to native sago starch, but the lowest reduction was in acetylated modified starch (AS). The amylose content influences characteristics such as gel formation, viscosity, and retrogradation behavior, which are critical for various food processing applications [52,53]. Adding high-amylose maize starch and chilling treatment can improve the texture of fresh noodles, but these benefits may be partially lost during the retorting process [54]. Studies have shown that modifications such as ozonation and acetylation can change the amylose content and structural properties of starch-based materials [41,55]. Ozonation was reported to cause degradation of amylose molecules, leading to decreased amylose content [44]. Likewise, acetylation can change amylose content due to chemical modifications and interactions with other components [56].

Pasting properties

Peak viscosity (PV) is an indicator of the swelling capacity of starch and its ability to form gels. The results of PV analysis for all prepared samples are presented in Table 2. PV values of the samples showed significant differences between samples (ANOVA, $p < 0.05$). The W sample (3377.5±13.44) had the lowest PV, while the AS sample had the highest (5560.5±21.92). In particular, modification by ozonation reduces PV, as evidenced by modifications involving ozonation (OS & OAS), which have lower PV values.

Trough viscosity (TV) is a indicator of the starch's ability to maintain its structure when cooled. The TV values of the samples, which exhibited significant differences between samples (ANOVA, $p < 0.05$), highlight the relevance of our study. Notably, the NS and W samples were similar and were exceptions. Furthermore, samples produced from a combination of ozonation and acetylation (OAS) modifications recorded the highest TV values compared to single modifications (OS & AS).

Table 1. Functional properties of native and modified sago starch

Sample	Water content (%)	WAI (%)	WSI (%)	Amylose (%)
NS	11.52±0.40 a	18.32±0.21 c	12.39±0.25 a	31.67±0.49 d
W	12.50±0.50 b	14.32±0.21 a	16.44±0.17 c	30.09±0.27 c
OS	12.72±0.25 b	18.29±0.18 c	15.2±0.40 b	25.04±0.52 b
OAS	12.76±0.61 b	16.88±0.31 b	17.55±0.11 d	30.45±0.46 c
AS	12.43±0.58 b	15.5±0.40 ab	19.04±0.21 e	23.13±0.45 a

Mean ± standard deviation. Values with same letter differ non-significantly (P > 0.05).

Table 2. Pasting properties of native and modified sago starch samples

Sample	Peak viscosity (RVU)	Trough viscosity (RVU)	Breakdown (RVU)	Final Viscosity (RVU)	Setback	Pasting Temperature (℃)
NS	5343.5±43.13d	1519.5±55.86a	3824±12.73d	2625.5±43.13a	1106±12.73a	74.85±0.28a
W	3377.5±13.44a	1414.5±6.36a	1963±7.07a	2861±18.38b	1446.5±12.02c	83.45±0.28b
OS	4474±11.31b	2510±28.28c	1964±16.97a	3664±28.28d	1154±56.57a	74.875±0.32a
OAS	5133±76.37c	2758.5±43.13d	2374.5±33.23b	3917±45.25e	1158.5±2.12a	74.675±0.04a
AS	5160.5±21.92c	1903±2.83b	3657.5±24.75c	3245.5±4.95c	1342.5±2.12b	75.4±0a

Mean ± standard deviation. Values with same letter differ non-significantly (P > 0.05).

Breakdown (BV) is a crucial indicator of the starch's stability and resistance to shear stress. The PV values of the W samples and OS, which did not show significant differences between samples (ANOVA, $p < 0.05$), and both were significantly different from other samples, underscore the importance of our study. Notably, single or dual-modified starch was found to have a lower B value than native sago starch.

Final viscosity (FV) shows the ability of starch to form a stable gel. FV values of the samples showed significant differences between samples (ANOVA, $p < 0.05$). The phenomenon of decreasing FV values is caused by oxidation and acetylation of sago starch, where modified starch (OS, OAS, AS) has a lower FV value than NS samples.

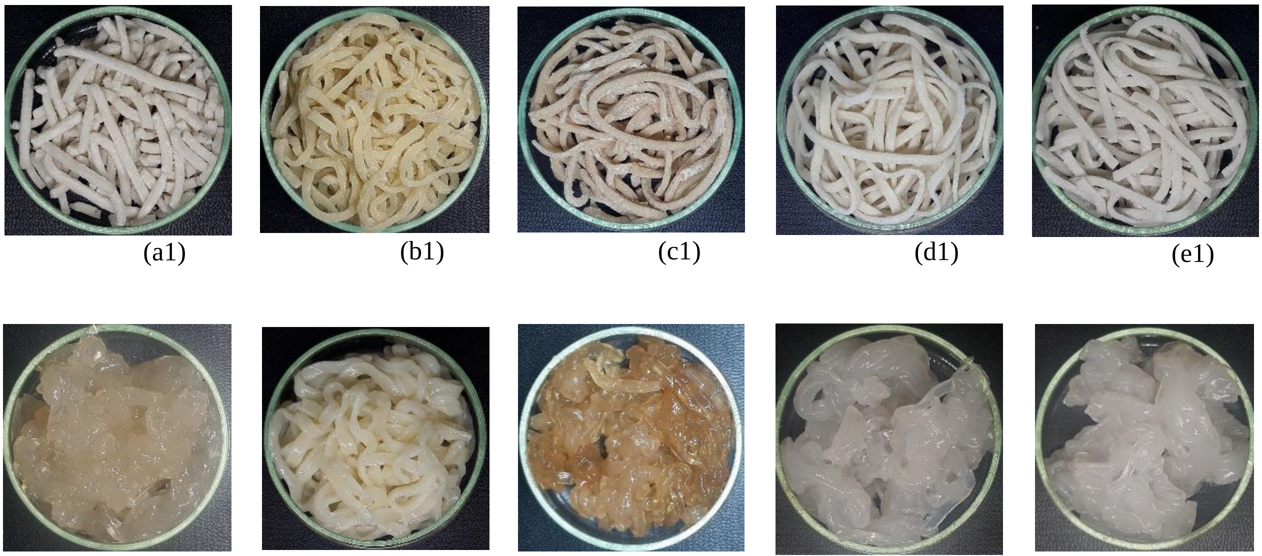
Setback (SV) is the increased viscosity of the starch paste after cooling and reheating. The S values of NS, OS, and OAS samples did not show significant differences between samples (ANOVA, $p <0.05$), so only the AS samples experienced an increase in S values due to acetylation modification.

Pasting temperature (PT) is an indicator of the starch's gelatinization temperature and its gel-forming ability. Sample W was the only one with a PT value above 80℃ compared to samples based on sago starch. For all starch-based samples did not show significant differences between samples (ANOVA, $p <0.05$) (Table 2).

Table 3. Noodles of native and modified sago starch samples

Sample	Colour cooked noodle (L/a/b)	Cooking time (minutes)	Water absorption (%)	cooking loss (%)
NS	52.4/-0.6/2.8	5±0.76a	90.22±3.39c	19.39±0.58d
W\	67.5/2.9/8.6	10±0.58d	110.4±2.71d	14.8±0.35b
OS	48.9/13.1/27.6	7±0.29c	89.622.56c	17.12±0.18c
OAS	72.8/3.4/2.5	7±0.50c	83.31±1.771b	15.55±0.38b
AS	88.3/1.7/6.1	6±0.29b	75.42±0.16a	12.04±1.15a

Mean ± standard deviation. Values with same letter differ non-significantly (P > 0.05).


(a1) (b1) (c1) (d1) (e1)

(a2) (b2) (c2) (d2) (e2)

Figure 1. Noodle appearance (a) Native sago (NS), (b) Wheat (W), (c) Ozonated-sago (OS), (d) Ozonated-Acetyalated sago (OAS), (e) Acetylated sago (AS); (1) before and (2) after cooking

Table 2 shows that the pasting properties of native sago starch (NS) samples changed due to modification by ozonation and acetylation. The peak viscosity of the OS and AOS samples experienced a decrease in PV, whereas the AS sample experienced an increase. Sample W has the lowest peak viscosity. Dimri et al. (2023) Additionally, it was noted that ozonated starch exhibits decreased viscosity due to the breakdown of starch molecules resulting from ozonation [57]. The increased presence of carboxyl groups may lead to lower viscosity values as more water molecules permeate the starch structure.The same phenomenon occurs in the acetylation process in starch, causing a decrease in the PV value in the acetylated sago starch (AS) sample [58].

The opposite phenomenon in TV, BV, and FV, which increased in all samples of modified sago starch (OS, OAS, AS) compared to native sago starch (NS); the increase in these three viscosities may be caused by slight cross-linking, which increases the integrity of the starch [59]. SV parameters were not significantly different in all samples based on sago starch (NS, OS, OAS) except for acetylated sago starch (AS) samples. The increasing setback viscosity indicates that starch retrogradation is increasing. Furthermore, sago starch modified by ozonation (OS and

OAS) differs from native starch. The oxidation level may still be relatively low. For AS samples with higher SV values, acetyl may promote the rearrangement of starch molecules with water molecules [60]. This phenomenon Aligns with research conducted by Khurshida et al. (2021). Meanwhile, the wheat sample had the highest SV value. Pasting temperature (PT) was visible between the sago starch group samples (unmodified and modified), which was not significantly different from that of the wheat samples (W).

Cooking performance

Figure 1 shows the noodles' appearance before and after cooking. The uncooked noodles of the NS sample appear broken and brittle; their appearance is almost similar (although better) to that of the AS sample noodles. Meanwhile, the noodles in the W and OAS samples show a similar, firmer appearance compared to the previous and OS samples. Table 3 presents the performance of noodles throughout the cooking process, focusing on parameters such as noodle color, cooking time, water absorption, and cooking loss. In addition to visual inspection, color parameters are assessed quantitatively and instrumentally. Notably, the noodles made of ozonated sago starch (OS) exhibited the darkest (lightness: 48.9) and lightest (lightness: 88.3) colors within the AS sample.

Cooking time is essential because precise cooking time control is important for optimal starch gelatinization and good noodle quality. Cooking time values showed significant differences between samples (ANOVA, $p < 0.05$), except for OS and OAS samples, which had no significant difference in cooking time. Wheat noodles require longer cooking time than sago starch-based noodles. The percentage of water absorption showed significant differences between samples (ANOVA, $p < 0.05$), except for the NS and OS samples, which were not significantly different ($p > 0.05$). All noodles based on sago starch, both modified and unmodified, have a lower water absorption percentage than wheat noodles. Cooking loss is material that dissolves during cooking. The cooking loss value of the noodles showed significant differences between samples (ANOVA, $p < 0.05$), except for the W and OAS noodles samples. Starch-based noodles have a more significant cooking loss percentage than wheat noodles.

Colorimetric analysis of food ingredients provides information about their visual appearance, critical for consumer acceptance and product quality. Analyzing these findings through the lens of established theory, the parameters L*, a*, and b* each correspond to distinct aspects of color. [61,62]. Significant differences were observed between samples regarding cooked noodles' L*, a*, and b* values. Table 3 shows that the lightness values for NS and W noodles have no significant difference. However, native sago starch is the noodle with a negative b value, which means the color tends to be greenish, in contrast to other noodles with positive values (which tend to be red). Figure 1 confirms that the modification process causes chemical changes that affect the color of starch-based materials. The oxidation process in sago starch (OS) results in darker cooked noodles, with this study demonstrating that it produced noodles with the darkest color. On the other hand, the acetylation (AS) process shows the brightest appearance of the noodles, followed by the OAS sample, which is noodles from double-modified sago starch, which is bright. Previous studies confirmed that ozonation treatment can induce a browning reaction, thereby causing essential changes in the color profile of starch-based materials [63,64]. In addition, several studies have confirmed that the acetylation process significantly influences starch's color properties, primarily through its ability to modify molecular interactions and structural characteristics [65]. The combination of ozonation and acetylation of sago starch positively impacts the noodles color properties, where the AOS noodles' color is not as pale as the AS sample and not as dark as the OS sample.

The disappearance of the white dot in the middle of the noodle strand indicates that the optimal cooking time has been reached [66]. The cooking time for starch-based noodles (NS, OS, OAS, and AS) tends to cook faster than that of wheat noodles. The broken structure of these noodles causes a decrease in cooking time for native sago starch noodles, thus facilitating a rapid rehydration process. AS noodle samples also have faster cooking times because the acetyl group easily interacts with water, reducing its gelatinization ability [45]. Ozonated starch samples (OS and AOS) produced longer cooking times than NS and A samples, and this was because the resulting noodle strands were firmer and less brittle.

Cooking loss is the number of solids in noodles released into the water during cooking [67]. The desired result in the cooking loss parameter is that the noodles produced have a low cooking loss value. Water absorption aims to determine the sample's ability to absorb water optimally [54]. The water absorption capacity of the native noodles is higher than that of modified sago starch noodles (OS, OAS, AS). The AS noodle sample had the lowest cooking loss compared to native sago starch noodles but had low absorption capacity. This profile is caused by the acetyl group is hydrophilic [59]. Incorporating acetyl groups into starch enhances its water affinity, while acetylation and ozonation disrupt the hydrogen bond network within starch granules. This reduction in intermolecular bonds allows water molecules to penetrate the droplets more quickly, increasing swelling and solubility [68]. OS and OAS samples produced cooking loss and water absorption values that were moderate and lower than NS.

Texture properties

Understanding noodles' sensory experience and mouthfeel is crucial, and textural properties play a key role. These properties can significantly differ based on factors such as the raw materials used in making the noodles. Texture Profile Analysis (TPA) is a method used to determine the textural properties of food. This method involves compressing the sample twice to mimic the chewing action in the mouth. TPA provides insight into how food behaves when consumed [69].

The hardness values of the samples showed significant differences between samples (ANOVA, $p < 0.05$), except for the W and OAS samples, which were not significantly different. The phenomenon of decreasing hardness values is caused by oxidation and acetylation of sago starch, where modified starch (OS, OAS, AS) has a lower hardness value than NS samples. NS noodle samples showed the greatest hardness, while noodles from modified sago starch showed lower hardness values. This result may be due to better expansion ability of starch after acetylation and ozonation [23,41].

Table 4: Noodles of native and modified sago starch samples

Sample	Hardness (g)	Adhesiveness (g.sec)	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
NS	593.46±4.78d	-53.68±6.48a	0.71±0.02a	0.74±0a	436.44±3.55d	310.39±8.45d	0.56±0.01a
W	416.07±40.22c	-17.22±5.39b	0.78±0.02a	0.79±0.03a	330.7±37.65c	258.16±22.67c	0.63±0.02b
OS	331.37±41.19b	-30.16±16.14ab	0.69±0.06a	0.77±0.05a	252.15±15.5b	172.8±15.8b	0.53±0.01a
OAS	451.02±8.61c	-50.08±14.99ab	0.75±0.02a	0.77±0.01a	349.08±5.36c	261.88±11.63cd	0.68±0.01b
AS	202.06±7.07a	-26.54±15.77ab	0.64±0.09a	0.78±0.03a	158.08±11.57a	101.09±19.04a	0.69±0.04b

Mean ± standard deviation. Values with same letter differ non-significantly (P > 0.05).

Adhesive power is required to overcome the attractive force between the surface of the noodles and the surface with which they are in contact. The adhesiveness value of the samples showed a significant difference between samples based on wheat and native sago starch (ANOVA, $p < 0.05$). The adhesiveness properties of noodles from modified starch (OS, OAS, AS) were between the W and NS samples. Springiness refers to the capacity of noodles to regain their initial shape after undergoing compression or elongation. The springiness values of all noodle samples did not show significant differences between samples (ANOVA, $p < 0.05$). Cohesiveness refers to the degree to which noodles hold together or break apart when chewed. Cohesiveness values for all samples did not show significant differences between samples (ANOVA, $p < 0.05$). Modifying sago starch may cause the introduction of acetyl groups and increase amylose to improve hydration ability [17,19]. The Springiness parameter, which shows how quickly the noodle sample returns to its original shape after being compressed and the cohesiveness parameter measures the relative resistance to deformation during compression of the two samples. All noodle samples, including wheat noodle samples (W), showed insignificant differences in both parameters.

Gumminess and chewiness are measures of the energy needed to chew noodles until they become a dough that can be swallowed. It combines hardness and chewiness and represents the effort required to break down noodles while chewing. The values of both parameters for all noodles did not show significant differences between samples (ANOVA, $p < 0.05$). Gumminess is calculated based on hardness and cohesiveness, adding the springiness parameter to measure chewiness. Modifying sago starch decreases gumminess and chewiness; this is the same as the hardness profile, which decreases due to modification.

Resilience measures the ability of noodles to recover their original shape after experiencing deformation. Similar to springiness, it focuses more on the elastic properties of noodles. In general, the resilience values were 2 groups of noodle samples, which did not show significant differences between samples (ANOVA, $p < 0.05$), where the first group was NS and OS. In contrast, the second group was W, OAS, and AS noodle samples. OAS maintained a balance between textural properties, with hardness (451.02 g) comparable to OS and superior to NS and AS. On texture parameters, although not performing at par with wheat-based noodles overall, OAS noodles are superior to NS, OS, and AS noodles.

4. Conclusions

Modifying sago starch through ozonation and acetylation profoundly affects its functional, pasting, cooking, and texture properties, which are crucial for noodle production. Ozonation tends to decrease water absorption and solubility, acetylation enhances these properties, along with peak viscosity. Modified sago starch noodles exhibit variations in color, cooking time, water absorption, and cooking loss, with modified starches generally showing faster cooking times but lower water absorption and higher cooking loss than native sago starch and wheat noodles. Texture properties are also affected, with modified sago starch noodles displaying softer textures, reduced adhesiveness, and gumminess. Among these modifications, ozonated-acetylated sago starch (OAS) demonstrated notable advantages compared to acetylated sago starch (AS), ozonated sago starch (OS), and native sago starch (NS). OAS exhibited lower peak viscosity (5133 RVU) and setback viscosity (1158.5 RVU) than AS, indicating improved viscosity characteristics for processing applications.

Furthermore, OAS displayed shorter cooking times (7 minutes) and higher water absorption capacity (83.31%) than NS, suggesting enhanced cooking efficiency and water retention properties. Additionally, OAS maintained a balance between textural properties, with hardness (451.02 g) comparable to OS and superior to NS and AS. On texture parameters, although not performing at par with wheat-based noodles overall, OAS noodles are superior to NS, OS, and AS noodles. So, sago starch modified using a dual process (ozonation-acetylation) shows its potential as an alternative to developing raw noodles material.

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Disclosure statement

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