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Integrated Effects of Hot Water Blanching on Alliin Degradation, Physical Quality, and Aroma Acceptability of *Lokio* (*Allium chinense* G. Don)

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ABSTRACT

Lokio (*Allium chinense* G. Don) is a traditional *Allium* vegetable widely consumed in Indonesia and has potential as a natural seasoning. However, its utilization is limited by excessive pungency associated with alliin. This study contributed to evaluate the effects of hot water blanching temperature and duration on alliin content, moisture content, color characteristics, textural properties, and aroma acceptability of *lokio*. Fresh *lokio* bulbs were blanched at 80, 90, and 100 °C for 2, 4, 6, 8, and 10 min using a factorial randomized design. Alliin content was quantified using HPLC, while moisture, color, texture, and aroma acceptability were analyzed using standard methods. Increasing blanching temperature and duration significantly reduced alliin content and hardness ($p<0.05$), accompanied by increased lightness, yellowness, and chroma, as well as decreased hue angle, indicating a shift toward yellow–orange color. Aroma acceptability increased significantly with blanching severity, reflecting reduced pungency. The optimal blanching condition was identified at 100 °C for 6–8 min, which effectively reduced alliin content while maintaining acceptable texture and color quality. These findings provide practical guidance for optimizing blanching pretreatment to achieve controlled pungency reduction and improved sensory acceptance in *lokio* processing.

KEYWORDS
Alliin; Color; Hot water blanching; Pungency; Texture

1. INTRODUCTION

Indonesia, as an archipelagic country with exceptionally rich biodiversity, holds substantial potential in the agricultural sector, particularly in indigenous vegetable commodities that play an important role in culinary traditions. One of the most widely utilized vegetable groups is the genus *Allium*, which is well recognized for its characteristic aroma, pungent flavor, and abundance of bioactive compounds [1], [2]. Among *Allium* species, *lokio* (*Allium chinense* G. Don) is a local vegetable commonly consumed as both a fresh vegetable and a seasoning ingredient in traditional Indonesian cuisine. Despite its considerable potential as a natural flavoring and functional ingredient, *lokio* remains less extensively studied and less popular than major *Allium* species such as garlic (*Allium sativum*) and onion (*Allium cepa*). Previous studies have demonstrated that *lokio* contains high levels of taste-active amino acids, particularly glutamic acid, which contributes to a pronounced umami taste and highlights its potential as a natural seasoning ingredient [3], [4].

However, its broader utilization and scientific exploration are constrained by its extremely pungent aroma, which is dominated by volatile sulfur compounds such as methanethiol, dimethyl disulfide, and dimethyl trisulfide. These compounds originate from alliin, a major S-alk(en)yl-L-cysteine sulfoxide that serves as a key precursor for sulfur volatilization through alliinase-catalyzed reactions upon tissue disruption. The rapid formation and accumulation of these highly volatile sulfur compounds not only result

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in an excessively sharp, cabbage-like odor but also accelerate quality deterioration during storage, thereby limiting the acceptability, handling stability, and experimental reproducibility of fresh *lokio* [5], [6], [7].

Blanching is typically conducted at temperatures exceeding 75 °C, depending on the physicochemical characteristics of the vegetable matrix being treated. It is widely applied as a pretreatment in vegetable processing to modulate the concentration of pungency-related precursors in *Allium* tissues [8], [9]. Pungency in *Allium* species arises when alliin is cleaved by the enzyme alliinase to form allicin and other thiosulfinates, a reaction that is highly sensitive to temperature and processing conditions [7], [10]. Therefore, hot water blanching plays an important role in controlling alliin content and reducing pungency in *Allium* tissues [11]. In addition to its effect on sulfur precursors, blanching induces structural modifications at the cellular level, including cell wall softening and increased tissue permeability, which subsequently influence textural properties and color appearance [12], [13]. Although these physicochemical changes are often considered secondary effects of thermal treatment, they are highly relevant, as they contribute to improved processing behavior and material uniformity during subsequent processing stages [14]. Previous studies have also reported that blanching reduces tissue hardness and alters color attributes, which may influence consumer perception of processed *Allium* products [15].

Despite extensive investigations on the thermal processing of *Allium* species, most studies have predominantly focused on garlic (*Allium sativum*) and onion (*Allium cepa*), particularly in relation to enzyme inactivation kinetics, thiosulfinate degradation, and associated changes in physicochemical and sensory attributes [16]. In contrast, existing studies on *lokio* have mainly emphasized its compositional characteristics and potential functional properties, with limited attention to process induced transformations and their implications for product quality and sensory acceptance [3], [6]. Therefore, investigating the combined effects of temperature–time dependent blanching on alliin degradation and quality attributes in *lokio* is of particular importance. Such an approach not only addresses the existing research gap in this underexplored *Allium* species but also provides a more comprehensive understanding of the interplay between chemical transformation and product quality. Accordingly, this study evaluated the effects of hot water blanching temperature and duration on alliin content, moisture content, color characteristics, textural properties, and aroma acceptability of *lokio*. The findings are expected to support the development of optimized blanching strategies that enable effective pungency reduction while maintaining desirable physicochemical properties and enhancing consumer acceptance.

2. MATERIALS AND METHODS

2.1. Materials

The material used in this study was *lokio* obtained from a local farmer in Bogor, Indonesia. The bulbs had an average length of 2.0–3.0 cm and a diameter of 1.5–2.5 cm. Standard Alliin, S-allyl-L-cysteine (S-ALC) and reagents were purchased from Sigma-Aldrich (St. Louis, Missouri, USA).

2.2. Blanching Treatment

Hot water blanching was performed by immersing 50 g of *lokio* bulbs in 100 mL of preheated water at target temperatures of 80 °C, 90 °C, and 100 °C for different blanching durations (2, 4, 6, 8, and 10 min) using a water bath (Memmert Waterbath WNB 29, Germany), followed by immediate cooling to stop further thermal reactions. The selected sample-to-water ratio (1:2, w/v) was applied to ensure sufficient heat transfer and to maintain a stable thermal environment during blanching (Figure 1), while also allowing controlled diffusion of soluble compounds from the plant tissue into the surrounding medium. This ratio has been widely adopted in blanching studies to balance heat penetration efficiency and mass transfer processes, particularly in vegetables with high water-soluble constituents such as *Allium* species. The study employed a factorial randomized experimental design to assess the combined influence of blanching temperature and duration on the thermal processing of *lokio*. Two independent variables were examined: blanching temperature and blanching duration. Blanching temperature was evaluated at three levels (80 °C, 90 °C, and 100 °C), while blanching duration consisted of five levels (2, 4, 6, 8, and 10 min). This factorial arrangement generated 15 treatment combinations, enabling the evaluation of both the main effects of each factor and their interaction.

Fresh *Lokio* (*Allium chinense* G. Don)
↓
Sample Preparation
(sorting → cleaning → trimming → weighing 50 g)
↓
Factorial Experimental Design
Temperature (T): 80, 90, 100°C
Time (t): 2, 4, 6, 8, 10 min
↓
Hot Water Blanching
(Immersion in water bath at controlled temperature)
↓
Ice Water Cooling
(Rapid cooling to stop thermal reaction)
↓
Sample Preparation
(Grinding / homogenization)
↓
Sample Analysis
├── Alliin content (HPLC)
├── Moisture content (oven method, wb)
├── Color (L*, a*, b*, C*, h°)
├── Texture (Hardness)
└── Aroma acceptability (sensory)

Figure 1. Flowchart of the hot water blanching process of *lokio*.

2.3. Quantification of Moisture Content

Moisture content was determined using the oven-drying method with a hot air oven (Memmert, Germany). Approximately 2–5 g of homogenized sample was weighed into a pre-dried and weighed moisture dish. Samples were dried at 105 °C until a constant weight was achieved, and moisture content was calculated based on the weight difference before and after drying, expressed on a wet basis (wb) as the percentage of water relative to the initial sample weight [10].

2.4. Quantification of Alliin

Alliin analysis was conducted following previously reported methods with minor modifications [17]. An accurately weighed portion of *lokio* puree was extracted with 100 mL of 10% (v/v) aqueous methanol. The mixture was subjected to ultrasonication at room temperature for 60 min to facilitate compound extraction, followed by filtration using double-layer filter paper. The filtrate was subsequently centrifuged at 6000 rpm for 30 min, and the resulting supernatant was transferred into a 250 mL volumetric flask, diluted to volume with distilled water, and filtered through a 0.22 µm microporous membrane prior to analysis.

For standard preparation, alliin (1 mg) was accurately weighed and dissolved in 10 mL of double-distilled water, then subsequently diluted to volume in a 50 mL volumetric flask and homogenized thoroughly. An aliquot (2 mL) of the alliin standard solution was transferred into a 5 mL centrifuge tube to obtain a mixed reference stock solution, which was stored at 4°C until analysis. Both sample extracts and standard solutions were filtered through a 0.22 µm Millipore membrane prior to injection. Quantitative analysis of alliin was performed using a Shimadzu HPLC system (Kyoto, Japan) equipped with a binary pump (LC-20AD), an autosampler (SIL-HTC), and a UV–Vis diode array detector (SPD-M20A). Separation was achieved on a C18 analytical column (150 mm × 4.6 mm, 5 µm particle size) maintained at 40 °C. The mobile phase consisted of distilled water and methanol (50:50, v/v), delivered at a flow rate of

0.5 mL/min. Detection was carried out at 240 nm, with a total run time of 20 min, and an injection volume of 20 µL.

2.5. Determination of Color Value

The color of the *lokio* samples was measured using a Hunter Lab color meter (CR-400, Konica Minolta Inc., Tokyo, Japan) [18], [19]. Prior to measurement, the instrument was calibrated using the standard white calibration plate provided by the manufacturer. Blanched *lokio* samples were placed on transparent petri dishes, and color measurements were obtained by bringing the aperture of the color meter into direct contact with the sample surface through the Petri dish. Color attributes were expressed in Hunter Lab units, namely L* (lightness), a* (redness/greenness), and b* (yellowness/blueness). For each treatment, measurements were performed in triplicate at different positions on the sample surface, and the mean values were used for further analysis. The L*, a*, and b* parameters were used to characterize color changes in blanched *lokio* samples resulting from different blanching conditions.

2.6. Texture Measurement

The Texture properties were evaluated using a texture analyzer (TA.XT Plus, Stable Micro Systems, UK) equipped with a cylindrical probe (P/36). The instrument was calibrated for force and distance prior to analysis, and hardness was measured as the maximum force (N) recorded during compression to 50% strain [20].

2.7. Sensory Evaluation

Sensory evaluation was conducted following the general procedure described by Bin Zhang et al. (2021) [10] with appropriate modifications. Aroma evaluation was carried out at room temperature using a nine-point hedonic scale (1.0 represented dislike extremely, 2.0 represented dislike very much, 3.0 represented dislike moderately, 4.0 represented dislike slightly, 5.0 represented neither like nor dislike, 6.0 represented like slightly, 7.0 represented like moderately, 8.0 represented like very much, and 9.0 represented like extremely). The sensory panel consisted of 25 untrained panelists who were regular consumers of *Allium*-based products and reported no olfactory or sensory impairments. Prior to evaluation, panelists were briefly instructed on the concept of aroma pungency to ensure a common understanding. Aroma pungency was described as a sharp, sulfurous, onion- or garlic-like odor that may induce a tingling sensation in the nasal cavity. Verbal reference explanations were provided without the use of standard reference samples to guide panelists in assessing aroma acceptability, defined as the degree of liking or disliking the aroma. Approximately 20 g of *lokio* puree from each treatment was placed on transparent plates, coded with random three-digit numbers, and presented to panelists in randomized order. Panelists were instructed to evaluate aroma intensity and aroma acceptability only, without tasting the samples, and to record their scores independently. A short rest period was provided between samples to minimize sensory adaptation and carry-over effects.

2.8. Data Analysis

The experimental data were analyzed using two-way analysis of variance (ANOVA) at a significance level of $p<0.05$ using IBM SPSS Statistics version 26 (IBM Corp., Armonk, NY, USA). The effects of blanching temperature, blanching time, and their interaction on all measured parameters were evaluated. When significant differences were observed, mean comparisons were performed using Duncan’s multiple range test. Pearson correlation analysis was conducted to examine the relationships among moisture content, alliin content, physicochemical properties (color and texture), and sensory attributes during blanching. Correlation coefficients were interpreted based on their magnitude and statistical significance ($p<0.05$).

3. RESULTS AND DISCUSSION

3.1. Moisture Content

Table 1 presents the response of *lokio* to hot water blanching at three temperatures (80 °C, 90 °C, and 100 °C) for various durations (2, 4, 6, 8, and 10 min), highlighting moisture-related changes induced by thermal treatment. The observed moisture behavior reflects the combined effects of blanching temperature and time on heat transfer and water migration within the tissue matrix. Higher blanching temperatures generally accelerated initial moisture loss ($p \leq 0.05$) due to increased vapor pressure gradients and partial tissue collapse [21], [22]. However, with prolonged blanching, particularly under extended hot water exposure, structural modifications such as cell wall softening and increased tissue porosity became more pronounced, facilitating internal water redistribution or reabsorption. This dual behavior explains the two-stage moisture response observed in *lokio*, characterized by an initial reduction in surface moisture followed by partial moisture retention or an increase at longer blanching times. Similar moisture dynamics have been reported in vegetables, where blanching alters microstructural integrity and diffusion pathways, thereby modifying moisture trajectories [23], [24], [25].

Table 1. Moisture content of *lokio* during hot water blanching.

Blanching treatment		Moisture content (%)
Temperature (°C)	Durations (min)	
80	2	86.29 ± 0.34^{bc}
80	4	86.63 ± 0.32^{bc}
80	6	87.01 ± 0.59^{ab}
80	8	87.44 ± 0.78^{a}
80	10	87.74 ± 0.98^{a}
90	2	85.97 ± 0.41^{c}
90	4	86.36 ± 0.33^{bc}
90	6	86.67 ± 0.60^{bc}
90	8	86.86 ± 0.68^{ab}
90	10	87.09 ± 0.62^{ab}
100	2	85.85 ± 0.50^{c}
100	4	86.03 ± 0.48^{c}
100	6	86.34 ± 0.25^{bc}
100	8	86.40 ± 0.35^{bc}
100	10	86.60 ± 0.34^{bc}

Notes: Data are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate significant differences among blanching treatments at $p \leq 0.05$.

3.2. Alliin Content

The effects of hot water blanching at three temperatures (80 °C, 90 °C, and 100 °C) and various durations (2, 4, 6, 8, and 10 min) on the alliin content of *lokio* are presented in Table 2. The identity and chromatographic behavior of alliin were confirmed by HPLC analysis, as shown in Figure 2. The observed degradation patterns demonstrate that alliin content decreased significantly ($p \leq 0.05$) with increasing blanching temperature and duration, indicating the high thermal sensitivity of this sulfur-containing precursor. The reduction in alliin content reflects the combined influence of thermal degradation and mass transfer phenomena within the tissue matrix. Increasing blanching temperature enhances thermal energy input, which promotes rapid structural disruption, increases tissue permeability, and modifies diffusion pathways for sulfur-containing compounds. As a result, alliin loss is facilitated through diffusion and leaching into the blanching medium [15]. A similar temperature-dependent decline in alliin and related sulfur precursors has been widely reported in garlic and onion during thermal processing, where blanching or heating significantly reduces thiosulfinate formation and pungency intensity [7] . In addition to thermal instability, the degradation of alliin is strongly influenced by the inactivation of alliinase, the key enzyme responsible for converting alliin into allicin and other volatile sulfur compounds following tissue disruption [15]. Elevated temperatures accelerate enzyme denaturation, thereby suppressing enzymatic conversion pathways and limiting the formation of pungent volatiles. Comparable findings have been reported in garlic, where rapid inactivation of alliinase during blanching significantly reduces allicin formation and alters the overall flavor profile [26], [27].

Table 2. Alliin content of *lokio* during hot water blanching.

Blanching treatment		Alliin content (%)
Temperature (°C)	Duration (min)	
80	2	0.35 ± 0.01^{a}
80	4	0.34 ± 0.01^{a}
80	6	0.33 ± 0.00^{b}
80	8	0.31 ± 0.01^{c}
80	10	0.28 ± 0.04^{d}
90	2	0.18 ± 0.02^{e}
90	4	0.14 ± 0.02^{f}
90	6	0.12 ± 0.03^{f}
90	8	0.09 ± 0.01^{g}
90	10	0.06 ± 0.02^{h}
100	2	0.06 ± 0.01^{h}
100	4	0.04 ± 0.00^{i}
100	6	0.04 ± 0.00^{i}
100	8	0.037 ± 0.01^{i}
100	10	0.027 ± 0.01^{j}

Notes: Data are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate significant differences among blanching treatments at $p \leq 0.05$.

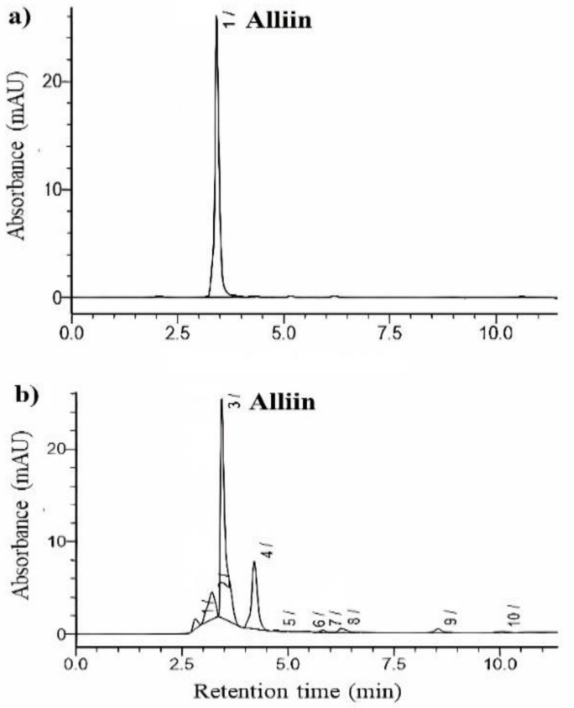

Figure 2. a) HPLC chromatogram of alliin standard solution by Diode Array Detector (DAD) recording at 240 nm; b). HPLC chromatogram of alliin *lokio*.

However, alliin degradation during blanching is not governed solely by enzymatic inactivation. Prolonged thermal exposure induces microstructural changes, including cell wall softening and expansion of intercellular spaces, which increase tissue porosity and enhance the diffusion of low-molecular-weight sulfur compounds out of the tissue matrix [10]. These structural modifications initially influence the accessibility of alliin to residual enzymatic activity and subsequently promote diffusion-driven losses as blanching progresses. Similar structural effects have been observed in thermally processed onion tissues, where increased permeability facilitates the migration of soluble compounds into the surrounding medium [28].

3.3. Color Measurement

The effects of hot water blanching at three temperatures (80 °C, 90 °C, and 100 °C) and different durations (2, 4, 6, 8, and 10 min) on the color characteristics of *lokio* are presented in Table 3. The results indicate that both blanching temperature and duration significantly influenced color parameters ($p \leq 0.05$), reflecting the combined effects of thermal reactions, pigment stability, and structural modifications within the tissue matrix. Increasing blanching temperature led to a progressive increase in lightness (L*) and yellowness (b*), accompanied by a shift of a* values toward fewer negative coordinates, indicating a gradual reduction in green color intensity and a transition toward yellow–orange hues [29], [30].

Table 3. Color of *lokio* during hot water blanching.

Blanching treatment		L*	a*	b*	Chroma (C*)	Hue angle (h°)	Color Description	
Temp. (°C)	Duration (min)						Name	Hue
80	2	56.79 ± 0.35^{a}	-7.50 ± 0.24^{a}	10.53 ± 0.17^{a}	12.93 ± 0.27^{a}	125.45 ± 0.47^{o}	Yellowish Green	Yellow-Green
80	4	57.17 ± 0.05^{b}	-6.03 ± 0.15^{b}	11.31 ± 0.06^{b}	12.95 ± 0.20^{b}	119.11 ± 1.06^{n}	Yellowish Green	Yellow-Green
80	6	57.43 ± 0.12^{c}	-5.63 ± 0.13^{c}	11.80 ± 0.07^{c}	13.03 ± 0.17^{c}	115.00 ± 0.89^{m}	Yellow Green	Yellow-Green
80	8	58.19 ± 0.08^{d}	-5.36 ± 0.07^{d}	12.34 ± 0.06^{d}	13.45 ± 0.10^{d}	113.38 ± 0.35^{l}	Yellow Green	Yellow-Green
80	10	59.27 ± 0.05^{g}	-5.05 ± 0.05^{e}	12.73 ± 0.06^{e}	13.77 ± 0.07^{e}	112.39 ± 0.27^{k}	Yellow Green	Yellow-Green
90	2	58.23 ± 0.05^{e}	-4.95 ± 0.06^{f}	13.02 ± 0.07^{f}	13.97 ± 0.07^{f}	111.19 ± 0.17^{j}	Olive Green	Yellow-Green
90	4	58.55 ± 0.13^{f}	-4.80 ± 0.06^{g}	13.53 ± 0.08^{g}	14.39 ± 0.06^{g}	109.85 ± 0.32^{i}	Olive Green	Yellow-Green
90	6	59.44 ± 0.11^{h}	-4.70 ± 0.05^{h}	13.88 ± 0.04^{h}	14.63 ± 0.05^{h}	108.37 ± 0.33^{h}	Olive	Yellow-Green
90	8	60.28 ± 0.08^{i}	-4.60 ± 0.05^{i}	14.12 ± 0.06^{i}	14.76 ± 0.04^{i}	106.97 ± 0.23^{g}	Olive	Yellow-Green
90	10	61.36 ± 0.11^{j}	-4.50 ± 0.05^{j}	14.32 ± 0.06^{j}	14.88 ± 0.05^{j}	105.81 ± 0.18^{f}	Olive	Yellow-Green
100	2	61.73 ± 0.08^{k}	-4.20 ± 0.06^{k}	14.94 ± 0.10^{k}	15.42 ± 0.08^{k}	104.39 ± 0.36^{e}	Yellowish Olive	Yellow-Green
100	4	62.23 ± 0.06^{l}	-3.80 ± 0.05^{l}	15.64 ± 0.08^{l}	15.97 ± 0.06^{l}	101.78 ± 0.38^{d}	Yellowish Olive	Yellow-Green
100	6	62.80 ± 0.07^{m}	-3.50 ± 0.04^{m}	16.34 ± 0.06^{m}	16.55 ± 0.04^{m}	98.98 ± 0.53^{c}	Yellow	Yellow
100	8	63.35 ± 0.09^{n}	-3.20 ± 0.05^{n}	17.56 ± 0.07^{n}	17.67 ± 0.05^{n}	96.43 ± 0.44^{b}	Yellow	Yellow
100	10	64.25 ± 0.14^{o}	-2.90 ± 0.06^{o}	18.03 ± 0.23^{o}	18.08 ± 0.24^{o}	94.30 ± 0.22^{a}	Yellow	Yellow

Notes: Data are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate significant differences among blanching treatments at $p \leq 0.05$.

Prolonged blanching further intensified these changes, resulting in higher chroma values and a marked decrease in hue angle, which reflects enhanced color saturation and a directional shift toward yellow-dominant color regions. These chromatic changes are primarily attributed to thermally induced pigment transformations, particularly chlorophyll degradation and the increased relative visibility of yellow–orange pigments such as carotenoids. Chlorophyll degradation under thermal conditions leads to the loss of green coloration, while carotenoids become more visually dominant, contributing to the observed increase in b* values and reduction in hue angle [31], [32]. In addition, blanching induced tissue softening alters optical properties and light scattering behavior, thereby contributing to increased brightness and color saturation [33]. Extended thermal exposure further amplifies these effects by promoting pigment redistribution and microstructural disruption, including cell wall weakening and expansion of intercellular spaces, which enhance light reflectance and reduce green tonal dominance [28], [34].

Similar color transformation patterns have been widely reported in thermally processed vegetables. In *Allium* species such as garlic and onion, blanching has been shown to increase lightness and reduce green color intensity due to chlorophyll degradation and tissue softening [15], [16]. Comparable trends have also been observed in non-*Allium* vegetables, including carrot and zucchini, where thermal treatment enhances chroma and shifts color toward yellow–orange regions through combined pigment degradation and structural modification mechanisms [35].

3.4. Texture Measurement

The effects of hot water blanching at three temperatures (80 °C, 90 °C, and 100 °C) and varying durations (2, 4, 6, 8, and 10 min) on the hardness of *lokio* are presented in Table 4. The results demonstrate a pronounced softening of *lokio* tissues as blanching temperature and time increased ($p \leq 0.05$), indicating that textural properties are highly sensitive to thermal treatment. At 80 °C, hardness values decreased progressively with longer blanching durations, reflecting gradual thermal softening of the tissue matrix. This softening became more pronounced at higher temperatures, where *lokio* blanched at 90 °C and 100 °C exhibited significantly lower hardness values even at shorter processing times. Prolonged exposure to elevated temperatures further intensified hardness reduction, with the lowest values observed at 100 °C for 10 min. These trends suggest that increasing thermal intensity accelerates cell wall degradation, pectin solubilization, and loss of structural integrity, leading to reduced mechanical resistance and softer texture in blanched *lokio*.

Table 4. Texture of *lokio* during hot water blanching.

Blanching treatment		Hardness (N)
Temperature (°C)	Duration (min)	
80	2	2.07 ± 0.03^{a}
80	4	2.03 ± 0.02^{a}
80	6	1.95 ± 0.09^{b}
80	8	1.77 ± 0.06^{c}
80	10	1.55 ± 0.04^{d}
90	2	1.45 ± 0.04^{e}
90	4	1.30 ± 0.03^{f}
90	6	1.22 ± 0.02^{g}
90	8	1.17 ± 0.03^{h}
90	10	1.11 ± 0.01^{i}
100	2	1.09 ± 0.02^{i}
100	4	0.84 ± 0.03^{j}
100	6	0.74 ± 0.02^{k}
100	8	0.48 ± 0.06^{l}
100	10	0.31 ± 0.03^{m}

Notes: Data are expressed as mean ± standard deviation (n = 3). Different superscript letters within the same column indicate significant differences among blanching treatments at $p \leq 0.05$.

Blanching at higher temperatures and longer durations markedly accelerates the softening of *lokio* tissues through concurrent structural and physicochemical mechanisms. Elevated thermal intensity promotes progressive disruption of cell wall components, particularly pectic substances, leading to weakened intercellular adhesion, increased tissue porosity, and enhanced water mobility within the matrix. In *Allium* vegetables, increasing blanching temperature reduces tissue rigidity by diminishing turgor pressure and altering membrane integrity [36], [37]. These effects are amplified at higher temperatures, where tissue deformation and hardness loss occur more rapidly than under moderate thermal conditions. Prolonged blanching further intensifies softening due to cumulative thermal exposure, which promotes sustained polymer breakdown, water redistribution, and loss of structural coherence, yielding progressively lower hardness values with increasing processing time [34], [38]. Similar trends have been widely reported in *Allium* and other vegetables, where texture degradation follows temperature and time dependent kinetic behavior and is closely associated with concurrent changes in moisture content [35].

3.5. Sensory

The effects of hot water blanching at three temperatures (80 °C, 90 °C, and 100 °C) and varying durations (2, 4, 6, 8, and 10 min) on the aroma hedonic scores of *lokio* are presented in Table 5. Aroma acceptability was evaluated at room temperature using a nine-point hedonic scale, where higher scores indicated greater liking of the aroma. The results demonstrated a significant increase in aroma acceptability with increasing blanching temperature and duration ($p \leq 0.05$), indicating that sensory perception of pungent aroma is highly sensitive to thermal treatment. At 80 °C, aroma scores increased gradually with longer blanching durations, reflecting a progressive reduction in pungent odor intensity that improved panelist acceptance. This effect became more pronounced at higher temperatures, where *lokio* blanched at 90 °C and 100 °C achieved significantly higher aroma scores even at shorter processing times. Prolonged exposure to elevated temperatures further enhanced aroma acceptability, with the highest hedonic scores observed at 100 °C for 10 min.

Table 5. Hedonic aroma scores of *lokio* during hot water blanching.

Blanching treatment		Aroma score
Temperature (°C)	Duration (min)	
80	2	2.3 ± 0.6^{a}
80	4	2.6 ± 0.6^{a}
80	6	2.9 ± 0.7^{a}
80	8	3.2 ± 0.7^{b}
80	10	3.5 ± 0.8^{b}
90	2	4.2 ± 0.6^{c}
90	4	4.5 ± 0.6^{c}
90	6	4.8 ± 0.7^{d}
90	8	5.1 ± 0.7^{d}
90	10	5.3 ± 0.8^{d}
100	2	5.6 ± 0.6^{e}
100	4	5.9 ± 0.6^{e}
100	6	6.2 ± 0.7^{f}
100	8	6.5 ± 0.7^{f}
100	10	6.8 ± 0.8^{f}

Note: Data are expressed as mean ± standard deviation (n = 25); 95% confidence interval. Means within the columns with different letters indicate a significant difference ($p \leq 0.05$).

The increase in aroma hedonic scores observed in blanched *lokio* can be directly attributed to thermally induced modifications of alliin. In fresh tissues, aroma pungency is primarily associated with the formation of allicin and related sulfur volatiles derived from alliin precursors through alliinase activity following tissue disruption [7], [39], [40]. Hot water blanching alters this pathway by progressively inactivating alliinase and destabilizing reactive sulfur intermediates, thereby reducing the formation and persistence of sharp, pungent volatiles [15]. The observed interaction between blanching temperature and duration indicates that higher thermal intensity accelerates enzyme inactivation and sulfur compound degradation more effectively than prolonged treatment at lower temperatures, leading to a more rapid attenuation of pungent aroma and a corresponding increase in aroma acceptability scores. In parallel, blanching-induced tissue softening and increased porosity modify the retention and release dynamics of volatile sulfur compounds, facilitating their volatilization or dilution within the aqueous matrix and further moderating perceived aroma intensity [10]. Collectively, these findings indicate that the reduction of alliin contributes to the improved aroma acceptability of blanched *lokio*, consistent with aroma modulation trends reported for other thermally pretreated *Allium* vegetables [16].

3.6. Pearson Correlation Heatmap

The Pearson correlation heatmap was used to evaluate the relationships among alliin content, physicochemical properties, and aroma acceptability of *lokio* during blanching (Figure 3). All variables were treated as continuous quantitative data, and Pearson correlation coefficients (r) were applied to assess linear associations among parameters. Moisture content exhibited relatively weak to moderate correlations with other variables ($r = -0.36$ to 0.42), suggesting that water content plays a secondary role compared to chemical degradation and structural modifications during blanching. Nevertheless, its positive correlation with hardness ($r = 0.30$) indicates that water retention may contribute to maintaining tissue integrity, particularly under milder thermal conditions. In contrast, alliin content showed a very strong negative correlation with aroma score ($r = -0.97$), indicating that the reduction of alliin during blanching was closely associated with improved aroma acceptability. This inverse relationship confirms the role of alliin as a key precursor of pungency, where its degradation limits the formation of volatile sulfur compounds responsible for sharp and undesirable odors. Consequently, treatments that effectively reduce alliin content contribute directly to improved sensory perception. This observation is consistent with previous studies reporting that thermal processing reduces sulfur-derived pungency compounds and enhances aroma quality in *Allium* products [16], [28]. The relationships between alliin content and physicochemical parameters further reveal important quality transitions during blanching. Alliin exhibited strong negative correlations with color parameters, including L* ($r = -0.89$), a* ($r = -0.88$), b* ($r = -0.90$), and chroma ($r = -0.87$), indicating that decreasing alliin content was associated with increased brightness, enhanced yellowness, and greater color saturation. These changes reflect thermally induced pigment transformations, particularly chlorophyll degradation and the emergence of yellow–orange hues. Conversely, alliin showed strong positive correlations with hue angle ($r = 0.91$) and hardness ($r = 0.93$), suggesting that higher alliin levels are associated with greener color tones and firmer tissue structure, which are typical characteristics of fresh, unprocessed *lokio*.

From a sensory perspective, aroma score demonstrated a strong negative correlation with hardness ($r = -0.99$), indicating that softer tissue structure is associated with improved aroma acceptability. In addition, aroma score exhibited strong positive correlations with color intensity parameters such as b* ($r = 0.98$) and chroma ($r = 0.95$), along with a strong negative correlation with hue angle ($r = -0.97$). These findings indicate that improvements in aroma acceptability occur simultaneously with visible color changes toward yellow hues, reflecting coordinated physicochemical transformations during blanching. These correlations highlight a critical trade-off among pungency reduction, color development, and texture preservation. Treatments with higher temperature and longer duration promote greater alliin degradation and improved aroma acceptability, but also lead to increased tissue softening. Conversely, milder treatments better preserve texture but retain higher alliin levels, resulting in lower sensory acceptability. Based on this integrated analysis, the optimal blanching condition can be identified at 100 °C for 6–8 min, where alliin reduction is sufficient to significantly improve aroma acceptability, while color development is desirable and texture softening remains within an acceptable range. This condition represents a balanced processing strategy that simultaneously optimizes chemical, physicochemical, and sensory attributes of *lokio*.

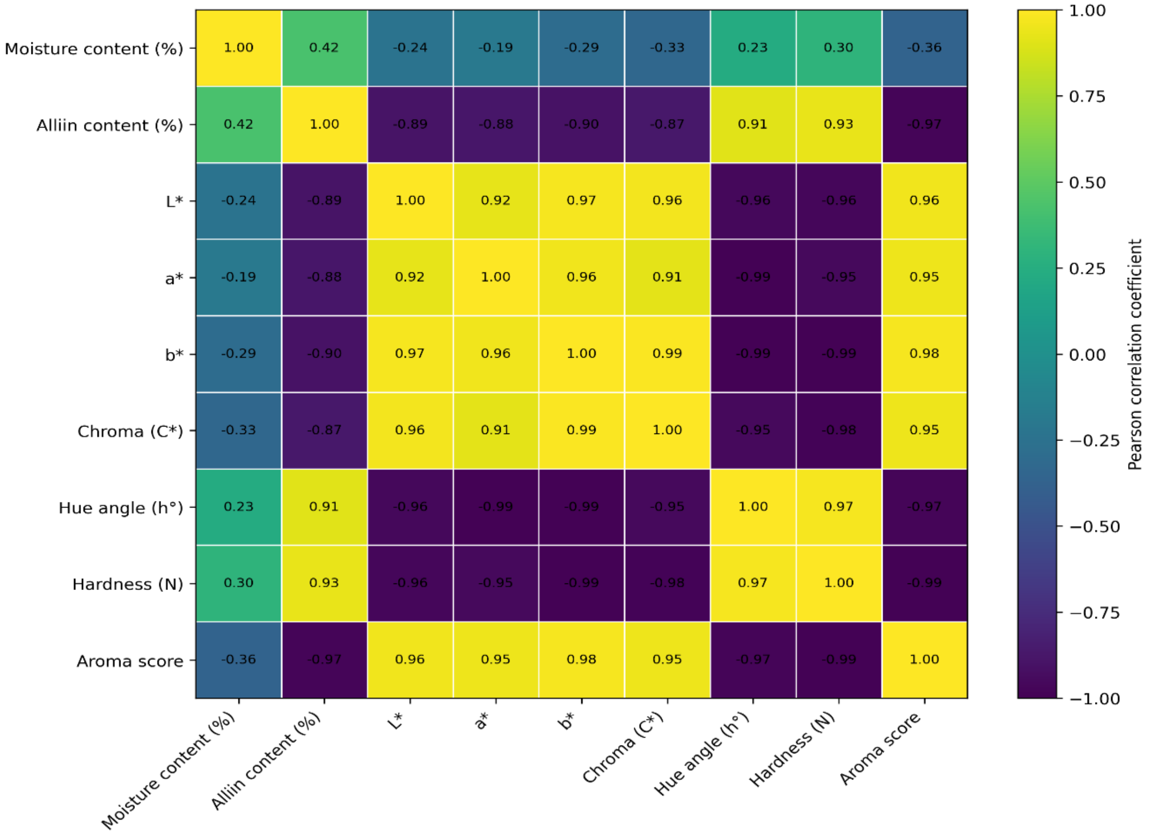

Figure 3. Pearson correlation heatmap in *lokio* during blanching treatments at different temperatures and times. Values in each cell represent Pearson's correlation coefficients (r).

4. CONCLUSION

Hot water blanching significantly influenced the chemical, physicochemical, and sensory characteristics of *lokio* in a temperature–time dependent manner. Increasing blanching intensity resulted in substantial degradation of alliin, accompanied by enhanced aroma acceptability, color development, and texture softening. Among the tested conditions, blanching at 100 °C for 6–8 min is recommended as the optimal condition, as it achieved effective pungency reduction while maintaining desirable color attributes and acceptable texture. These findings provide a scientific basis for the application of blanching as a pretreatment strategy in *lokio* processing, particularly for developing products with reduced pungency and improved consumer acceptance. However, this study has several limitations. The sensory evaluation was limited to aroma acceptability without including taste or overall preference, and volatile sulfur compounds were not directly quantified. In addition, the study was conducted at laboratory scale, which may differ from industrial processing conditions. Future research should focus on comprehensive flavor profiling, including volatile compound analysis, taste evaluation, and multivariate sensory approaches. Furthermore, scaling up the blanching process and evaluating its impact on nutritional quality and storage stability will be essential to support industrial application.

AUTHOR CONTRIBUTION

All authors contributed equally to the main contributor to this paper. **Eva Mayasari**: Writing (review & editing), writing (original draft), and formal analysis. **Supriyadi Supriyadi**: Investigation, writing (review & editing), supervision, conceptualization, and funding acquisition. **Retno Indrati**: Writing (review & editing), supervision, investigation, and formal analysis. **Widiastuti Setyaningsih**: Writing (review & editing), supervision, investigation, and formal analysis.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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