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Physical Properties of White Pepper as Affected by Skin-Peeling Method: A Comparative Study of Soaking and Boiling on Green and Red Pepper Fruits

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ABSTRACT

Skin-peeling method is a critical determinant of white pepper quality. This study evaluated the effects of two skin-peeling treatments, soaking at room temperature (30 °C for 10–14 days) and boiling at high temperature (100 °C for 10 minutes), on three physical properties of white pepper produced from green and red pepper fruits (*Piper nigrum L.*): moisture content (wet-basis/MC wb and dry basis/ MC db), color attributes (L*, a*, b*), and hardness. A total of 150 fresh pepper fruits from Bulukumba Regency, sorted at two maturity levels (green and red, 5.5–6.0 mm diameter), were divided into four treatment groups. This study was descriptive and comparative in nature without statistical replication; results are presented as single-point observations. The boiling treatment produced the lowest MC wb in peeled red pepper (LMPK: 8.83%), the only sample approaching the maximum threshold set by SNI 0004:2013 (≤13.0%). Soaking resulted in MC wb values of 25.05% for peeled pepper across both maturity levels. In terms of surface lightness, soaked peeled red pepper (LMRK: L* = 11.86) outperformed boiled peeled red pepper (LMPK: L* = 8.51), indicating that soaking better preserved kernel brightness. Hardness values of peeled pepper ranged from 27.68 N (LHPK) to 36.62 N (LMPK), with the boiling treatment producing comparable or slightly higher hardness than soaking. The soaking method produced brighter white pepper kernels, while boiling more effectively reduced moisture content and is better suited when shelf life is the priority.

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1. INTRODUCTION

Pepper (*Piper nigrum* L.) is one of the most important spice commodities cultivated in Indonesia, including South Sulawesi (Permadi et al., 2022). White pepper is produced from fully ripe pepper fruits that undergo a skin-removal (decortication) process, distinguishing it from black pepper, which is produced without peeling. The decortication method significantly influences the physical quality of white pepper, including moisture content, color, and hardness (Kusmiadi et al., 2017), all of which determine market acceptance and compliance with national quality standards.

Physical quality parameters of white pepper carry direct practical implications. Moisture content is closely linked to shelf life and safety: pepper with moisture content above 13% (the SNI 0004:2013 threshold) is susceptible to mold growth and mycotoxin contamination during storage (Badan Standardisasi Nasional, 2013). Surface color, measured through the CIE L*a*b* system, is a primary driver of consumer acceptance and market grading, since brighter (higher L*) white pepper commands higher commercial value. Hardness relates to downstream processing quality, particularly grinding efficiency, as harder kernels with lower moisture content are more suitable for consistent particle size reduction during milling (Setiasih et al., 2018).

Traditional processing methods used by farmers generally involve soaking pepper fruits in water for several days or boiling them in hot water for a shorter period (Rosa & Mesin, 2018). Soaking relies on microbial fermentation activity that softens and decomposes the pericarp through enzymatic degradation of pectin and cellulose, allowing gradual, gentle decortication (Kusmiadi et al., 2017). Boiling, by contrast, accelerates skin loosening through thermal energy and steam pressure, achieving decortication in minutes rather than days (Sutamihardja et al., 2018). These mechanistic differences imply contrasting effects on physical properties: soaking may produce brighter kernels because pigment leaching and enzymatic bleaching occur gradually without heat-induced color change, while boiling risks thermal degradation of surface pigments, reducing L* values.

Previous studies have documented that soaking improves surface brightness but tends to elevate moisture content due to prolonged water contact, while boiling reduces moisture content and shortens processing time (Kusmiadi et al., 2017; Sutamihardja et al., 2018). Hernani et al. (2023) evaluated the combination of soaking duration (4–6 days) and boiling time (5–20 minutes) and found that the combination of short soaking followed by brief boiling produced white pepper meeting SNI quality requirements, with the best treatment being 6 days of soaking combined with 5 minutes of boiling. However, comparative evaluations that simultaneously examine moisture content, color attributes, and hardness across two maturity levels, green and red pepper fruits, under contrasting soaking-only and boiling-only conditions remain limited in the literature, particularly for pepper from South Sulawesi sources. Understanding these trade-offs is essential for guiding post-harvest decision-making by smallholder processors.

Soaking and boiling are not the only decortication routes reported in the recent literature; they represent the two traditional ends of a broader range of methods that also includes microbial fermentation and ozone-assisted treatment. Fermentation with selected bacterial starters, such as Acetobacter sp., can soften and degrade the pericarp enzymatically within a shorter soaking window than untreated water soaking while producing white pepper with measurable lightness and chroma characteristics comparable to conventional processing (Sasmitaloka et al., 2021, 2022). Ozone application during or after soaking has likewise been investigated as a way to shorten processing time and improve microbiological quality without resorting to high-temperature boiling, with treated samples meeting SNI bulk density and moisture targets at shorter soaking durations than the traditional 10–14-day window (Sukasih et al., 2021). These methods were not evaluated in the present study, but they indicate that the soaking-versus-boiling trade-off examined here sits within a wider design space in which processors can, in principle, decouple decortication speed from the heat-driven moisture and color changes that boiling introduces. A broader review of pre- and postharvest pepper processing factors similarly emphasizes that soaking duration and drying conditions are major determinants of final moisture content and microbial safety, reinforcing the practical relevance of the moisture and color trade-offs examined in this study (Shango et al., 2021).

Therefore, this study aimed to evaluate the effects of soaking (30 °C, 10–14 days) and boiling (100 °C, 10 minutes) skin-peeling methods on moisture content, color attributes (L*, a*, b*), and hardness of white pepper produced from green and red pepper fruits sourced from Bulukumba Regency, South Sulawesi.

2. MATERIALS AND METHODS

2.1 Materials and Equipment

Fresh pepper fruits of *Piper nigrum* L. were obtained from Bulukumba Regency, South Sulawesi, following common sampling practices for pepper quality evaluation (Kusmiadi et al., 2017). Fruits were visually sorted at two maturity levels: green (unripe) and red (fully ripe), with surface defects and damaged fruits excluded. Uniform fruit size (5.5–6.0 mm diameter) was ensured using a digital caliper. Equipment used included a colorimeter, penetrometer, oven, thermometer, caliper, measuring cylinder, aluminum container, pot, and stove.

2.2 Experimental Procedure

A total of 150 pepper fruits were selected and divided across four treatment groups based on fruit maturity and peeling method: (1) soaking green pepper at 30 °C, (2) boiling green pepper at 100 °C, (3) soaking red pepper at 30 °C, and (4) boiling red pepper at 100 °C, with an untreated control group for each maturity level (Rosa & Mesin, 2018). Initial measurements of moisture content, color (L*, a*, b*), and hardness were taken before treatment. Soaking was conducted in room-temperature water (30 °C) for 10–14 days until the pericarp was soft and easily removable. Boiling was carried out in water at 100 °C for 10 minutes after the water reached its boiling point. After each treatment, pepper skins were manually removed and all parameters were measured again on the peeled kernels.

2.3 Parameter Measurement

Moisture content was measured using the oven-drying method. Wet-basis moisture content (MC wb) and dry-basis moisture content (MC db) were calculated using the following formulas:

$$\text{MC wb } (\%) = [(W_{wet} - W_{dry}) / W_{wet}] \times 100 \tag{1}$$

$$\text{MC db } (\%) = [(W_{wet} - W_{dry}) / W_{dry}] \times 100 \tag{2}$$

where W_{wet} is the initial sample weight before oven drying and W_{dry} is the sample weight after drying to a constant mass. Color was measured using a colorimeter, which yielded three values: L* (lightness, 0–100), a* (redness/greenness), and b* (yellowness/blueness). Hardness was measured using a penetrometer, with values reported in Newtons (N).

2.4 Data Analysis

Data were analyzed descriptively by comparing observed values of moisture content, color, and hardness among treatment groups (Nasution, 2017). This study did not include statistical replication; therefore, results are presented as single-point observations and differences between treatments are interpreted as directional trends rather than statistically confirmed effects. Conclusions drawn from this study are preliminary and descriptive in nature.

3. RESULTS AND DISCUSSION

3.1 Moisture Content

Moisture content is one of the most critical quality indicators for white pepper, directly affecting shelf life, mold susceptibility, and compliance with SNI 0004:2013, which sets a maximum threshold of 13.0% MC wb (Badan Standardisasi Nasional, 2013). Table 1 presents the MC wb and MC db values for all treatment groups.

Table 1. Wet-Basis (MC wb) and Dry-Basis (MC db) Moisture Content of Pepper Samples

Code	Maturity / Skin	Treatment	MC wb (%)	MC db (%)	SNI ≤ 13%
LHTP	Green / With skin	Control (no treatment)	60.76	154.84	x
LHRBK	Green / With skin	Soaking 30 °C	48.04	92.44	x
LHPBK	Green / With skin	Boiling 100 °C	56.99	132.51	x
LHRK	Green / Peeled	Soaking 30 °C	25.05	33.42	x
LHPK	Green / Peeled	Boiling 100 °C	20.87	26.37	x
LMTP	Red / With skin	Control (no treatment)	51.99	108.28	x
LMRBK	Red / With skin	Soaking 30 °C	39.16	64.37	x
LMPBK	Red / With skin	Boiling 100 °C	44.54	80.29	x
LMRK	Red / Peeled	Soaking 30 °C	25.05	33.42	x
LMPK	Red / Peeled	Boiling 100 °C	8.83	9.68	v

Note: v = meets SNI 0004:2013 requirement (MC wb ≤ 13.0%); x = does not meet requirement.

The data show that removing the pericarp substantially reduced moisture content across all treatment groups, regardless of method. Among the peeled pepper samples, the boiling treatment consistently produced lower MC wb than soaking: boiled peeled red pepper (LMPK: 8.83% MC wb) had notably lower moisture than soaked peeled red pepper (LMRK: 25.05% MC wb), and boiled peeled green pepper (LHPK: 20.87%) was lower than soaked peeled green pepper (LHRK: 25.05%). The LMPK sample was the only group to meet the SNI 0004:2013 maximum moisture content threshold of 13.0% without post-processing drying.

The mechanism behind the lower moisture in boiled samples relates primarily to thermal moisture evaporation during the boiling process. At 100 °C, thermal energy drives rapid moisture loss from the pepper kernel surface and outer tissue layers, reducing the overall water content of the seed (Sutamihardja et al., 2018). In contrast, soaking in water at 30 °C for 10–14 days allows the pepper seeds to remain in prolonged contact with water, promoting water absorption through osmosis and the hygroscopic nature of spice commodities. Sutamihardja et al. (2018) confirmed that when pepper is placed in a high-humidity environment, it absorbs moisture from its surroundings, which contributes to elevated MC in soaked samples. Hernani et al. (2023), in a study combining soaking and boiling treatments for white pepper, similarly observed that boiling duration positively influenced moisture reduction, with longer boiling times associated with lower final moisture content. This dependence of final moisture content on the intensity and duration of a heat-based treatment is not unique to boiling: in black pepper, ultrasound-assisted pretreatment prior to drying has likewise been shown to shorten drying time and lower final moisture content relative to untreated samples, though through cavitation-assisted water removal rather than direct thermal evaporation (Johnson et al., 2025). More broadly, a review of pre- and postharvest pepper processing has highlighted that excessive or poorly controlled soaking before decortication tends to increase final moisture content and the proportion of broken or light berries, which is consistent with the elevated MC wb values observed here in the soaked groups relative to their boiled counterparts (Shango et al., 2021).

The notably low MC wb of LMPK (8.83%) compared to LMRK (25.05%) is the most practically significant finding of this study. However, a potential confounding factor must be acknowledged: the original manuscript notes that LMPK samples were predominantly composed of smaller pepper grains (5.5 mm diameter), whereas other samples contained a more heterogeneous size distribution. Smaller grains have a higher surface-area-to-volume ratio, which may facilitate more efficient moisture evaporation during boiling and contribute to lower measured MC wb values independent of the treatment effect. This size variability limits the strength of the conclusion that boiling alone was responsible for the observed moisture reduction in LMPK, and should be controlled in future studies through stricter size grading.

Despite this caveat, the directional trend is consistent across both maturity levels: boiling produced lower MC wb in peeled pepper than soaking. For producers prioritizing shelf life and SNI compliance, the boiling method with subsequent drying represents the more efficient route to achieving moisture content within acceptable limits.

A practical caution accompanies the recommendation to rely on boiling for moisture reduction. Rapid surface evaporation at 100 °C can, in principle, dry the outer layer of the kernel faster than internal moisture can migrate outward , a phenomenon recognized in food-drying literature as case hardening, in which a dense, low-permeability outer layer forms and traps residual moisture in the kernel core. If this occurred to any degree in the boiled samples, the bulk MC wb values reported in Table 1 (measured by oven-drying the whole kernel) would still capture the trapped internal moisture, but that moisture could redistribute toward the surface during subsequent storage, creating localized conditions favorable to mold growth even though the bulk average appears to comply with SNI 0004:2013. This risk is not assessed by the present descriptive design, since it would require monitoring MC wb at the kernel surface versus core, or repeated measurement over a storage period rather than a single post-treatment reading. Producers adopting the boiling route for moisture control should therefore confirm compliance with additional post-boiling drying and monitor moisture stability during storage, rather than treating the immediate post-treatment MC wb value as a guarantee of long-term shelf stability.

3.2 Color Characteristics

Surface color is a critical quality attribute of white pepper, directly influencing consumer acceptance and commercial grading. The CIE L*a*b* color system was used to quantify color, where L* represents lightness (0 = black, 100 = white), a* represents the red-green axis (positive = red, negative = green), and b* represents the yellow-blue axis (positive = yellow, negative = blue). Table 2 presents all color values recorded in this study.

Table 2. CIE L*a*b* Color Parameters of Pepper Samples

Code	Maturity / Skin	Treatment	L*	a*	b*
LHTP	Green / With skin	Control	9.62	-3.76	18.40
LHRBK	Green / With skin	Soaking 30 °C	6.78	0.24	11.97
LHPBK	Green / With skin	Boiling 100 °C	6.17	-0.64	13.08
LHRK	Green / Peeled	Soaking 30 °C	9.91	2.56	10.65
LHPK	Green / Peeled	Boiling 100 °C	9.77	1.96	11.91
LMTP	Red / With skin	Control	8.44	9.31	10.83
LMRBK	Red / With skin	Soaking 30 °C	7.36	7.62	9.58
LMPBK	Red / With skin	Boiling 100 °C	7.38	6.37	10.83
LMRK	Red / Peeled	Soaking 30 °C	11.86	3.90	14.49
LMPK	Red / Peeled	Boiling 100 °C	8.51	3.80	13.01

Note on measurement methodology: the L* values reported in this study (range: 6.17-11.86) are substantially lower than values typically reported for white pepper in the literature (often 50–80 on the standard 0–100 CIE scale). For comparison, recent work measuring CIE color parameters directly on black peppercorns (Piper nigrum) under ozone treatment reported L* values in a markedly higher range, consistent with the literature norm for whole peppercorns measured with a properly calibrated aperture (Massango et al., 2025). The discrepancy between that range and the present results is likely attributable to the measurement of individual small peppercorns within the colorimeter aperture, where a portion of the measured area includes the dark background surface rather than the pepper kernel surface alone. This systematic limitation affects the absolute L* values but does not necessarily invalidate the relative comparisons among treatment groups, since all samples were measured under the same conditions. Future studies should specify the colorimeter model, aperture diameter, and calibration procedure to enable cross-study comparisons.

Regarding the lightness values (L*), peeled pepper samples consistently showed higher L* than their unpeeled counterparts across both maturity levels, confirming that removal of the dark outer pericarp improves surface brightness. Among peeled samples, soaked pepper exhibited higher L* than boiled pepper: LMRK (soaked peeled red, L* = 11.86) vs. LMPK (boiled peeled red, L* = 8.51); and LHRK (soaked peeled green, L* = 9.91) vs. LHPK (boiled peeled green, L* = 9.77). These differences suggest that the soaking process better preserved surface brightness of the kernel after decortication. This pattern is broadly consistent with findings from alternative decortication routes: white pepper produced by microbial fermentation with Acetobacter sp., which similarly avoids direct heat exposure to the kernel, has been reported to retain a relatively bright surface color when fermentation time is kept short, while extended fermentation duration increasingly favors brown pigment formation (Sasmitaloka et al., 2021). Ozone-assisted soaking has likewise been reported to support lightness values compliant with SNI grading without requiring boiling (Sukasih et al., 2021), reinforcing the broader pattern that heat avoidance during decortication tends to favor brightness retention, regardless of which non-thermal method is used to soften the pericarp.

The reduction in L* following boiling can be partially attributed to thermal pigment degradation during the 100 °C treatment. Heat, particularly when combined with the acidic or aqueous environment generated during processing, accelerates the loss of the central magnesium ion from the chlorophyll porphyrin ring, converting chlorophyll to pheophytin and shifting the pigment toward an olive-brown tone; this demetalation mechanism and its kinetics have been characterized in detail for green table olive processing, a system that shares the same core chemistry of heat- and moisture-driven chlorophyll degradation in plant tissue (Mínguez-Mosquera et al., 1994). In red pepper, carotenoid pigments (responsible for the red-orange hue of the pericarp) can similarly undergo thermal degradation, affecting the residual color of the kernel surface. Maillard browning, the non-enzymatic reaction between reducing sugars and amino acids, typically proceeds most rapidly at temperatures above 140 °C; at 100 °C it is considerably slower, and given the short boiling duration of only 10 minutes in this study, it is unlikely to be the primary mechanism for the observed darkening. This needs verification against a source that has specifically measured Maillard browning kinetics in pepper or a comparable spice matrix at 100 °C, which the present study did not include. Nonetheless, early-stage Maillard intermediates (Amadori products) can in principle form at 100 °C under conditions of intermediate water activity, and their contribution to surface browning cannot be entirely excluded on the basis of color measurement alone. The gradual, enzymatic nature of soaking, which avoids direct heat application to the kernel, likely accounts for the higher L* values in soaked samples. It should be noted that pigment degradation pathways in soaking are not necessarily benign over the 10-14-day duration used here: prolonged microbial fermentation can itself generate organic acids that promote chlorophyll demetalation by the same magnesium-loss mechanism, so the brightness advantage of soaking observed in this study may reflect a slower rate of degradation rather than its complete absence.

For the a* values, the untreated green pepper control (LHTP) had the most negative a* value (−3.76), indicating a distinctly green hue. After soaking (LHRBK: a* = 0.24; LHRK: a* = 2.56) and after boiling (LHPBK: a* = −0.64; LHPK: a* = 1.96), the a* values shifted toward positive, suggesting a reduction in greenness and a slight movement toward red tones. This shift in green pepper after treatment reflects the degradation of chlorophyll pigments, which are responsible for the negative a* values in unprocessed green pepper. The a* reduction in treated red pepper (from LMTP = 9.31 to LMRK = 3.90 after soaking and LMPK = 3.80 after boiling) indicates that both methods resulted in some loss of red pigmentation, likely through leaching during soaking or thermal degradation during boiling, with the two methods producing comparable outcomes for red pepper color.

The b* values represent the yellow-blue component of color. Soaked peeled red pepper (LMRK) had the highest b* value (14.49), followed by boiled peeled red pepper (LMPK: 13.01), indicating that both treatments shifted the color of peeled red pepper toward yellow compared to the untreated control (LMTP: 10.83). In the context of white pepper quality, an increase in yellowness is generally undesirable when the commercial standard requires a bright white appearance; however, in this study, no reference value for acceptable b* in white pepper was specified in the SNI 0004:2013 standard. For green pepper, both soaking and boiling reduced b* relative to the control (LHTP: 18.40), indicating that treatment reduced the yellow-green tones of the unprocessed fruit.

Hernani et al. (2023) reported that soaking-boiling combination treatments produced white pepper with acceptable color characteristics meeting SNI requirements, supporting the finding that controlled soaking contributes positively to surface color quality.

3.3 Hardness

Hardness is relevant to white pepper quality because this spice is typically ground or crushed before use, and kernel hardness influences both grinding efficiency and the physical integrity of the product during storage. Table 3 presents hardness values for all treatment groups.

Table 3. Hardness (N) of Pepper Samples

Code	Maturity / Skin	Treatment	Hardness (N)
LHTP	Green / With skin	Control (no treatment)	5.63
LHRBK	Green / With skin	Soaking 30 °C	35.02
LHPBK	Green / With skin	Boiling 100 °C	21.56
LHRK	Green / Peeled	Soaking 30 °C	28.22
LHPK	Green / Peeled	Boiling 100 °C	27.68
LMTP	Red / With skin	Control (no treatment)	5.69
LMRBK	Red / With skin	Soaking 30 °C	33.96
LMPBK	Red / With skin	Boiling 100 °C	26.72
LMRK	Red / Peeled	Soaking 30 °C	36.02
LMPK	Red / Peeled	Boiling 100 °C	36.62

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The most striking finding in the hardness data is the large increase from untreated controls (LHTP: 5.63 N; LMTP: 5.69 N) to all treated samples. Both soaking and boiling produced substantially harder kernels than the untreated fruits, which were soft and moist. This hardening effect is consistent with the significant moisture reduction that occurred in all treated samples after peeling: as moisture content decreases, turgor pressure in the cell walls diminishes, and the physical structure of the endosperm becomes more compact and resistant to deformation, a pattern of moisture loss accompanying firmness gain that parallels observations reported for other plant tissues during storage and processing (Setiasih et al., 2018).

Among the treated peeled pepper groups, the observed differences between soaking and boiling methods were numerically small. For peeled red pepper, LMPK (boiling: 36.62 N) was only 0.60 N higher than LMRK (soaking: 36.02 N). For peeled green pepper, LHRK (soaking: 28.22 N) was only 0.54 N higher than LHPK (boiling: 27.68 N). Given that this study was descriptive without statistical replication, these differences of less than 1 N cannot be interpreted as meaningful; it is not possible to conclude that one method produced significantly harder kernels than the other from the available data. What can be stated with greater confidence is that both treatments substantially increased hardness relative to the untreated control.

The general inverse relationship between moisture content and hardness observed across the treatment groups is consistent with the pattern reported by Setiasih et al. (2018) in star fruit (Averrhoa carambola) during storage, where lower moisture content was likewise associated with greater firmness; while that study examined a different commodity and a different treatment (ozonation rather than soaking or boiling), the underlying physical principle, that water loss reduces cell turgor and increases tissue rigidity, is not commodity-specific and offers a plausible mechanistic parallel for the present pepper data. This relationship is most clearly illustrated by comparing LMPK (MC wb = 8.83%, hardness = 36.62 N) with the untreated LMTP (MC wb = 51.99%, hardness = 5.69 N). However, this relationship is not perfectly consistent across all groups, for example, LHRBK (soaked green with skin, MC wb = 48.04%) had higher hardness (35.02 N) than LHPBK (boiled green with skin, MC wb = 56.99%, hardness = 21.56 N), despite lower MC wb in the soaked-with-skin group. This apparent inconsistency may be related to structural changes in the pericarp during soaking: prolonged microbial activity during soaking may harden the outer skin through enzymatic cross-linking of cell wall components, even while the kernel itself retains water. A formal analysis of the correlation between moisture content and hardness across all samples, using Pearson or Spearman correlation, would help to quantify and confirm this relationship but is beyond the scope of the current descriptive study.

From a processing standpoint, the practical relevance of the hardness data extends beyond the numerical comparison between soaking and boiling. Both treated groups (21.56–36.62 N) sit well above the untreated control range (5.63–5.69 N), which means that, regardless of which peeling method is used, the decortication step itself is the primary driver of the hardness gain that downstream grinding operations rely on for consistent particle size reduction. This suggests that, for processors whose main concern is milling performance rather than visual grade, the choice between soaking and boiling may be made on the basis of cost, processing time, and color requirements without a meaningful trade-off in grinding behavior, since the data here do not show either method producing kernels that are disproportionately harder or softer once peeling is complete. This interpretation should be treated as provisional, since hardness measured by penetrometer at a single point in time does not necessarily predict behavior under the shear and impact forces of an industrial grinder, and the present study did not evaluate actual milling yield or particle size distribution.

4. CONCLUSION

This study compared the effects of soaking (30 °C, 10–14 days) and boiling (100 °C, 10 minutes) skin-peeling methods on the physical properties of white pepper produced from green and red *Piper nigrum* L. fruits sourced from Bulukumba Regency. The following conclusions are drawn from the descriptive data:

1. The boiling method produced lower moisture content in peeled pepper than soaking. Boiled peeled red pepper (LMPK, MC wb = 8.83%) was the only treatment group to approach the SNI 0004:2013 maximum threshold of 13.0% without additional drying, while soaked peeled pepper reached 25.05% MC wb. Boiling is therefore more effective for achieving moisture reduction in a single processing step. A size-related confounding factor (smaller grains in LMPK samples) was acknowledged as a limitation of this comparison.
2. The soaking method produced brighter white pepper kernels: soaked peeled red pepper (LMRK, L* = 11.86) had higher lightness than boiled peeled red pepper (LMPK, L* = 8.51). The lower L* values in boiled samples are attributed primarily to thermal degradation of pericarp pigments (chlorophyll and carotenoids) during the 100 °C treatment. Early-stage Maillard browning may also contribute but is unlikely to be the dominant mechanism given the short boiling duration of 10 minutes.
3. Both soaking and boiling substantially increased peppercorn hardness relative to untreated controls (from ~5.7 N to 21.56–36.62 N). The differences between the two methods in peeled pepper were small (≤0.60 N) and cannot be meaningfully interpreted without statistical replication. The observed hardening trend across samples is broadly consistent with the inverse relationship between moisture content and hardness reported in the literature.
4. This study was descriptive in nature without statistical replication; all results represent single-point observations and should be interpreted as preliminary trends. Future research should incorporate replicated experimental designs, statistical analysis (ANOVA and post-hoc tests), and tighter control of sample size uniformity to confirm these findings and quantify the magnitude and significance of treatment effects.

In summary, soaking is recommended when visual quality (brightness) is the primary criterion, while boiling is more suitable when moisture reduction and shelf life are the priority. A combination of short soaking followed by brief boiling, as demonstrated by Hernani et al. (2023), may offer a viable compromise between color preservation and moisture control and warrants further investigation under the specific agroclimatic conditions of South Sulawesi.

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