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Effect of Time and Cycle Number of Hot Water Blanching on the Hardness of Waxy Granola Potato

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Abstract

Texture is an important quality attribute of fried potatoes having the mealy as the common cultivar to use and pre-treated by blanching. Considering the scarcity of the cultivar, the use of the waxy is unavoidable. This study aims to evaluate the effects of cycled blanching on the hardness of waxy Granola potato. The study has been conducted through steps of potato preparation, determination of blanching interval, blanching experiments, texture analysis, and data analysis. Potato dices (1.3 mm in length side) were subjected to water blanching (1:4, w/v) at 90 °C for 1–5 min and 1–5 cycles with an interval of 16 min predetermined from the time required the for internal temperature of dices immediately after blanching to lower to room temperature (approximately 27°C) prior to texture analysis. The results of the study show that depending on the time and cycle number, the hardness of blanched potato ranges from 82.67 to 928.80 g. Increase in hardness of potato (ranges from 534.14 to 928.80 g) was found on the potato mildly blanched, either at the time up to 2 min or cycle number up to 2 and a consistent softening (ranges from 753.00 to 82.67 g) was found on those beyond. Blanching for 1 min and cycled up to 5 consistently increased hardness (534.13–753.00 g), fitting to a linear regression (R^2 = 0.97). It can be concluded that both time and cycle number significantly ($p<0.05$) affect the hardness of blanched potato. Blanching for 1 min and cycled up to 5 is proposed to be exploited in further study in potato frying optimization of Granola potato suggesting that cycled short blanching may serve as a suitable pretreatment strategy for improving the textural quality of the cultivar.

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Introduction

Potato (*Solanum tuberosum* L.) is one of global staple food producing 390.3 million metric tons annually (FAOSTAT, 2026a). The global potato market was valued at approximately USD 96.3 billion in 2022 and is projected to reach USD 119.79 billion in 2025, with estimates suggesting growth to USD 142.27 billion by 2030 (Hu et al., 2025). For industrial purposes accounting more than 50% of the production (*FAOSTAT*, 2026b), special cultivars are usually used of those mealy having high dry matter such as Tutaekuri, Huakaroro, Moemoe (Singh et al., 2016), Russer Burbank, Ranger, Shepody, Kennebec, (*Potato Varieties Guide*, 2026), and Atlantic that is widely used in Indonesia for the purpose (Wibowo et al., 2021).

Despite not being the global player, Indonesia produces 1.2 - 1.3 million tons annually an undisputed largest producer in Southeast Asia (BPS, 2024; Potato Production and Consumption, 2026). Moreover, potato is worth $883k in 2023 as export commodity to Singapore and Malaysia despite being net importer from India, Canada, and Germany up to $37.2M in 2023 (Potatoes in Indonesia Trade, 2026), especially those for chips/Fries (Primawan, 2021). From a sustainable food systems perspective, the utilization of locally available resources and the development of more closed production systems are important considerations (Ragany et al., 2023; Stein & Santini, 2022).

In Indonesia, Atlantic is the cultivar well-known for its good processing performance in producing fried potato with bright brown color and crispy texture although contribute only less than 20 % of national cultivated potatoes (Wheatley et al., 2013) and Granola is being the vast majority accounting more than 80% (Gunadi et al., 2012) due to its disease resistance, high productivity reaching 30–35 tons per hectare, and a relatively short growing period of about 90 days (Adnan et al., 2022). Waxy potato like Granola contains relatively high moisture, low dry matter, and low starch content (16–18%), contributing to a softer texture during thermal processing (Arum et al., 2022) and are undesirable for fried products such as potato chips and French fries. Therefore, Granola is usually processed as table potatoes. The scarcity of mealy potato limits the potential economic benefits that could be derived from the growing fried potato market and highlights the need for processing strategies that enable the utilization of the widely available Granola cultivar.

Blanching is a thermal pretreatment commonly applied in potato processing (Teshome Ayele et al., 2025) to modify texture (Abu-Ghannam & Crowley, 2006; Jiang et al., 2020; Liu & Scanlon, 2007; Zhang et al., 2018) and improve product quality such as prevent undesired colour darkening (Reis et al., 2008), and reduce oil absorption (Regasa et al., 2025). Additionally, blanching may reduce acrylamide precursors such as reducing sugars and asparagine, thereby lowering acrylamide formation during frying (Liyanage et al., 2021).

In respect to textural improvement, blanching has been reported to be successful on potato (Abu-Ghannam & Crowley, 2006; Aguilar et al., 1997), carrot (Sanjuán et al., 2005), and yellow peaches (Xian et al., 2024). In more recent studies, several techniques have been reported to attempt for potato blanching such as steam and microwave blanching (Saini et al., 2023) that found to lower the hardness and radio frequency (Jiang et al., 2020) that found to improve the hardness after combined with a shorter hot water blanching. However, very limited study applying cycled-blanching but a study reporting that blanching at 90 °C for 15, 30, or 45 s for up to 6 cycles found to decrease the activity of polyphenol oxidase to induce enzymatic browning of potato (Park et al., 2020).

The main key difference between single and multiple blanching is that on cycled-blanching, starch is suggested to undergo retrogradation during interval between blanching treatments (Shu et al., 2022). As reported elsewhere, starch retrogradation increase hardness of potato (Jankowski, 1992). This phenomenon suggests that repeated heating–cooling cycles may provide a means of enhancing the texture of waxy potato cultivars. Previous studies on Granola potatoes have primarily focused on chemical and sensory modifications through soaking treatments using 0.5% $Ca(OH)_2$, 1% $Ca(OH)_2$, $Na_2S_2O_5$ 0.5%, 1% $Na_2S_2O_5$, 0.5% $CaCl_2$ and 1% $CaCl_2$ solutions prior frying (Arum et al., 2022) or on the effects of boiling, steaming, edible-coating pre-treatments on the color, chemical, oil uptake, textural properties (Parhusip et al., 2021). However, information regarding the application of cycled blanching to improve the texture of Granola potatoes remains unavailable.

During frying, excessive moisture loss promote pore formation and oil absorption, resulting in undesirable texture characteristics (Mandei, 2018). Limited moisture release during processing may contribute to texture softening in Granola potatoes (Parhusip et al., 2021). Therefore, effective pretreatment strategies are required to improve the textural quality of Granola potatoes for fried products such as potato chips and French fries. Cycled blanching may offer a promising approach by inducing structural modifications in both pectin and starch during repeated heating (Xu et al., 2021) and cooling (Cao et al., 2025) stages, potentially enhancing hardness and overall textural quality.

Considering the limited availability of mealy potato cultivars in Indonesia and the predominance of Granola potatoes, developing suitable pretreatment methods for this cultivar is of considerable practical importance. In brief, the controlled texture of blanched potato is expected to influence subsequent texture development during frying as fried potato texture affected by the development (Thussu & Datta, 2012) and size (van Koerten et al., 2015) of crust, while pore formed during blanching assist the mass transfer occur during frying (Andrés et al., 2013). Therefore, this study evaluated the effects of blanching time and cycle number on the hardness characteristics of Granola potatoes. The findings are expected to contribute to the development of effective pretreatment strategies for improving the processing quality and industrial utilization of Granola potatoes for fried products.

Materials and Methods

Sample preparation

Potatoes of Granola cultivar were obtained from PT Agro Lestari Merbabu, Ngablak Subdistrict, Magelang Regency, Central Java, Indonesia situated at Mount Merbabu (±1,333 m above sea level). Potato tubers were selected based on uniform size (weight ranging from 125.00 – 135.00 g), smooth surface, and absence of sprouts or physical defects. The tubers were washed, air-dried, and stored in plastic containers under dark conditions at room temperature (approximately 27 °C, RH of 87%) prior to processing for no longer than one week. For the blanching experiments, potatoes were peeled and cut into cubes (1.3 cm x 1.3 cm x 1.3 cm) using a potato slicer.

Methods

Blanching experiment

The blanching experiment was conducted following (Park et al., 2020) with some modifications. The potato cubes were kept being immersed in water to prevent enzymatic browning prior to blanching. Subsequently, potato cubes were immersed in hot water (1:4, w/v) at 90°C using a double-boiler technique for a period of 1, 2, 3, 4, and 5 min and cycle number 1, 2, 3, 4, 5. The temperature of core of potato cubes was monitored using paired of K-type temperature sensors and Picolog TC-08 data logger (Picotech, Cambridgeshire, United Kingdom). When the desired time was achieved, the potato cubes were removed from the hot water. In the current study, no cooling treatment was applied considering the practicality for small scale industries.

Determination of blanching interval

The interval between blanching cycles was determined from the time required for the temperature of potato cubes immediately after being blanched to equilibrate to room temperature (approximately 27°C), according to (Purbasari et al., 2022) with minor modifications. To do so, regression modelling approaches was implemented using Microsoft 365 (Microsoft, Redmond, Washington, USA). In addition, no force cooling was conducted during temperature equilibration for the ease and applicability in small industry.

Texture Analysis

After being blanched, and equilibrated at the room temperature, the potato cubes were test for the texture following (Hu et al., 2024). A compression test to a depth of 2.0 mm, speed of 1.0 mm/s and a trigger force of 1.0 g was applied using a Brookfield CT3 texture analyser (AMETEK Brookfield, Middleboro, United States). As the cell and starch granule integrities were to measure, the knife-edge TA7 (AMETEK Brookfield, Middleboro, United States) probe was used to assess the entire potato cube texture rather than the crust. For each potato cube, at least triplicate test was conducted.

Data Analysis

Initially, inferential statistics by mean of two-way analysis of variance (ANOVA) at significance level of 95% was implemented to understand the effect of time and cycle number of blanching on the hardness of potato cubes. Further analysis by mean on Duncan's Multiple Range Test was implemented to determine the difference among treatments. Both the analyses were conducted using SPPS version 24 (IBM, USA). Considering blanching as pre-treatment prior potato frying, a controllable condition of potato blanching needs to be determined. To do so, the fitness to a linear model (R~1) was applied as the criterion to select the blanching conditions and the resulting hardness having clear linear relation.

Results and Discussion

Blanching interval

Figure 1 presents the change in potato temperature after blanching. It shows that when potato cubes were exposed to the room temperature (approximately 27°C), the temperature of potato cubs decreased exponentially from the blanching temperature of 90°C along time and ultimately equilibrated with the room temperature. The decreasing temperature was found to fit (R^2 = 0.9451) a polynomial order 2 namely $y = 0.0002x^2 - 0.1926x + 72.878$ (Figure 1). To determine the time required both potato cube and room temperatures equilibrated, the first differential (Ostertagová, 2012) of the equation found zero when the equilibrating time reach to 963 s (equal to 16.05 min). Furthermore, an approximation for linear model (Buzrul, 2025) was found to fit (R^2 = 0.7498) for ln-linear plot of the temperature-time data. The corresponding equation $y = -0.065x + 59.167$ found the equilibrating rate of 3.91°C/min and resulting in equilibrating time of 16 min to reach the temperature gradient of 63°C (90–27 °C). The equilibrating rate is influenced by the temperature gradience between potato and the room temperature hence the higher gradient generally result in higher cooling rates (Purbasari et al., 2022).

The 16-min is the time used as interval between blanching cycles or the equilibrating time prior texture test. The equilibrating phase following blanching is important for preventing excessive structural damage caused by thermal treatment and may also promote starch retrogradation, which influences potato texture. Following gelatinization during blanching, resting at room temperature allows the starch molecules to reorganize into a more ordered and crystalline structure (Ding et al., 2019; Q. Liu et al., 2024), which may contribute to hardness development during cycled blanching treatments (Xu et al., 2022). Thus, this equilibrating time was used as the standardized interval time between cycled blanching to ensure consistent heating-cooling treatment conditions throughout the experiment.

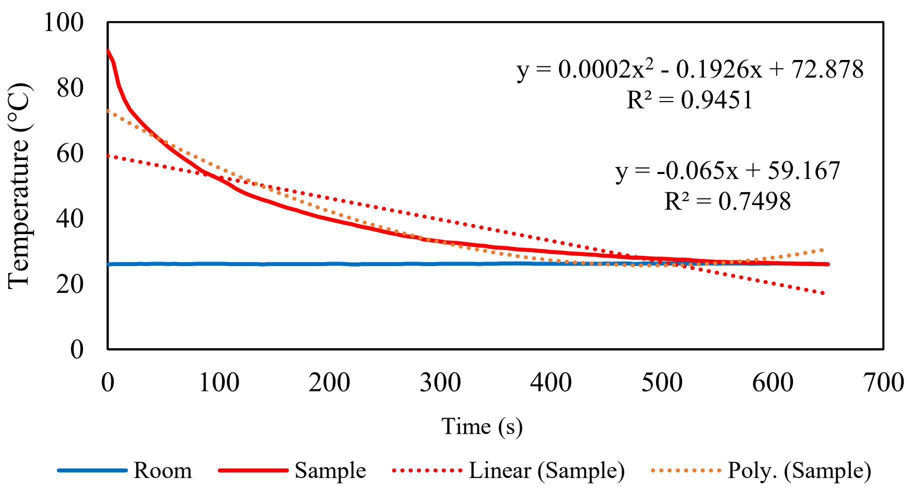

Figure 1. The Change in Temperature of Potato Cube after Blanching

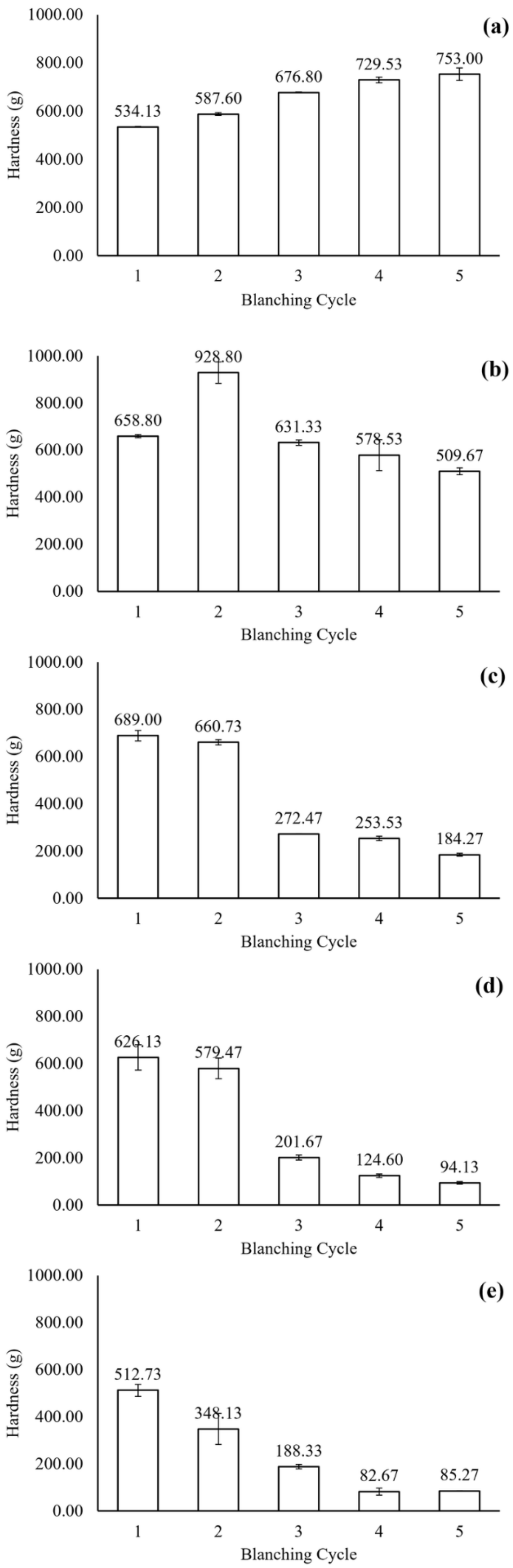

Figure 2. Hardness of Granola Potato After Various Blanching Cycles for the Time of 1 (a); 2 (b); 3 (c); 4 (d); and 5 (e) minutes

Effect of Blanching Cycles at Different Blanching Time on the Hardness of Potato

Figure 2 presents the Hardness of Granola Potato After Various Blanching Cycles for the Time of 1–5 min. For one min Time of blanching, increasing cycle number leads to increase in the potato hardness from 534.13 to 753 g (Fig 2.a). For 2 min Time of blanching, one cycle blanching resulted in a hardness of 658.80 and additional cycle of two increased the hardness to 928.80 g. However further addition of cycle number decreased the hardness leading to the lowest as 509.67 of those 5 cycles (Fig. 2.b). for 3 min time, one cycle blanching, resulted in a 689.00 g. however, additional cycle number decreased the hardness of potato leading to as low as 184.27 of those 5 cycles. Similar trends of decreasing hardness with increasing blanching cycles were observed at much lower levels namely 626.13 to 94.13 g and 512.73 to 85.27 g of those blanching time of 4 and 5 min (Fig 2 c–d).

Effect of Blanching Time at Different Blanching Cycles on the Hardness of Potato

Figure 3 presents Hardness of Granola Potato After Various Blanching Time for 1 – 5 Cycles. It is shown that for one cycle blanching, the hardness of potato is time-dependent. Briefly, for one min, 534.13 g was achieved. However, extended blanching time up to 4 min resulted in equally hardness ranging from 626.13 to 689.00 g higher than that of one min and extended blanching time to 5 min decreased the hardness of potato to 512.73, slightly lower than that of one min. (Fig 3.a).

A different trend was found on blanching for 2 cycles at which decreasing hardness ranging from 928.90 to 348.13 with increasing blanching time was found after significant increases of 2 min blanching time of 928.90 g, higher than that of 1 min (587.60 g) (Fig 3.b). As also shown, blanching time of 3 and 4 min resulted in the hardness not far from the one min. For blanching cycles more than 2, the hardness of potato was found to decrease with increasing blanching time, ranging from 676.80–188.33; 729.53–82.67; 753.00–85.27, respectively for 3, 4, and 5 blanching cycles (Fig 3. c, d, e).

Discussion

The increase in hardness of potato either consistently or time-dependence (for one and two cycles) and/or 2 min - 2 cycles combination indicates that the increase in hardness occurred mainly after mild blanching cycles. Cycled blanching for 1 minute over 5 cycles on potato cubes is suggested to lead hardness by triggering either PME activation or starch gelatinization-retrogradation. The increase in potato hardness is suggested to be associated with pectin modification and improved cell wall structural integrity during cycled blanching treatments. Blanching is suggested to activate pectin methylesterase (PME), which promotes pectin demethylation and contributes to firmer potato texture through strengthening of the cell wall structure (Liu et al., 2020). Pectin demethylation cause the release of methyl ester groups from the homogalacturonan chains, resulting in free carboxyl groups (Maulida et al., 2023). The free carboxyl groups may subsequently form ionic

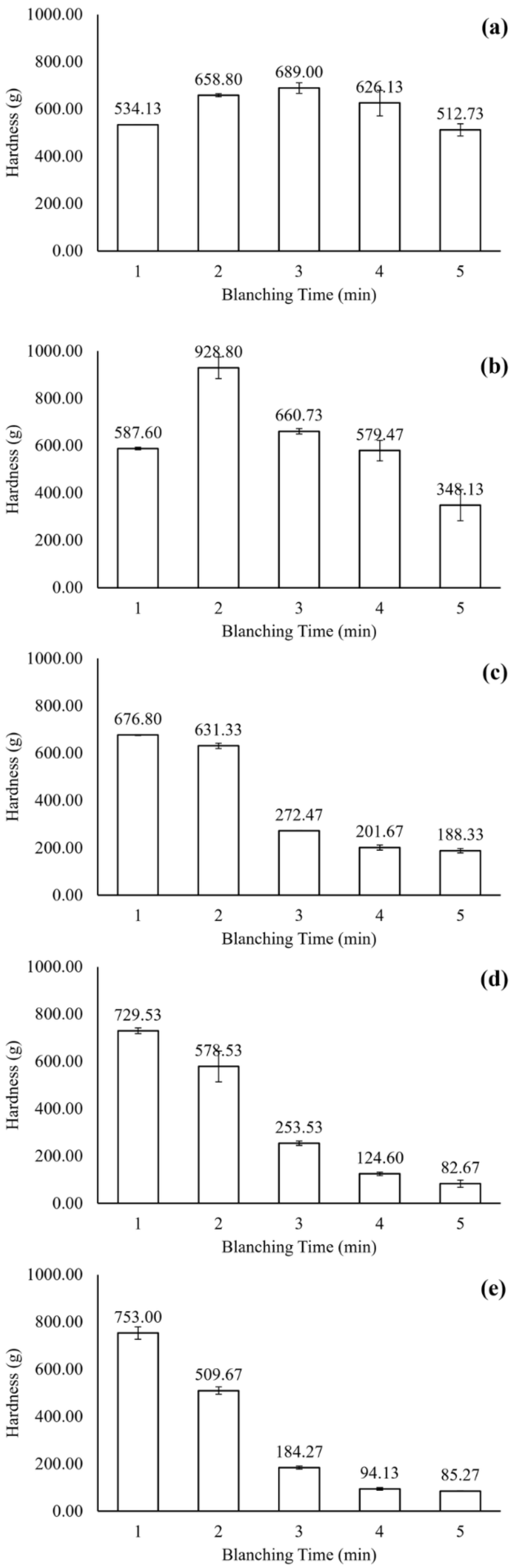

Figure 3. Hardness of Granola Potato After Various Blanching Time for 1 (a); 2 (b); 3 (c); 4 (d); and 5 (e) Cycles

cross-links with naturally occurring divalent cations such as Ca^{2+} in potato tissues, resulting in the formation of pectin–calcium ("egg-box") structures that contribute to increased cell wall rigidity and firmer texture (Moens et al., 2021). Similar texture enhancement associated with PME activation and calcium–pectate cross-link formation has been reported in thermally treated potatoes (Liu et al., 2020). These mechanisms may explain the increased hardness observed in potatoes subjected to cycled short-time blanching treatments.

In addition to cell wall strengthening via the pectin–PME mechanism, the increase in potato hardness following cycled blanching may also be associated with the changes in starch structure resulting from repeated gelatinization and retrogradation. During blanching, starch undergoes gelatinization, causing starch granules to swell and release amylose. Subsequently, the temperature equilibration after blanching triggers retrogradation, reassociation of amylose and amylopectin, forming a new, more compact crystalline structure that contributes to texture firming (Zhang et al., 2025).

During cooling, starch can undergo short-term retrogradation through the formation of hydrogen bonds between hydroxyl groups of amylose molecules (Shu et al., 2022). Gelatinized potato starch may subsequently form a stronger gel network structure during retrogradation, contributing to increased starch gel strength and firmer potato texture. Starch with a higher degree of starch gelatinization has been reported to exhibit greater susceptibility to retrogradation compared with starch with lower starch gelatinization (Xu et al., 2021). Although the cooling treatment in this study was conducted only at room temperature for a relatively short time, the cumulative effects of repeated retrogradation and its relationship with progressive starch gelatinization during cycled blanching may contribute to the observed increase in potato hardness.

The increase in potato hardness after mild blanching observed in the current study aligns with other study on potato of moderately gelatinized (Xu et al., 2021) which reported to exhibit a higher gel strength after reheating at 90°C for 20 min compared to native potato starch and potato starch with higher degree of gelatinization (Xu et al., 2021). The finding of the current study also consistent those of (Gryszkin et al., 2014), at which thermal modification of starch can form a stronger gel than unmodified starch. The increase in hardness has also been reported to occur on mashed potato after prolonged retrogradation (Cao et al., 2025). These results suggest that cycled heating–cooling treatment during blanching contribute to texture strengthening through modification of starch structure and gel formation.

On the other hand, the consistent decreases in potato hardness after longer time or more cycle number of blanching indicate that the corresponding blanching condition (time and/or cycle) thermal degradation effect of cell-wall system and starch go beyond the structural reorganization due to starch retrogradation and pectin-pectin methylesterase system as discussed earlier. Excessive thermal treatment may lead to degradation of cellular structure and reduced firmness as reported in a study by (Zhang et al., 2020), at prolonged heating on

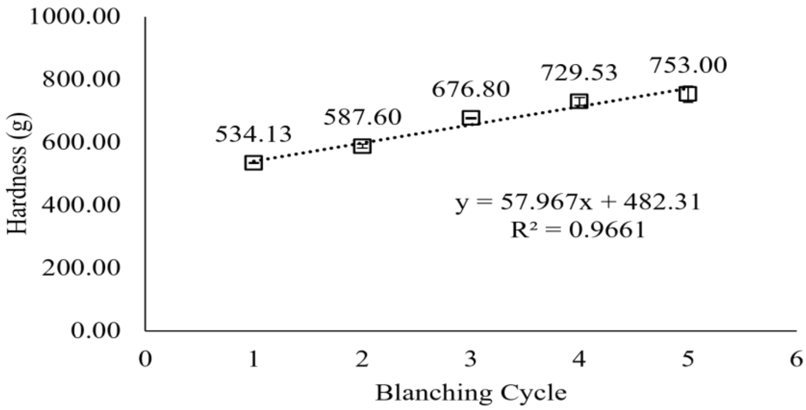

Figure 4. Changes in The Hardness of Granola Potatoes as The Number of Blanching Cycles Increases

potato caused cellular damage, starch gelatinization, and stretching of cell walls, leading to softer texture characteristics. The lowering hardness of blanched potato with increasing blanching intensity (62.8–90.6°C, 2–20 min) was also reported (Liu & Scanlon, 2007) when hot water blanching combined with radio frequency (Zhang et al., 2018). In respect to pectic-PME system, excessive thermal treatment inactivates PME and increase cell membrane permeability, resulting in softer potato texture (Bai et al., 2024; Liu et al., 2020). Crude PME enzyme extracted from Granola potato cultivars exhibits the highest activity at 50°C for 5 minutes and decreases at 60°C for the same time (Abduh et al., 2025). These findings suggest that controlled thermal treatment during cycled blanching may play an important role in maintaining potato texture through regulation of PME activity and cell wall stability.

Based on the results of texture tests, potatoes treated with 2-minute blanching – for 2 cycles exhibited the highest hardness value (928.80 g). However, neither the 2-minute blanching treatment group nor the 2-cycle blanching treatment group showed a consistent trend of increasing hardness across treatment. Whereas in fact, linear model is preferred, whenever possible, in process design due to its practicality and controllability. Furthermore, the resulting hardness values did not meet a validated hardness range of 714.62–751.09 g (Saini et al., 2023). Therefore, we don't use these treatment groups to consider in optimisation.

In contrast, the 1 min blanching treatment group with 1-5 blanching cycles showed a consistent trend of increasing hardness, with the highest hardness value reaching 753.00 g, close to the hardness range of a study by Saini et al (2023). These results indicate that short blanching time combined with number of blanching cycles may provide more controlled texture development compared with longer thermal treatments. The increase in potato hardness blanched for 1 min at increasing cycle fits linearity, obeying order 0 kinetic (R^2 = 0.9661) (Figure 4) showing a rate constant of 57.97 g per cycle. Therefore, the 1 min blanching treatment with cycle variations (1–5 cycles) was selected as the blanching treatment recommended for further optimisation of frying.

Conclusion

This study evaluated the effects of time (1–5 min) and cycle number (1–5) of blanching at interval of 16 min at room temperature (approximately 27 °C) on the hardness of Granola potato. Both time and cycle number significantly ($p<0.05$) affect the hardness of blanched potato. Mild blanching either at the time up to 2 min or cycle number up to 2 increased the hardness and blanching beyond either these conditions led to consistent softening of potato. Blanching for 1 min cycled from 1 to 5 consistently (R2 = 0.97) increased the potato hardness hence being proposed for further study in frying optimization. Nevertheless, further validation of hardness involving sensorial and hedonic test is recommended.

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