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ORIGINAL PAPER

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COMMERCIAL GRADING AND DOMESTIC PROCESSING OF INDONESIAN MZ POTATO: IMPLICATIONS FOR NUTRITIONAL AND TEXTURAL PROPERTIES

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ABSTRACT

Background. Locally produced and domestically processed intact real foods such as potatoes are considered good choices to maintain food security and sustainability. In Indonesia, potato processing begins on the farm with grading that is done visually based on size and dimensions. Unfortunately, the nutritional properties of graded potatoes and their processing performance under domestic processing techniques – namely steaming, baking, and microwave heating – has not been widely studied. Therefore, this study aimed to evaluate the nutritional properties and the performance under steaming, baking, and microware heating of Indonesia MZ potatoes.
Material and methods. After being graded, cleaned, and sorted, MZ potatoes were characterized by weight, dimension, color distribution, and chemical properties. The processing time under steaming, baking, and microwave heating techniques was then optimized. Subsequently, the processed potatoes were characterized by their chemical, textural and starch hydrolysis properties. The data were analyzed by means of analysis of variance, but the weight, dimensions and color distribution of the raw potatoes were analyzed by means of principal component analysis.
Results. The results revealed that commercial grading does affect potato weight and dimensions but does not affect chemical properties. Regarding processing, the greater the size of the potato, the longer the time required to process it, regardless of the techniques. At a given commercial grade, the processing time was found to be longest for steaming, followed by baking and then microwave heating. Processing techniques had an impact on the starch hydrolysis of all grades, the protein content of B, D, E grades, and the moisture content of C, D, and E grades. Hence, the smaller the potato, the more susceptible it is to processing. The processing techniques had an effect on the hardness of grades D and E, and the gumminess of grade E.
Conclusion. These findings contribute to a deeper understanding of how potato size, grading, and processing methods collectively influence their nutritional attributes and textural properties, providing valuable insights for both the agricultural and food processing industries.

Keywords: potatoes, grades, processing techniques, starch hydrolysis, nutritional properties

INTRODUCTION

Food sustainability and security are becoming important global issues (Arora, 2018; Berry et al., 2015; El Bilali et al., 2019; Pachapur et al., 2020; Vågsholm et al., 2020). In this context, local food and domestic

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processing are considered effective solutions. Furthermore, intact real food is considered nutritionally better than intensively manufactured food. Hence, potatoes might help improve food security in Indonesia (Devaux et al., 2014; 2021; Van Asselt et al., 2014), because unlike rice, potato is a complex food rather than a starch-only source (Andre et al., 2014; Gupta and Gupta, 2018).

Despite being one of the world's most consumed staple foods and playing a pivotal role in global nutrition and the food processing industry, the potential of potatoes in Indonesia has yet to be optimized (Andriyanto et al., 2013; Muchransyah et al., 2018). In households, potatoes are cooked and consumed in limited quantities, usually as complementary dishes during traditional or religious events. This trend reflects the high value of potatoes both economically and socially. Indeed, people in Indonesia consider potato a tasty food compared to rice, which been a staple food for decades. Nevertheless, potatoes have become an important commodity for the food industry. They are prepared as fried potatoes and sold frozen or distributed in fast food retail. Most of the potatoes consumed in Indonesia are imported. From 2017 to 2021, the country was a net importer of potatoes, with a net inflow of as much as 131,861.8 tons on average. This huge quantity of imported potatoes mostly (81.72%) came in the form of processed potato products, such as frozen, powder, chips, granules, pellets, starch, or slices from countries such as the Netherlands, the USA, Germany, Belgium, and Canada (Mas'ud et al., 2022). On the other hand, total exports during the same period were 5,981.6 tons, of which 51.98% was frozen while the remaining percentage was fresh (Mas'ud et al., 2022).

Potato processing begins on the farm with grading, which is done visually based on size and dimensions. However, it is still unknown whether this assessment of potato properties might underestimate the potential of the potatoes. In this study, we delve into the comprehensive characterization of MZ potatoes, a local breed, focusing on their nutritional composition and response to domestic processing techniques including steaming, baking, and microwave heating. MZ potato, also known as Tedjo MZ was pedigreed from Granola L potato (Terryana et al., 2022) in Batur District, Banjarnegara Regency by a local farmer named Muhzoto together with a team from the Ministry of Agriculture (Anonymous, n.d.) for its tuber size, which is 149–187% larger than its pedigree depending on location and cultivation frequency (Pertiwi and Cempaka, 2020). Due to its agricultural performance, the cultivar has been studied in recent years (Pertiwi et al., 2022; Winarto et al., 2021), and the understanding of its nutritional properties and processing performance is crucial for the optimization of their utilization in various culinary applications.

By evaluating factors such as weight, dimensions, color distribution, and chemical composition, we aim to elucidate the impact of commercial grading and processing methods on the nutritional integrity and textural attributes of potatoes. Furthermore, exploring starch hydrolysis, protein content, moisture retention, and textural properties across different potato grades and processing techniques has the potential to offer valuable insights into the optimization of potato-based food formulations and processing protocols. Through meticulous analysis utilizing techniques such as analysis of variance and principal component analysis, this research endeavors to provide comprehensive insights into the nutritional profile and processing dynamics of potatoes, thereby contributing to enhanced utilization and value addition in the food industry. To the best of the authors' knowledge, this work is the first paper to study commercial grading of Indonesian potatoes and their domestic processing by mean of steaming, baking and microwave heating. Moreover, the number of studies evaluating the effects of processing on different potato tuber sizes is limited.

MATERIALS AND METHOD

Potato preparation

The potato tubers used in the study had been stored for one week after harvest. They had been preliminarily commercially graded into five categories, namely A, B, C, D, and E, by a farmer in Sumberejo Village, Ngablak District, Magelang Regency, Central Java situated at Mount Merbabu (±1,333 m above sea level). Several tubers were collected for each grade, and they were sorted to obtain intact and healthy ones, resulting in a different number of tubers for each grade, namely 11 for A, 19 for B, 20 for C, 58 for D, and 98 for E. Subsequently, the tubers were washed under flowing tap water and wiped using a dry cloth. They were then weighed using a digital scale (SF-400, Jiangyin City, China), and their dimensions, namely length, width and height, were measured using calipers (Mitutoyo, Japan).

Determination of the color distribution of the potato peel and flesh of raw and processed potatoes

The color distribution of potato peel and flesh was analyzed based on the similarity of images. Images of potato surface and flesh were captured in constant lighting conditions using a photo box (Plux HI98103, China) and a digital camera (Olympus SZ-10, Tokyo, Japan). The captured images were then processed using the Image Analytics widget on Orange 3.36.2 (Ljubljana, Slovenia) (Demšar et al., 2013) to classify the potatoes according to their color, based on the similarity of their visual appearance. This technique used a machine learning algorithm rather than numerical color measurement (such as *CIELab* color scale).

Determination of moisture and protein content

The moisture content of raw and processed potato was determined by means of gravimetry at 105°C until a constant weight was achieved, while the protein content of raw and processed potatoes was measured by means of the Kjeldahl method (Mardhika et al., 2020).

Isolation of potato starch

Starch was isolated from potato tubers using a previously reported method (Abduh et al., 2019; Phogat et al., 2020). Briefly, 1 kg of clean potatoes were peeled, grated, and transferred into a container with 1 liter of warm water and subsequently macerated for 1 min. The suspension was then filtered using a kitchen sieve and the filtrate was collected while the remaining solid was re-macerated and refiltered in the same way before being added to the previously collected filtrate. The filtrate was then allowed to sit for 1 hour to let the starch settle. Subsequently, the water was discarded, leaving the settling starch. Clean water was then added to the settling starch and stirred manually, after which the starch was left to sit for another 1 hour before the water was discarded again. This step was repeated twice. The wet starch was dried using a cabinet drier at 70°C for 36 h, leaving solid starch chunks which were then manually separated and sieved.

Observation of starch morphology

The morphology of starch granules was observed following Abduh et al. (2019) with modifications. Initially, 0.02 g of starch was dispersed in 1 ml of distilled water, placed on a microscope slide, covered, and placed under a polarized light microscope (Olympus CX23, Olympus, Tokyo, Japan) to observe starch granule morphology at a magnification of 40 times. The microscopy images were then captured using a digital camera and processed using Micro cam Version 5.6. software.

Measurement of viscosity of starch dispersion

The viscosity of starch dispersion testing was conducted as follows. Initially, 5 g starch was dispersed in 45 ml of distilled water and then heated in a water bath at 85°C to reach a temperature of 70°C, and the viscosity was immediately measured using viscometer (Rion VT-06, Rion, Tokyo, Japan) when starch gel formed.

Potato steaming, baking, and microwave heating

All unpeeled potatoes were processed according to the processing techniques employed, namely steaming, baking and microwave heating. For each processing technique, different conditions were used, namely, a temperature of 85°C for steaming, a temperature of 170°C for baking and an energy of 80% of 1,000 watt for microwave heating. For each processing technique, an optimum processing time was determined by finding the time needed to achieve an equal degree of cooking as verified by piercing the center of the tuber using a toothpick and verifying if it was soft and if the flesh had turned pale. For each processing technique and for each commercial grade, three potato tubers were used. The optimized processing times for the given techniques and potato grades are presented in Table 4.

Determination of starch hydrolysis of processed potato

Starch hydrolysis was tested following the method of Abduh et al. (2019) and Abduh et al. (2023) to simulate digestion in the small intestine. Initially, 3.3 mL of α-amylase (Novozyme, Denmark) and 6.7 mL of gluco-amylase (Novozyme, Denmark) were mixed, and the pH was adjusted to 6.7 using 0.1 M NaOH (Merck, Darmstadt, Germany) solution. The mixture was incubated for 30 minutes at a temperature of 37°C with shaking at 55 strokes/minute using an orbital shaker (KJ-201BS, China). During the incubation period, raw potatoes were processed based on their respective treatments, and the processing time was adjusted accordingly. When the potatoes were cooked, 0.5 g of sample was immediately introduced into the enzyme mixture prepared earlier to avoid retrogradation, and the incubation was continued for 120 min. The glucose released in the mixture was assayed using a glucose oxidase-peroxidase system (Allmedicus, Seongnam-si, South Korea).

Texture analysis of processed potato

Texture testing was conducted using a texture analyzer instrument (LLOYD Instrument TA Plus Ametek, England) with a spherical probe TA18 (diameter: 1.25 cm, length: 10 cm), a trigger setting of 0.1 kg, and a test speed of 1 mm/s. The Texture Analyzer was operated using the Nexygen program on a computer. The procedure was adjusted according to the specifications of the spherical probe, and the instrument was configured with the appropriate test speed and trigger settings. The test results were then displayed on the computer in the form of tables, graphs, and numerical data.

Data analysis

The data obtained on moisture, protein, starch viscosity, starch hydrolysis, and texture were analyzed using analysis of variance (ANOVA) and Duncan's Multiple Range Test post hoc. Statistical analysis was performed using SPSS 26.0 for Windows. The captured potato images were analyzed by means of Principal Component Analysis (PCA) using Orange software (Demšar et al., 2013). PCA was also applied to potato weight data, potato dimensions, potato water content, and potato protein content using Chemoface software version 1.6.5 (Lavras, Brazil) (Nunes et al., 2012).

RESULTS AND DISCUSSION

Properties of raw potato

Weight and dimensions of raw potato

Commercial grading carried out by farmers categorized potatoes into grades A to E with their respective weight ranges as follows: grade A (>250 g), grade B (150–250 g), grade C (70–150 g), grade D (30–70 g), and grade E (<30 g). Table 1 shows the descriptive statistics for potato weight and dimensions of grade A, B, C, D, and E. The grading includes very small (<25 g) and large (>75 g) tubers (Asnake et al., 2023), but overall, they are relatively larger than those reported by Sato et al. (2017).

Figure 1 presents the corresponding biplot of principal component analysis (PCA) and effectively illustrates the variation in potato weight and dimensions across different commercial grades.

The PCA biplot in the figure successfully elucidates the variation in PC1, accounting for a substantial eigenvalue of 94.95%. Notably, a distinct separation is evident among potato grades, with a more pronounced variation observed in the higher grades despite clear differentiation across all grades. The tuber size of potato is influenced by factors such as yield, number of

Table 1. Weight and dimensions of MZ potato of various commercial grades

Grade	Weight, g	Length, mm	Width, mm	Height, mm
A	385.64 ±84.59	114.72 ±11.83	87.81 ±7.71	67.35 ±6.84
B	195.47 ±40.89	83.51 ±9.48	74.92 ±9.97	57.37 ±3.71
C	100.2 ±17.61	66.27 ±6.27	58.53 ±3.69	46.76 ±4.39
D	42.41 ±11.87	48.19 ±5.91	42.68 ±5.05	36.66 ±3.33
E	17.48 ±7.49	27.47 ±4.85	34.84 ±5.80	30.35 ±5.62

Data are presented as mean ± standard deviation (*n* = 11 for A, 19 for B, 20 for C, 58 for D, 98 for E).

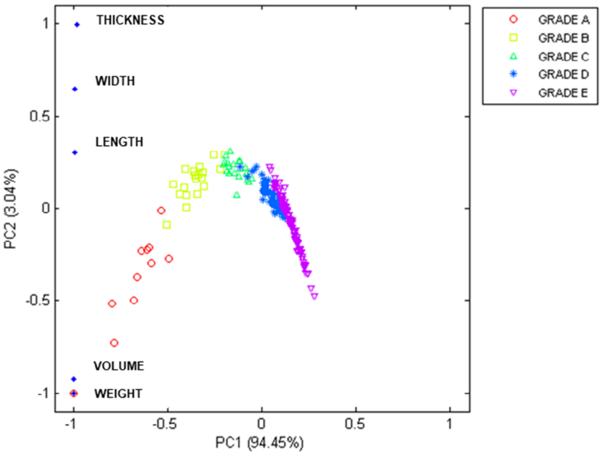


Fig. 1. PCA biplot of potato weight and dimension of different commercial grades

tubers per stem, number of stems per plant, plant density (Blauer et al., 2013; Ebrahim et al., 2018; Struik et al., 1990) and cultivation frequency (Pertiwi and Cempaka, 2020).

Color distribution of unpeeled potatoes and flesh of raw potatoes

Figure 2 presents images of unpeeled potatoes and cross sections of potato flesh across commercial grades. The unpeeled potatoes exhibit colors ranging from yellow to brown and may also display shades of green. Additionally, the smaller the potato, the more likely it is to have a rounder and more uniform shape. The coloration of the potato flesh, when unpeeled, also ranges from yellow to brown with possible green tones, though the flesh tends to be lighter in color compared to the potato peel. Potatoes with a yellowish color are expected to contain relatively low antioxidant activity compared to those with purple and red flesh due to their low anthocyanin content (Hamouz et al., 2011).

Along with visual aids, a machine learning tool was used to process the captured images of unpeeled potato and potato flesh. Such image analysis has become increasingly important due to its practicality in industrial settings (Noordam et al., 2000; Si et al., 2017). Figure 3 shows the PCA sample plot of the color distribution of unpeeled potato (a) and potato

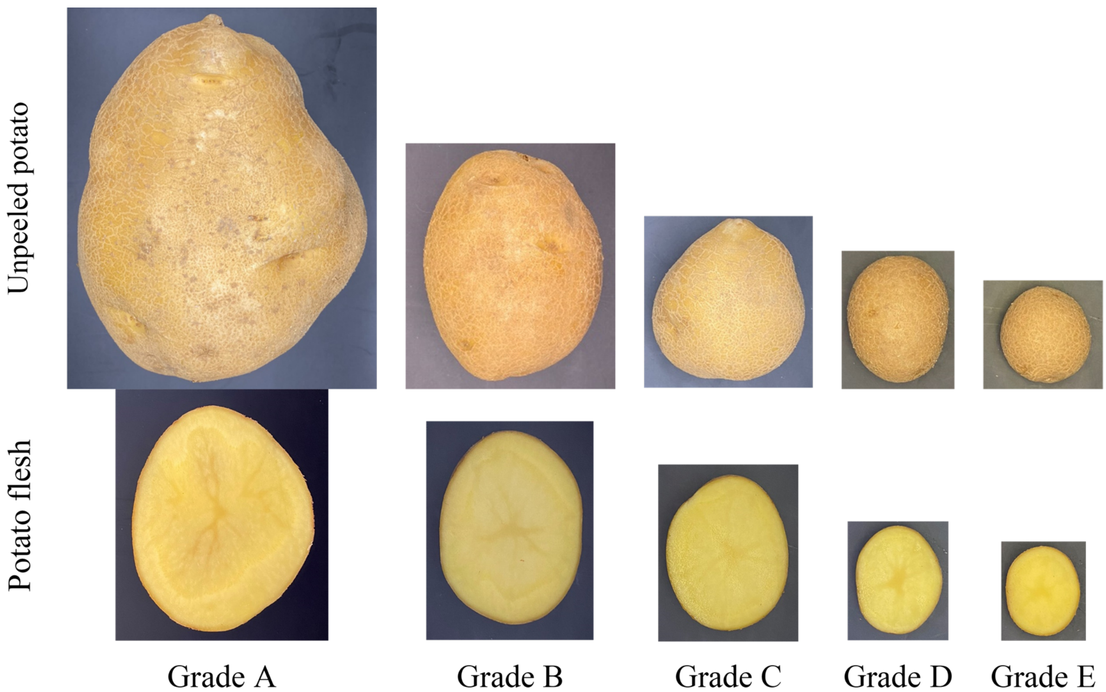
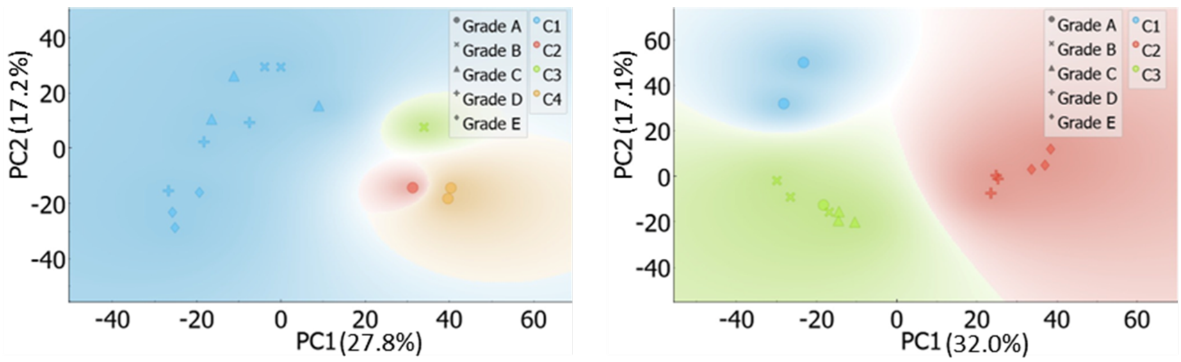


Fig. 2. Images of unpeeled potato and potato flesh of different commercial grades



(a) (b)

Fig. 3. PCA plot of color distribution of unpeeled potatoes (a) and potato flesh (b) across commercial grades

flesh (b). The unpeeled potatoes of grade A exhibit a noticeable and distinct color, forming a unique cluster that sets them apart from the other commercial grades. Despite this distinctiveness, within grade A, there is still color variation, represented by the presence of yellow and red clusters. Conversely, the color distribution of the remaining grades collectively forms a shared large blue cluster, indicating their similarity in color. In terms of potato flesh, the color distribution follows a different pattern, with three distinct clusters identified. The first cluster encompasses grade A potatoes, the second cluster encompasses grade B and grade C, and the third cluster encompasses grades D and E. The ability of machine learning to analyze images and generate distributions of potato color in the current study was beyond that of visual assessment. It is suggested that the color distribution across tuber size follows the change in color during potato development, as influenced by the concentration of anthocyanin, flavonoid, phenolic acid (Lewis et al., 1999), anthocyanidin (Šulc et al., 2017) and phenylpropanoid (Navarre et al., 2013).

Chemical properties of raw potato

Table 2 presents the moisture and protein of MZ potatoes of various commercial grades. It reveals no significant differences in moisture content, potato peel protein, and potato flesh protein across grades.

Moreover, a clustering analysis did not identify distinct clusters among the commercial grades, indicating their similarity in composition and characteristics.

Table 2. Moisture and protein of MZ potato of various commercial grades

Grade	Potato moisture %	Potato peel protein %	Potato flesh protein %
A	76.78 ±1.54	4.61 ±1.66	1.63 ±0.73
B	76.16 ±2.52	3.55 ±0.56	1.81 ±0.53
C	74.97 ±2.20	3.79 ±1.05	2.10 ±0.18
D	77.17 ±1.66	3.49 ±0.98	1.66 ±0.32
E	74.02 ±4.16	4.38 ±3.05	1.40 ±0.76

Data are presented as mean ±standard deviation (n = 3) from analysis of variance and Duncan Multiple Range Test post hoc test ($\alpha = 0.05$).

These findings suggest a consistency in moisture levels and protein content across different grades of potatoes, highlighting the uniformity of quality within the commercial potato market. Such uniformity can be advantageous for industries relying on potatoes as a primary ingredient, ensuring predictable and standardized product attributes regardless of the commercial grade.

Figure 4 presents a PCA biplot of the chemical properties of potatoes of various commercial grades. The analysis of the commercial grades of potato reveals an unclear grouping and separation, indicating a lack of distinct differentiation among the grades, confirming the analysis of variance of data in Table 2 and providing agreement with Altuntas et al. (2013)

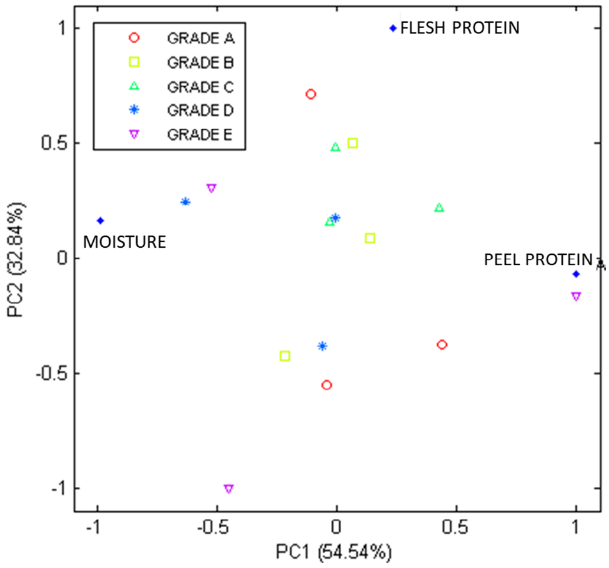


Fig. 4. PCA biplot of chemical properties of potato of various commercial grades

that there is no difference in dry matter and starch index across various tuber sizes. However, grade B and C demonstrate a higher degree of homogeneity in moisture content, peel protein, and flesh protein compared to other grades, as evidenced by more cohesive clustering patterns. This suggests that grades B and C exhibit greater similarity in composition and characteristics, potentially due to similar growing conditions, handling processes, or genetic factors. The observed clustering pattern implies that grade B and C potatoes may offer more consistent quality attributes in terms of moisture and protein content, which could be advantageous for industries seeking standardized ingredients for product formulations or culinary applications.

Properties of potato starch

Table 3 presents the properties of starch isolated from MZ potato tuber. Potatoes of medium to large size evidently yielded a higher starch output, while those of medium to small size yielded comparatively less starch. Notably, starch from potatoes of the higher size grade (A) exhibits increased viscosity when dispersed in hot water. On the other hand, no substantial differences were observed in damaged starch across various commercial grades of potatoes. Minor damage was found in the form of a limited number of starch granules on the surface of potatoes of grades A, B, and C, and no damage was found in starch from potatoes of grades D and E. Greater damage may be present when mechanical processing is used (Barrera et al., 2013; Li et al., 2014) intensively during starch isolation. Nevertheless, all remaining starch granules exhibited birefringence, indicating that they remained native (Abduh et al., 2019).

Properties of processed potatoes

Optimization of potato processing times

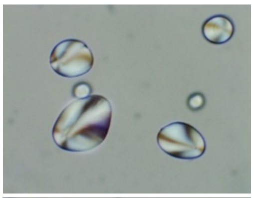
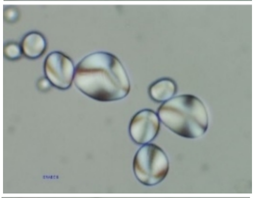
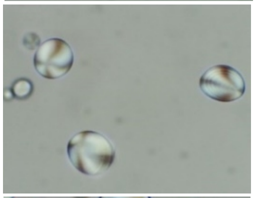
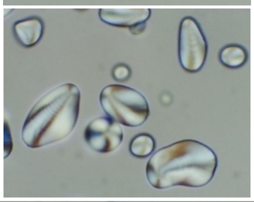
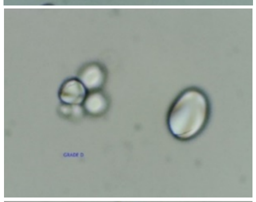
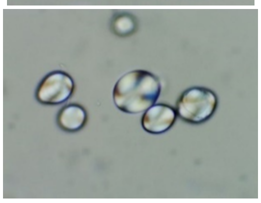
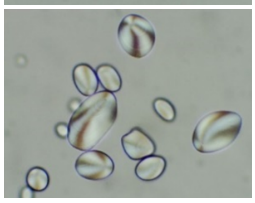
Table 4 presents the optimized times for potato processing. The time required for steaming, baking, and microwave heating decreases as the size of the potato grade decreases. Steaming demands the lengthiest cooking time, whereas microwave heating requires the shortest, irrespective of the potato grade. For a given processing technique, the shorter the time the better for the nutritional properties of the potato (Coe and Spiro, 2022; Jayanty et al., 2019).

Chemical properties of processed potatoes

Table 5 presents the moisture and protein content of processed potatoes of various commercial grades. The moisture content of potatoes varies significantly depending on the processing methods utilized and the specific sizes of the potatoes. For grade A and grade C potatoes, the impact of processing methods on moisture levels is minimal, with consistency maintained regardless of the technique employed. In contrast, grades B, D, and E demonstrate notable variations in moisture content across different processing methods. Notably, steamed potatoes exhibit the highest moisture content among these sizes, while grade E potatoes consistently show the lowest moisture content across most processing methods. Raw and baked potatoes exhibit similar moisture levels, with grade B displaying the lowest moisture content.

Microwave processing highlights distinct trends, with grade D potatoes showing the lowest moisture content and grade C potatoes exhibiting the highest. Furthermore, while grades A and B demonstrate lower moisture content than grade C in microwaved form, they still have higher moisture levels than grade D. These observations underscore the intricate relationship between processing methods and moisture retention across various sizes of potatoes.

Table 3. Properties of potato starch

Potato grade	Starch yield (%)*	Viscosity (dpas)**	Microscopy of intact granules	Microscopy of damaged granules
A	3.4	310.00 ±43.59^{a}		
B	3.1	356.67 ±25.17^{b}		
C	3.7	286.67 ±5.77^{a}		
D	2.1	363.33 ±20.82^{b}		
E	1.9	386.67 ±5.77^{b}		

*Data collected from single batch isolation.
**Data are presented as mean ±standard deviation (n = 3) from analysis of variance and Duncan's Multiple Range Test post hoc test (α = 0.05).

Table 4. Optimized time of steaming, baking and microwave heating processing techniques of potato

Grade	Steaming (s)	Baking (s)	Microwave heating (s)
A	4760 ±34.64^{aA}	2900 ±34.64^{bA}	450 ±30.00^{cA}
B	4220 ±34.64^{aB}	2680 ±34.64^{bB}	240 ±0.00^{cB}
C	3900 ±0.00^{aC}	2240 ±34.64^{bC}	180 ±0.00^{cC}
D	2440 ±69.28^{aD}	1760 ±34.64^{bD}	120 ±0.00^{cD}
E	1500 ±0.00^{aE}	1440 ±0.00^{bE}	100 ±17.32^{cD}

Data are presented as mean ± standard deviation (n = 3). Data not sharing small superscripts are significantly different across processing technique while data not sharing capital superscripts are significantly different across grades as analyzed by means of analysis of variance and Duncan's Multiple Range Test post hoc test (α = 0.05).

Table 5. Properties of processed potatoes

Property	Grade	Raw	Steamed	Baked	Microwave heating
Moisture %	A	76.78 ±1.54	76.68 ±4.06^{AB}	76.44 ±3.55^{AB}	74.57 ±3.63^{BC}
	B	76.16 ±2.52^{b}	80.81 ±2.31^{aAB}	76.11 ±2.40^{bAB}	78.43 ±1.91^{abAB}
	C	74.97 ±2.20	82.92 ±0.19^{AB}	79.20 ±1.41^{A}	79.96 ±3.10^{A}
	D	79.55 ±4.39^{ab}	82.14 ±1.19^{aA}	75.50 ±2.72^{bcAB}	71.76 ±1.40^{cC}
	E	77.36 ±6.79^{a}	75.04 ±3.28^{aB}	66.57 ±8.18^{aB}	54.16 ±2.46^{bD}
Protein %	A	1.63 ±0.73^{b}	2.16 ±0.36^{ab}	2.80 ±0.30^{aA}	2.10 ±0.18^{abC}
	B	1.81 ±0.53^{b}	2.45 ±0.35^{b}	2.28 ±0.17^{bB}	3.73 ±1.01^{aAB}
	C	2.10 ±0.18^{ab}	1.81 ±0.27^{b}	2.22 ±0.40^{abB}	2.39 ±0.10^{aC}
	D	1.66 ±0.32^{b}	2.57 ±0.36^{a}	1.55 ±0.10^{bC}	2.74 ±0.36^{aBC}
	E	1.40 ±0.76^{b}	1.99 ±0.71^{b}	2.16 ±0.27^{bB}	4.73 ±0.61^{aA}
Starch hydrolysis mg/g	A	2.60 ±0.35^{b}	21.09 ±2.08^{aAB}	19.77 ±0.43^{aB}	23.67 ±8.26^{aB}
	B	2.34 ±1.42^{b}	18.43 ±1.49^{aB}	20.67 ±2.41^{aB}	19.26 ±0.65^{aB}
	C	2.59 ±0.78^{b}	19.27 ±0.64^{aAB}	18.29 ±1.30^{aB}	18.81 ±1.23^{aB}
	D	1.87 ±0.96^{c}	23.20 ±4.23^{bA}	26.40 ±2.40^{bA}	41.11 ±8.77^{aA}
	E	3.20 ±0.87^{b}	19.86 ±0.82^{aAB}	20.81 ±1.78^{aB}	21.52 ±0.43^{aB}
Hardness kgf	C	–	1.36 ±0.32	1.47 ±1.02^{B}	1.16 ±0.51^{B}
	D	–	0.97 ±0.10^{b}	2.14 ±0.55^{aAB}	1.53 ±0.38^{abB}
	E	–	1.47 ±0.59^{b}	3.51 ±1.14^{aA}	2.49 ±0.47^{abA}
Cohesiveness	C	–	0.12 ±0.05	0.34 ±0.35	0.09 ±0.05
	D	–	0.10 ±0.05	0.07 ±0.01	0.09 ±0.02
	E	–	0.07 ±0.06	0.05 ±0.02	0.08 ±0.02
Springiness mm	C	–	6.27 ±2.34	4.42 ±3.26	4.01 ±0.40^{B}
	D	–	6.48 ±2.36	5.60 ±1.54	6.08 ±1.19^{A}
	E	–	3.49 ±2.53	4.50 ±1.26	3.07 ±0.25^{B}
Gumminess kgf	C	–	0.17 ±0.09	0.35 ±0.38	0.12 ±0.11
	D	–	0.21 ±0.21	0.15 ±0.05	0.14 ±0.04
	E	–	0.08 ±0.04^{b}	0.18 ±0.08^{a}	0.18 ±0.03^{a}
Chewiness kgf	C	–	1.15 ±1.02	3.29 ±4.31	0.47 ±0.45
	D	–	0.56 ±0.57	0.84 ±0.36	0.84 ±0.36
	E	–	0.35 ±0.45	0.82 ±0.49	0.56 ±0.13

Data are presented as mean ±standard deviation ($n = 3$ for moisture, protein, starch hydrolysis and $n = 4$ for hardness, cohesiveness, springiness, gumminess, and chewiness). Data not sharing small superscripts are significantly different across processing technique while data not sharing capital superscripts are significantly different across grades as analyzed by means of analysis of variance and Duncan's Multiple Range Test post hoc test ($\alpha = 0.05$).

The protein content of potatoes varies significantly across different sizes and processing methods. Baked potatoes, particularly those of grade A, the largest size, demonstrate the highest protein content, while raw potatoes, particularly those of grade E, the smallest size, exhibit the lowest levels. Steamed and microwaved forms show comparable protein levels across all sizes. Conversely, in grade B potatoes, those that have been microwaved display higher protein content than raw, steamed, or baked potatoes, which maintain similar levels.

Among grade C potatoes, those that have been microwaved have the highest protein content, whereas steamed ones have the lowest, with raw and baked forms exhibiting equal protein levels. Grade D steamed potatoes present the highest protein content, while raw and baked ones have similarly lower levels. Microwaved grade E potatoes have a higher protein content than their raw, steamed, and baked counterparts, for which the protein content remains uniform. The size of the potato does not impact its protein content in raw and steamed forms. In baked potatoes, grade A boasts the highest protein content, while grade D has the lowest, with grades B, C, and E showing equivalent protein levels. In microwaved potatoes, grade E displays the highest protein content, while grades A and C have the lowest, and grades B and D demonstrate identical protein levels under the same processing method. These observations underscore the intricate relationship between potato size and processing method in determining protein content. Thus, while the specific effects may vary depending on the processing method and potato grade, steaming typically preserves higher moisture levels, while protein content remains relatively consistent across different processing methods, with some variations observed among specific potato grades. A study by Bailey et al. (2023) found that protein quality remained similar after boiling, baking and microwave heating but became lower after frying.

Table 5 presents starch hydrolysis data for processed MZ potato of various commercial grades. Processing techniques were found to enhance the starch hydrolysis of potatoes across all grades (A, B, C, D, and E). Irrespective of the processing method employed, including steaming, baking, or microwave heating, potatoes of grades A, B, C, and E exhibited a consistent increase in starch hydrolysis levels. Notably, grade D potatoes experienced the highest starch hydrolysis when subjected to microwave heating, surpassing the levels observed with steaming and baking. This suggests that microwave heating is particularly effective in facilitating starch hydrolysis in grade D potatoes, while steaming and baking result in comparatively lower levels of starch hydrolysis across all grades. This facilitation of starch hydrolysis by microwave heating in grade D potatoes is not consistent with the findings of Narwojsz et al. (2020), who found that microwave heating together with grilling (considered as dry heating) retained starch hydrolysis, as indicated by higher resistant starch and lower rapidly digestible starch fractions compared to those found after wet heating (namely steaming in a steel pot or combi oven). Notably, no tuber size data is provided by Narwojsz et al. (2020), and different tuber sizes probably led to their different result.

Textural properties of processed potatoes

Table 5 presents the textural properties of processed MZ potato of various commercial grades. The influence of processing technique on the hardness of potatoes varies across different grades. Grade C potatoes exhibit consistent hardness ranging from 1.16 ±0.51 to 1.47 ±1.02 kgf regardless of processing method, while baking results in a harder texture (2.14±0.55 and 3.51 ±1.14 kgf) compared to steaming (0.97 ±0.10 and 1.47 ±0.59 kgf) for grade D and E potatoes. Potato size plays a role in the hardness of steamed potatoes, with smaller sizes (grade C to E) generally displaying a harder texture. These findings highlight how processing technique affects potato texture (Cunningham et al., 2008) in ways which can also be detected after further storage (Van Marle et al., 1997).

However, processing technique and potato size do not significantly affect the cohesiveness and chewiness of steamed, baked, and microwaved potatoes. Similarly, processing technique does not impact the springiness of steamed, baked, and microwaved potatoes, although grade D baked potatoes demonstrate higher springiness compared to grades C and E, which exhibit similar levels. Moreover, potato size does not influence the gumminess of steamed, baked, and microwaved potatoes, except for grade E potatoes, where gumminess is lower in steamed form.

CONCLUSION

Commercial grading categorizes potatoes into five grades (A to E) based on weight, with clear distinctions observed among the grades, hence grading for quality assessment is essential. Grade A potatoes exhibit unique color characteristics; the remaining grades share similar color distributions. Nevertheless, moisture and protein are uniform within the commercial grades.

Processing methods significantly influence moisture levels, with steamed potatoes showing higher moisture content compared to other methods. Protein content varies across processing methods and grades, with grade A displaying the highest protein content in baked form. Starch hydrolysis increases with processing across all grades, with microwave heating particularly effective in grade D potatoes.

Regarding texture, grade C potatoes maintain consistent hardness across processing methods, while baking results in a harder texture for grade D and E potatoes. Smaller potato sizes generally exhibit harder textures in steamed form. However, processing technique and size do not significantly affect cohesiveness, chewiness, springiness, or gumminess across various processing methods. These findings contribute to our understanding of the complex relationships between potato characteristics, processing techniques, and final product attributes which are crucial for industrial applications and product development in the potato industry.

OUTLOOK

Future research could explore advanced grading techniques and technologies to enhance accuracy and efficiency in potato grading processes. Implementing standardized grading criteria across different regions in the country could also ensure consistency in potato quality assessment. Future studies could focus on refining processing parameters to maximize desirable attributes such as moisture retention, protein content, and texture while minimizing processing time and energy consumption. Future studies on consumer perceptions and preferences regarding different potato varieties, sizes, and processing methods could inform product development strategies and marketing initiatives in the potato industry. The environmental footprint of potato production and processing operations and sustainable practices to minimize environmental impact such as waste valorization and by-product utilization could also be studied to contribute to sustainable resource management in the potato industry.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical Approval

Not applicable.

Competing Interests

The authors declare that they have no conflicts of interest.

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REFERENCES

Abduh, S. B. M., Bintoro, V. P., Mulyani, S., Al-Baarri, A. N. (2023). Dissimilarity Analysis of Wheat Dough of Different Final Thermal Processing Techniques Based on the Chemical Composition and Starch Hydrolysis. AIP Conference Proceedings, 2586(1). https://doi.org/10.1063/5.0107951/2870233

Abduh, S. B. M., Leong, S. Y., Agyei, D., Oey, I. (2019). Understanding the properties of starch in potatoes (*Solanum tuberosum* var. *Agria*) after being treated with pulsed electric field processing. Foods, 8(5), 159. https://doi.org/10.3390/foods8050159

Altuntas, E., Yilmaz, G., Karan, Y. B., Dulger, E. (2013). Assessment of the physico-mechanical, chemical and colour characteristics of potatoes depending on tuber size and cultivar. Int. J. Food Eng., 9(4), 487–497. https://doi.org/10.1515/IJFE-2012-0212/ijfe-2012-0212

Andre, C. M., Legay, S., Iammarino, C., Ziebel, J., Guignard, C., Larondelle, Y., …, Miranda, L. M. (2014). The Potato in the Human Diet: a Complex Matrix with Potential Health Benefits. Potato Res., 57(3–4), 201–214. https://doi.org/10.1007/S11540-015-9287-3/METRICS

Andriyanto, F., Setiawan, B., Riana, F. D. (2013). Impact of Imported Potatoes for Indonesian Market. Habitat, 24(1), 59–70. Retrieved from https://habitat.ub.ac.id/index.php/habitat/article/view/95

Anonymous (n.d.). Deskripsi Kentang Varietas Tedjo MZ. Retrieved March 31, 2024, from https://horti.pertanian.go.id/databenih/file/daftarvar/Kentang%20Tedjo%20MZ.pdf

Arora, N. K. (2018). Agricultural sustainability and food security. Environ. Sustain., 1(3), 217–219. https://doi.org/10.1007/S42398-018-00032-2

Asnake, D., Alemayehu, M., Asredie, S. (2023). Growth and tuber yield responses of potato (*Solanum tuberosum* L.) varieties to seed tuber size in northwest highlands of Ethiopia. Heliyon, 9(3), e14586. https://doi.org/10.1016/J.HELIYON.2023.E14586

Bailey, T., Franczyk, A. J., Goldberg, E. M., House, J. D. (2023). Impact of cooking on the protein quality of Russet potatoes. Food Sci. Nutr., 11(12), 8131–8142. https://doi.org/10.1002/FSN3.3734

Barrera, G. N., Calderón-Domínguez, G., Chanona-Pérez, J., Gutiérrez-López, G. F., León, A. E., Ribotta, P. D. (2013). Evaluation of the mechanical damage on wheat starch granules by SEM, ESEM, AFM and texture image analysis. Carbohydr. Polym., 98(2), 1449–1457. https://doi.org/10.1016/J.CARBPOL.2013.07.056

Berry, E. M., Dernini, S., Burlingame, B., Meybeck, A., Conforti, P. (2015). Food security and sustainability: can one exist without the other? Pub. Health Nutr., 18(13), 2293–2302. https://doi.org/10.1017/S136898001500021X

Blauer, J. M., Knowles, L. O., Knowles, N. R. (2013). Manipulating Stem Number, Tuber Set and Size Distribution in Specialty Potato Cultivars. Am. J. Potato Res., 90(5), 470–496. https://doi.org/10.1007/s12230-013-9317-0

Coe, S., Spiro, A. (2022). Cooking at home to retain nutritional quality and minimise nutrient losses: A focus on vegetables, potatoes and pulses. Nutr. Bull., 47(4), 538–562. https://doi.org/10.1111/NBU.12584

Cunningham, S. E., Mcminn, W. A. M., Magee, T. R. A., Richardson, P. S. (2008). Effect of processing conditions on the water absorption and texture kinetics of potato. J. Food Eng., 84(2), 214–223. https://doi.org/10.1016/J.JFOODENG.2007.05.007

Demšar, J., Erjavec, A., Hočevar, T., Milutinovič, M., Možina, M., Toplak, M., …, Zupan, B. (2013). Orange: data mining toolbox in Python. J. Machine Learn. Res., 14, 2349–2353. Retrieved from https://www.jmlr.org/papers/volume14/demsar13a/demsar13a.pdf

Devaux, A., Goffart, J. P., Kromann, P., Andrade-Piedra, J., Polar, V., Hareau, G. (2021). The Potato of the Future: Opportunities and Challenges in Sustainable Agri-food Systems. Potato Res., 64(4), 681–720. https://doi.org/10.1007/S11540-021-09501-4/FIGURES/10

Devaux, A., Kromann, P., Ortiz, O. (2014). Potatoes for Sustainable Global Food Security. Potato Res., 57(3–4), 185–199. https://doi.org/10.1007/S11540-014-9265-1/METRICS

Ebrahim, S., Mohammed, H., Ayalew, T. (2018). Effects of seed tuber size on growth and yield performance of potato (*Solanum tuberosum* L.) varieties under field conditions. Afr. J. Agric. Res., 13(39), 2077–2086. https://doi.org/10.5897/AJAR2018.13405

El Bilali, H., Callenius, C., Strassner, C., Probst, L. (2019). Food and nutrition security and sustainability transitions in food systems. Food Energ. Sec., 8(2), e00154. https://doi.org/10.1002/FES3.154

Gupta, U. C., Gupta, S. C. (2018). The Important Role of Potatoes, An Underrated Vegetable Food Crop in Human Health and Nutrition. Curr. Nutr. Food Sci., 15(1), 11–19. https://doi.org/10.2174/157340131466618090613417

Hamouz, K., Lachman, J., Pazderů, K., Tomášek, J., Hejtmánková, K., Pivec, V. (2011). Differences in anthocyanin content and antioxidant activity of potato tubers with different flesh colour. Plant Soil Environ., 57(10), 478–485. https://doi.org/10.17221/265/2011-PSE

Jayanty, S. S., Diganta, K., Raven, B. (2019). Effects of Cooking Methods on Nutritional Content in Potato Tubers. Am. J. Potato Res., 96(2), 183–194. https://doi.org/10.1007/S12230-018-09704-5/METRICS

Lewis, C. E., Walker, J. R. L., Lancaster, J. E. (1999). Changes in anthocyanin, flavonoid and phenolic acid concentrations during development and storage of coloured potato (*Solanum tuberosum* L). J. Sci. Food Agric., 79(2), 311–316. https://doi.org/10.1002/(SICI)1097-0010(199902)79:2<311::AID-JSFA199>3.0.CO;2-Q

Li, E., Dhital, S., Hasjim, J. (2014). Effects of grain milling on starch structures and flour/starch properties. Starch - Stärke, 66(1–2), 15–27. https://doi.org/10.1002/STAR.201200224

Mardhika, H., Dwiloka, B., Setiani, B. E. (2020). Pengaruh berbagai metode thawing daging ayam petelur afkir beku terhadap kadar protein, protein terlarut dan kadar lemak steak ayam. J. Teknologi Pangan, 4(1), 48–54. https://ejournal3.undip.ac.id/index.php/tekpangan/article/view/26546

Mas'ud, Wahyuningsih, S., Rinawati (2022). Analisis Kinerja Perdagangan Kentang. Jakarta: Pusat Data dan Sistem Informasi Pertanian Kementerian Pertanian. Retrieved from https://satudata.pertanian.go.id/assets/docs/publikasi/Analisis_Kinerja_Perdagangan_Kentang_2022.pdf

Muchransyah, M. H. Q., Sarma, M., Najib, M. (2018). Analisis Internal dan Eksternal Kentang Indonesia dalam Menghadapi Masyarakat Ekonomi ASEAN (MEA) Indonesian Potential Internal and External Analysis in Facing the ASEAN Economic Community (MEA). Jurnal Manajemen Dan Organisasi (JMO), 9(2), 115–121. https://doi.org/10.29244/jmo.v9i2.26095

Narwojsz, A., Borowska, E. J., Polak-Śliwińska, M., Danowska-Oziewicz, M. (2020). Effect of Different Methods of Thermal Treatment on Starch and Bioactive Compounds of Potato. Plant Foods Human Nutr., 75(2), 298–304. https://doi.org/10.1007/s11130-020-00808-0

Navarre, D. A., Payyavula, R. S., Shakya, R., Knowles, N. R., Pillai, S. S. (2013). Changes in potato phenylpropanoid metabolism during tuber development. Plant Physiol. Biochem., 65, 89–101. https://doi.org/10.1016/J.PLAPHY.2013.01.007

Noordam, J. C., Otten, G. W., Timmermans, T. J. M., Zwol, B. H. van. (2000). High-speed potato grading and quality inspection based on a color vision system. Proceedings Volume 3966, Machine Vision Applications in Industrial Inspection VIII, 206–217. https://doi.org/10.1117/12.380075

Nunes, C. A., Freitas, M. P., Pinheiro, A. C. M., Bastos, S. C. (2012). Chemoface: a novel free user-friendly interface for chemometrics. J. Braz. Chem. Soc., 23(11), 2003–2010. https://doi.org/10.1590/S0103-50532012005000073

Pachapur, P. K., Pachapur, V. L., Brar, S. K., Galvez, R., Le Bihan, Y., Surampalli, R. Y. (2020). Food Security and Sustainability. In: R. Surampalli, T. Zhang, M. K. Goyal, S. Brar, R. Tyagi (Eds.), Sustainability: Fundamentals and Applications (pp. 357–374). Hoboken, New Jersey, USA: Wiley and Sons. https://doi.org/10.1002/9781119434016.CH17

Pertiwi, M. D., Cempaka, I. G. (2020). Pengaruh Pola Tanam Terhadap Pertumbuhan dan Hasil Kentang di Wilayah Dataran Tinggi Dieng, Jawa Tengah. Jurnal Ilmu-Ilmu Pertanian, 27(1), 9. https://doi.org/10.55259/JIIP.V27I1.564

Pertiwi, M. D., Sulistyaningsih, E., Murti, R. H., Purwanto, B. H. (2022). Identification of High-Temperature Tolerance of Some Potato Varieties Based on Stress Tolerance Indice and Cluster Analysis. J. Agric. Sci., 34(1), 79–88. https://doi.org/10.24246/agric.2022.v34.i1.p79-88

Phogat, N., Siddiqui, S., Dalal, N., Srivastva, A., Bindu, B. (2020). Effects of varieties, curing of tubers and extraction methods on functional characteristics of potato starch. J. Food Meas. Charact., 14(6), 3434–3444. https://doi.org/10.1007/S11694-020-00579-X/METRICS

Sato, H., Koizumi, R., Nakazawa, Y., Yamazaki, M., Itoyama, R., Ichisawa, M., …, Takano, K. (2017). Data on the weights, specific gravities and chemical compositions of potato (*Solanum tuberosum*) tubers for food processing from different areas of Hokkaido, Japan. Data in Brief, 11, 601–605. https://doi.org/10.1016/J.DIB.2017.03.009

Si, Y., Sankaran, S., Knowles, N. R., Pavek, M. J. (2017). Potato Tuber Length-Width Ratio Assessment Using Image Analysis. Am. J. Potato Res., 94(1), 88–93. https://doi.org/10.1007/S12230-016-9545-1/METRICS

Struik, P. C., Haverkort, A. J., Vreugdenhil, D., Bus, C. B., Dankert, R. (1990). Manipulation of tuber-size distribution of a potato crop. Potato Res., 33(4), 417–432. https://doi.org/10.1007/BF02358019

Šulc, M., Kotíková, Z., Paznocht, L., Pivec, V., Hamouz, K., Lachman, J. (2017). Changes in anthocyanidin levels during the maturation of color-fleshed potato (*Solanum tuberosum* L.) tubers. Food Chem., 237, 981–988. https://doi.org/10.1016/J.FOODCHEM.2017.05.155

Terryana, R. T., Prihaningsih, A., Nugroho, K., Kusmana, Lestari, P., Wardhana, I. N. A., Suprayogi. (2022). Diversity of 33 Genotypes of Potato Revealed by Simple Sequence Repeats Markers. J. Adv. Agric. Technol., 9(2). https://doi.org/10.18178/JOAAT.9.2.40-45

Vågsholm, I., Arzoomand, N. S., Boqvist, S. (2020). Food Security, Safety, and Sustainability – Getting the Trade-Offs Right. Front. Sustain. Food Syst., 4, 487217. https://doi.org/10.3389/FSUFS.2020.00016/BIBTEX

Van Asselt, E. D., Van Bussel, L. G. J., Van Der Voet, H., Van Der Heijden, G. W. A. M., Tromp, S. O., Rijgersberg, H., …, Van Der Fels-Klerx, H. J. (2014). A protocol for evaluating the sustainability of agri-food production systems – A case study on potato production in peri-urban agriculture in The Netherlands. Ecol. Indicators, 43, 315–321. https://doi.org/10.1016/J.ECOLIND.2014.02.027

Van Marle, J. T., Van Der Vuurst De Vries, R., Wilkinson, E. C., Yuksel, D. (1997). Sensory evaluation of the texture of steam-cooked table potatoes. Potato Res., 40(1), 79–90. https://doi.org/10.1007/BF02407564/METRICS

Winarto, B., Cempaka, I. G., Jatuningtyas, R. K., Budisetyaningrum, S. C., Hartoyo, B. (2021). In vitro shoot growth performances and responses of potato (*Solanum tuberosum* L.) "Muhzoto" under different treatments and explant types. Agraarteadus, 32(1), 150–158. https://doi.org/10.15159/JAS.21.07