Agriculture and Food

AIMS Agriculture and Food, 11(1): 40–71.
DOI: 10.3934/agrfood.2026003
Received: 09 October 2025
Revised: 21 January 2026
Accepted: 02 February 2026
Published: 04 March 2026

https://www.aimspress.com/journal/agriculture

Review

Physicochemical characteristics, pasting behaviors and production cost of pre-soaked soybean and corn flours from local and improved varieties for supporting local food utilization

Sri Satya Antarlina[1], Joko Susilo Utomo[1,*], Erliana Ginting[1], Dian Adi Anggraeni Elisabeth[2], Aniswatul Khamidah[1], Indrie Ambarsari[1], Heni Purwaningsih[1], Siti Dewi Indrasari[1], Ulyatu Fitrotin[1], Alit Pangestu[1], Fitri Nur Kayati[1], Yessy Anna Pratiwi[1], Sugeng Pondang Sugiharto[1] and Hozin Aziz[1]

[1] Research Center for Food Technology and Processing, National Research and Innovation Agency Republic of Indonesia. Jl. Jogja-Wonosari KM. 31.5, Gading. Playen, Gunung Kidul, Yogyakarta 55861, Indonesia

[2] Research Center for Behavioral and Circular Economics, National Research and Innovation Agency Republic of Indonesia. Jl. Jendral Gatot Subroto No. 10, Jakarta 12710, Indonesia

* **Correspondence:** Email: joko044@brin.go.id; Tel: +6281320683338.

Abstract: Flour production from soybeans and corn is a promising strategy to increase their use as local ingredients in diverse food applications. In this study, local and improved varieties of soybean and corn seeds collected from Sumenep, Indonesia, were subjected to soaking pretreatments for 0, 24, 48, and 72 h prior to flour production. The resulting flours were characterized for their physicochemical and pasting properties and evaluated regarding their production cost. The results showed that variety and soaking time significantly affected the physicochemical properties of soybean and corn flours ($p < 0.05$). Longer soaking time reduced the bulk density and increased the whiteness of soybean and corn flours, except for the local corn variety, which was similar to the control (0 h). The yield increased for corn flour, while it decreased for soybean flour. Greater yield values were obtained for improved varieties relative to local varieties. The fat, protein, and amylose contents of both flours increased along with soaking time; however, ash and carbohydrate contents decreased. The pasting behaviors showed that soybean flours were hardly gelatinized, with no detectable peak viscosity at any soaking time. Conversely, corn flours gelatinized at a range of 72.35–75.65 °C, with the highest values noted for 0-h soaking. Soaking for 24 h resulted in the highest peak viscosity, with values of 303.33 cP for the local Sumenep and 201.67 cP for HJ 21. A soaking pretreatment for 24 h was likely suitable for soybean seed, while corn required a longer (48 h) period. The economic analysis showed that home-scale production was feasible and profitable to be developed in the study area, with B/C ratios of 1.11–1.14 for soybean flour and 1.40–1.45 for corn flour.

Keywords: flour; soaking time; functional properties; economic feasibility

1. Introduction

Soybean (*Glycine max* [L. Merr.]) and corn (*Zea mays* L.) have been cultivated for a long time and are widely utilized as food sources in Indonesia. Both commodities are popular with regard to their essential nutrients and bioactive compounds that are beneficial for human health [1–4]. Soybean is frequently regarded as the golden or miracle bean due to its essential role in human and animal nutrition, being a cheap source of protein, with multipurpose uses, and having high weight in the world agriculture trade [5]. Soybean seeds contain approximately 33%–50% protein and 18%–22% fat [6,7], which consists predominantly of unsaturated fatty acids [8]. Tempe and tofu represent the major use of soybeans in Indonesia (83.7%), while soy sauce, soy milk, sprouts, and flour comprise the rest [7]. Meanwhile, corn is widely known as a rich source of carbohydrates and energy, with starch as the major component (75%) [9] and protein in a lesser amount (12.32%–13.50%) [10]. The main use of corn is for animal feed and non-food industries (78%), while the remaining is for direct food consumption and seeds (2%) [11]. In terms of food, corn can be consumed either as fresh or dried grains, with a consumption level of 2.27 and 0.57 kg/capita/year, respectively [11].

The domestic production of soybeans and corn was reported to be approximately 0.56 million tons and 14.77 million tons in 2023, respectively [12]. Corn is mainly grown in the dry land (non-paddy fields) with a monoculture cropping pattern using hybrid (70.75%), composite (6.35%), and local (22.9%) varieties. Conversely, the majority of soybeans are grown in paddy fields, while only 33.56% is cultivated in dry land with a monoculture cropping pattern [13,14]. The use of improved varieties of both crops is essential in terms of increasing domestic production. These varieties are particularly superior in terms of their high-yielding potential, adaptability to different agroecology and growing conditions, and resistance to pest and disease attacks [14–16]; therefore, they are intensively introduced and disseminated to users/farmers.

In Sumenep Regency, which belongs to Madura Island in East Java Province, Indonesia, agricultural activities, including the cultivation of corn and soybean crops, are mainly managed in the dry land [17] with a planting time of corn at the beginning of the rainy season (December), followed by soybean in March [18,19]. The total production of corn was about 455,808 tons in 2022, which contributed 6.14% to East Java's total production, being the largest corn-producing area in Indonesia [20]. About 90% of farmers in this region plant local corn varieties, such as Guluk-Guluk, Manding, and Talango, due to their color, taste, and small size preferences, as well as early maturity and longer storage life [21–23]. Conversely, a much lesser quantity of soybean (206 tons) was produced in this region (BPS Jawa Timur, 2024), which commonly uses local and old improved varieties.

Corn is normally consumed either as a staple food or snacks, which are mostly limited to traditional food, such as *Durnang*, *Nasi Jagung*, and *Marning* [24–26]. The main use of soybeans is for tempeh and tofu, particularly consumed as side dishes and cheap protein sources [27–29], followed in small amounts by snacks, namely *Kedelai Goreng* [30]. These facts reflect limited corn and soybean food products available in this region; thus, diversification is needed to provide more attractive and added-value products derived from corn and soybean.

Research activities regarding the introduction of high-yielding improved varieties and appropriate cultivation technologies of both corn and soybean have been intensively performed in Madura Island, including the Sumenep region, to effectively solve the dry land limitation for increasing production [31–34]. However, these activities have not been accompanied by studies on the utilization of the resulting produce for food applications, including their physicochemical properties and quality attributes. Therefore, in this study, considering that local varieties are still grown by farmers in this region, both local and improved varieties of corn and soybean produced from Sumenep were used as ingredients for flour-making to compare the profiles of both varieties.

Processing corn and soybean seeds into flour makes them flexible to be used as an ingredient or composite flour with rice, wheat, legumes, sago, root, or tuber flour, for making a variety of food products that are normally produced from rice or wheat flour. Additionally, nutritional balance can be obtained through composite flours of cereals and legumes, particularly regarding amino acids. Cysteine and methionine, the limiting amino acids in legumes, are highly available in cereals, while lysine, the limiting amino acid in cereals, is present in large amounts in legumes [35]. Being rich in protein and bioactive components, soybean flour can also be applied to enrich other food products [36,37].

Prior to milling into flour, the seeds of corn and soybean need to be treated by soaking to soften the cellular structure of the kernels/cotyledons and facilitate the removal of the seed coat [38]. Soaking may also remove anti-nutritional compounds and enhance the physical characteristics and functional properties of the products prepared from the flour [39]. However, longer soaking time may decrease the amounts of total solids and nutrients due to leaching into the soaking water [40]. Therefore, this study aimed to find out the proper soaking time for both local and improved varieties of corn and soybean collected from Sumenep for flour preparation based on their physicochemical and pasting properties. The effective cost of flour production was also covered in this study to estimate its development opportunities as a local business or small-scale industry in this region. The results should be beneficial for the development of local source-based food products, supporting the national food diversification program [41–44].

2. Materials and methods

2.1. Materials

Soybean seeds and corn kernels were collected from cultivation crops in Sumenep Regency, East Java Province, Indonesia. The light-yellow local corn variety of Sumenep and the orange improved variety (HJ 21) were harvested from a monoculture cropping system in dry land (first planting time during the rainy season) from December until March. Meanwhile, soybeans consisted of the local variety of Sumenep and the improved variety Dering I. Both varieties were also harvested from a monocropping system conducted in dry land from March to June (second planting time). The soybean shoots and corn cobs were first sun-dried and then threshed to separate the seeds and kernels, winnowed, sorted, and redried to a safe moisture content of below 10%. They were then packed in plastic bags for further use.

2.2. Flour preparation

Soybean flour was prepared using the method previously shown by Fanzurna & Taufik [45] with a minor modification. The processing steps are illustrated in Figure 1, starting from sorting the dry seeds to obtain good seeds and separating the damaged or moldy seeds. Approximately 200 g of seeds were washed and subsequently soaked in water at a ratio of 1:3 by volume for 0, 24, 48, and 72 h at room temperature. Soaked seeds were then manually dehulled or peeled, washed, and drained. Subsequently, seeds were dried using a cabinet dryer at a temperature of 55 ± 1 °C for 16 h until the seed moisture content was less than 10%. Dried seeds were milled (Disk Mill FFC 15, Futake, Indonesia) and sieved using an 80-mesh sieve to obtain the final flour.

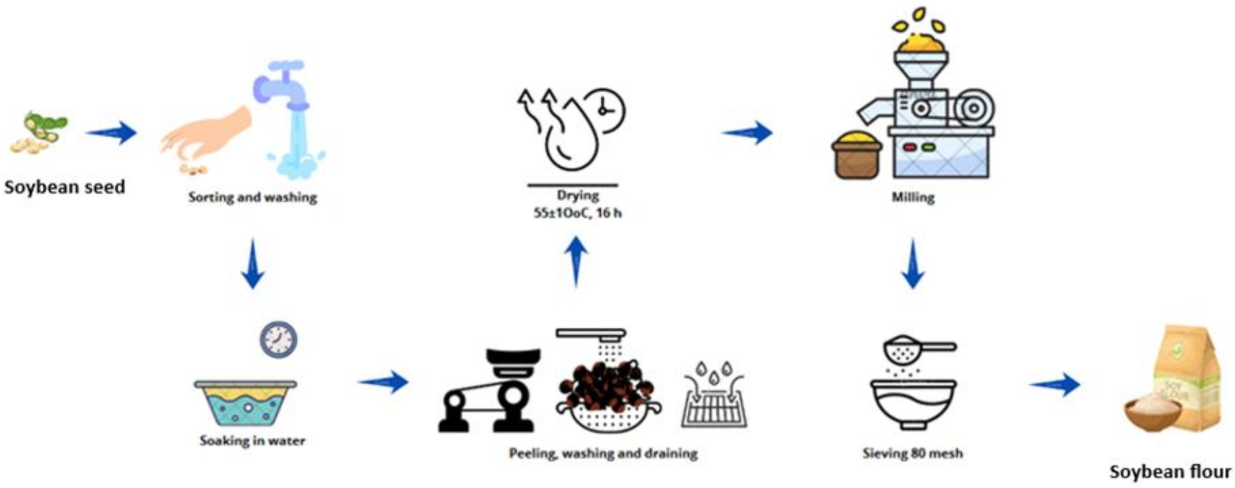

Figure 1. Preparation method of soybean flour [41].

The preparation of corn flour followed the method by Aini et al. [46] with a slight modification (Figure 2). Corn kernels were cleaned of dirt and separated from the damaged kernels. The kernels were then washed and soaked in water at a ratio of 1:3 for 0, 24, 48, and 72 h. Soaked kernels were drained and then dried using a cabinet dryer at 55 ± 1 °C for 16 h until the seed moisture content was less than 10%. Dry kernels were ground into corn rice, and the shell was separated. Corn rice was subsequently milled into flour and sieved using an 80-mesh sieve. A flow diagram of corn flour preparation is presented in Figure 2.

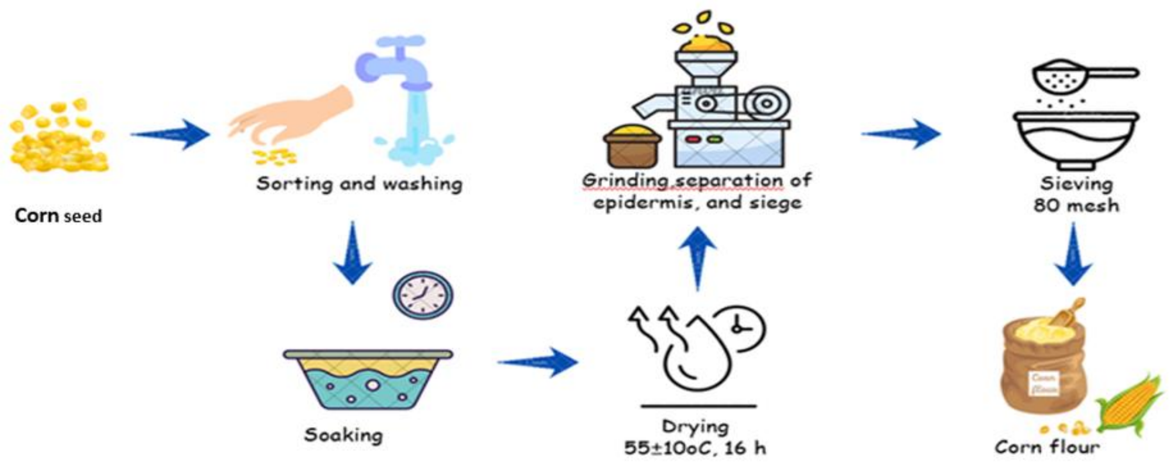

Figure 2. Preparation method of corn flour [42].

2.3. Data collection

2.3.1. Physical properties

Physical properties of soybean and corn seeds included bulk density and hardness. Bulk density was determined by putting the seeds of known weight into a measuring glass containing a certain volume of distilled water and recording the increase in volume (Archimedes' principle). The bulk density was calculated by dividing the seed weight by the volume [47], expressed in g/L [48]. Seed hardness was measured using a Digital Grain Hardness Tester (AGW-20, Graigar, China) with a maximum load of 20 kg. The bulk density of soybean and corn flour was measured using a similar method to that conducted for seeds. A whiteness tester (Kett C100, Tokyo, Japan) was applied to measure the whiteness level of both flours using $BaSO_4$ powder as a standard [49].

2.3.2. Chemical composition

Proximate analysis was performed for soybean and corn seed samples and flours. The procedures followed the American Association of Cereal Chemists methods [50], including moisture (method 44-01.01), ash (method 08-01.01), protein (method 46-10.01 with a conversion factor of 5.69 and 5.61 for soybean and corn, respectively), and lipid (method 30-20.01). Difference (100%–moisture–ash–protein–lipid) was used for the calculation of carbohydrate content. Amylose content was determined using a spectrophotometric method, which was detected at a wavelength of 625.9 nm and quantified using a potato amylose (A0612-1G, Sigma-Aldrich Co, USA) calibration curve [51].

2.3.3. Pasting properties

The pasting properties of soybean and corn flours were determined using a Rapid Visco Analyzer (RVA) (Model 45000, Perten Instruments, Australia) following the AACC International Method 76-21.01 and ICC Standard No. 162 with STD1 pasting profile [52]. This instrument was equipped with a heating and cooling system to measure the sample resistance during controlled stirring [53]. A fine sample (2.5–3.5 g) was put in an RVA canister and mixed well with 25 mL of distilled water. The temperature used for RVA observation ranged from 50 to 95 °C for 13 min. First, the speed applied was 960 rpm, then it was reduced to 160 rpm after 10 s. Temperature was increased from 50 to 95 °C, held at 95 °C for 3 min, and then reduced to 50 °C at a rate of 11 °C per min, with a final hold at 50 °C for 2 min. Observations included pasting temperature (°C), peak viscosity (cP), through/hold viscosity (cP), breakdown viscosity (cP), final viscosity (cP), and setback viscosity (cP).

2.4. Experimental design and statistical analysis

A factorial randomized block design was applied for the experimental design of each soybean and corn flour with three replicates. The first factor was variety (local and improved varieties), while the second factor was seed soaking time (0, 24, 48, and 72 h). Data were statistically analyzed using a two-way ANOVA (MSTAT–C version 1.4, Michigan University), followed by the least significant differences (LSD) test to assess differences between treatments ($p < 0.05$).

2.5. Ethics approval of research

No human or animal was used as the research object in this study.

3. Results and discussion

3.1. Physical properties of corn and soybean seeds

Bulk density represents the ratio of the seeds' weight to their total volume and can be used as a reference to design the packaging material and define storage room, the capacity of processing tools, and the transportation means for the seeds as raw materials [54–56]. Figure 3 shows that corn seeds presented higher bulk density than soybeans. This finding is consistent with previous studies, which reported that soybeans have lower bulk density compared to corn [57–59]. A study in Nigeria exhibited a greater bulk density of corn, ranging from 1140 to 1200 g/mL, and from 1010 to 1140 g/mL for soybean [58]. Another study noted smaller bulk density ranges of 639–773 g/mL for corn and 585–617 g/mL for soybean [57].

Moreover, the bulk density of the local corn variety was higher than that of the improved variety. In contrast, such a difference was not observed in soybean varieties. Several studies have shown that bulk density is strongly influenced by seed moisture content [61]. Different seed varieties can produce similar or completely different bulk densities depending on their moisture content. Bulk density shows a negative correlation in some seeds, like wheat, coriander, okra, arecanut, gram, amaranth, rapeseed, Turkish mahaleb, and soybean, as well as some legumes [54,55,62,63]. This suggests that the weight gain due to an increase in moisture content is lower than the volumetric expansion of the seeds [50]. However, in this study, the moisture content and bulk density were positively correlated, with $R^2 = 0.86$ (Figure 4). Differences in the shape, size, weight, and volume of corns and soybeans may be attributed to this finding. A lower bulk density indicates that a larger volume is required to store the exact weight of seeds (voluminous). Concerning the soaking process, bulk density is an important variable, as seeds with high bulk density typically have low porosity, which would consequently result in low water absorption capacity [60].

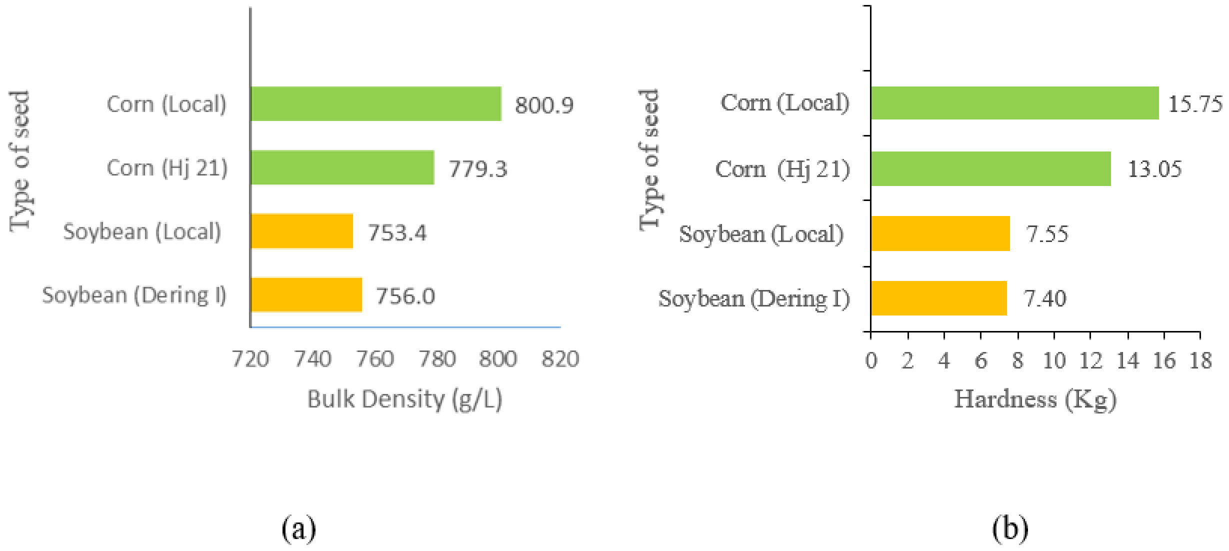

Figure 3. Bulk density (a) and hardness (b) of soybean and corn seeds.

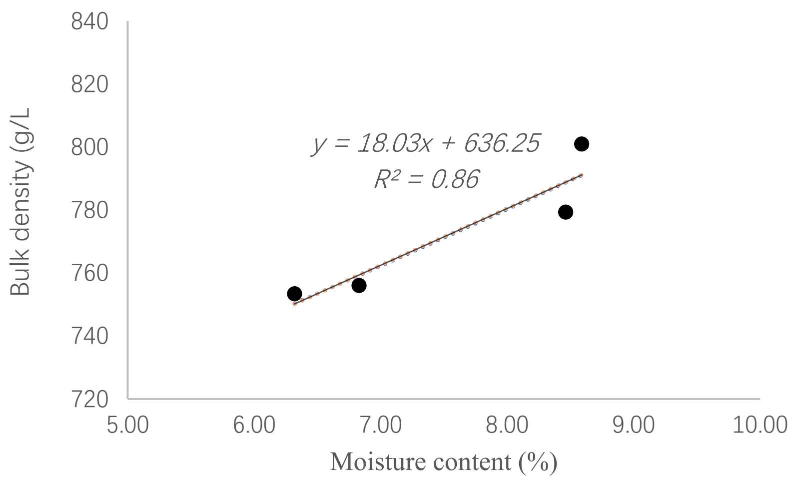

Figure 4. Relationship between moisture content and bulk density of soybean and corn seeds.

Corn seeds exhibited much higher levels of hardness compared to soybeans (Figure 3). In particular, the local corn variety showed a slightly higher hardness value than the improved variety, whereas the hardness of both soybean varieties was nearly the same. Similar to bulk density, seed hardness is influenced by moisture content [64]. High moisture content will lower the seed's rupturing forces, thus decreasing the hardness level, and vice versa [64]. Seed hardness affects flour processing, particularly the type of milling machine and the yield obtained. A hammer mill is commonly used for hard seeds (e.g., corn), whereas an abrasive mill is used for softer seeds, such as rice and soybeans [65].

3.2. *Chemical composition of corn and soybean seeds*

Seed moisture contents of corn and soybean ranged from 6.32% to 6.83% (Table 1) and were considerably affected by the drying process [66]. The amount of moisture influences the storage life of the seeds, the handling and processing method, and the selling price [67]. High seed moisture consequently provides high flour moisture and shortens the storage life by being susceptible to microorganism attacks. Therefore, a low moisture content (<10%) is normally required for grain storage purposes [68].

Soybeans, as legumes, have a much higher protein content than cereals (Table 1). This is not surprising, as soybeans are known to be rich in protein; their protein content can reach up to 40% [58]. In this study, the protein content of soybean Dering 1 was slightly higher than that of the local variety. Much lower protein contents of Dering 1 (34.95% dw) grown in Malang, East Java, were noted [7]; the value listed in its variety description is also lower, ca. 34.20% dw [14], reflecting the effects of different planting seasons and growing conditions. Meanwhile, a similar protein content was observed for both corn varieties. This would benefit the community's protein intake, which can be met through local or improved varieties. The protein content of corn observed in this study was within the range (8%–10%) typically present in corn, as well as the values (5.20%–13.70%) noted in nine Indonesian corn varieties [69].

Table 1. Chemical composition of corn and soybean seeds.

Chemical composition	Soybean		Corn	
	Local Sumenep	Dering I	Local Sumenep	HJ 21
Moisture (%)	6.32 ± 0.33	6.83 ± 0.31	8.59 ± 0.09	8.46 ± 0.13
Protein (% dw)	38.24 ± 0.87	39.67 ± 0.45	9.42 ± 0.52	9.69 ± 0.71
Ash (% dw)	5.56 ± 0.57	5.19 ± 0.39	0.92 ± 0.04	1.45 ± 0.32
Fat (% dw)	18.46 ± 0.62	17.88 ± 0.74	4.99 ± 0.32	4.32 ± 0.33
Carbohydrate (% dw)	37.76 ± 0.62	37.27 ± 0.81	84.68 ± 0.85	84.55 ± 0.63
Amylose (% dw)	2.12 ± 0.07	2.12 ± 0.13	21.25 ± 0.68	19.41 ± 0.57

Soybean seeds also showed higher contents of ash relative to those of corn (Table 1). A slight difference in ash content between two soybean varieties and two corn varieties was predominantly due to genetic factors, as they were planted in the same exact location. The effect of location can be seen for Dering 1, which showed a slightly higher ash value (5.74% dw) when grown in Malang, East Java [7]. A previous study revealed a wider range of ash content (1.00%–2.90%) found in nine corn varieties [69] compared to the present study. Similarly, soybeans contained higher fat levels than corn (Table 1). This result was consistent with an earlier study [70]. Besides being known as a good source of protein, soybeans are also rich in excellent lipids [71]. Slightly higher fat contents were observed for both improved soybean and corn varieties than for local varieties, following their protein contents. Typically, protein and fat contents are negatively correlated, as observed in soybeans [8,72] and corn [73]. Dering 1, harvested in another region (Malang), showed slightly lower fat content, ca. 17.24% dw [7], relative to this study. In comparison, the corn fat amounts were within the range (2.20%–5.70%) reported for nine Indonesian corn varieties [73].

As cereals, corn had a much higher carbohydrate content than soybean (Table 1). The local corn variety showed a slightly greater amount of carbohydrates, while it was the same for both soybean varieties. Soybean comprises approximately 25% carbohydrates [74], while corn contains around 74%–80% [75]. The amounts of carbohydrate determined in the present study were greater than those of four soybean varieties collected from Brazil, ca. 25.3%–27.60% dw [76]. The present study also showed greater carbohydrate contents of both corn varieties compared to nine Indonesian varieties (66.00%–76.30%) reported by Widowati [69], suggesting that genetics and growing environments considerably affect the carbohydrate content. Similarly, higher contents of amylose were also recorded for corn relative to soybean, as amylose is a component of carbohydrate (starch). Starch normally accounts for 70%–75% of the corn kernel, which greatly dictates its functional properties [77]. Both corn varieties belonged to the non-waxy type, which normally contains ≥23% amylose, while it is 4%–7% for the waxy type [77–79].

3.3. Physical properties of corn and soybean flours

The bulk density of soybean and corn flours was significantly affected by seed variety and soaking time ($p < 0.05$) (Tables 2 and 3). The highest value was observed in soybean flour prepared from the improved variety (Dering 1) without soaking. Such treatment also showed the highest value of corn flour bulk density derived from both varieties. The longer the soaking time, the smaller the bulk density noted in both soybean and corn flours. Soaking is greatly associated with water absorption and diffusion into the seed intercellular spaces, causing enlargement of the space, followed by cell wall expansion and disruption. Simultaneously, losses of cellular soluble solids (2%–19%) may occur through leaching out into the soaking water, depending upon the soaking temperature, time, type, and defect of the seed [80,81]. Such lost soluble solids mainly consist of carbohydrates and protein (80%–91%), pigments, acidic compounds, vitamins, minerals, and anti-nutritional factors, such as phytate, trypsin inhibitors, and hemagglutinins [80–82], resulting in a lower weight of the seed after drying and ultimately reducing the bulk density of the flour. Bulk density is a measure of flour heaviness and is normally influenced by the particle size [83]. Soaking may also increase the seed porosity (due to a volume development) along with a decrease in bulk density. A previous study on African yam beans soaked for 9 h revealed that the porosity increased from 48.33% to 70.30%, while the bulk density decreased from 0.80 to 0.64 g/mL [84]. Bulk density is an essential variable for determining flour handling, packaging requirements, and application in the food industry [83]. In this study, both soybean and corn flours obtained from the soaked seeds exhibited lower values of bulk density and moisture, thus requiring a larger packaging volume per unit weight compared to the unsoaked flour. Flour with low bulk density is an advantage for formulations of infant food [85].

Significant effects of seed variety and soaking time on the whiteness levels of both soybean and corn flours are presented in Tables 2 and 3. Longer soaking time resulted in a whiter color of soybean flour. This may be due to leaching of the natural pigments existing in the soybean seed coat and cotyledon, like chlorophyll, flavonoids, and yellow pigments (xanthophylls and carotenes), into the soaking water [82]. Losses of such pigments were not measured in this study; however, an earlier study noted a significant decrease in the lightness (L*) of the soaking water after 120 min, but the greenness (a*) and yellowness (b*) increased [82,86], reflecting the dissolution of such pigments during soaking.

Table 2. Bulk density, whiteness, and yield recovery of soybean flour pretreated with different soaking times.

Variety	Soaking time (h)	Bulk density (g/L)	Whiteness (%)	Yield recovery (%)
Local Sumenep	0	745.70 ± 3.70^{b}	62.20 ± 0.55^{d}	51.05 ± 1.62^{cd}
	24	654.60 ± 1.00^{c}	67.40 ± 0.70^{c}	49.81 ± 1.62^{de}
	48	582.70 ± 0.95^{e}	67.50 ± 2.05^{c}	48.63 ± 1.90^{e}
	72	563.70 ± 2.55^{g}	68.80 ± 0.45^{bc}	46.09 ± 1.62^{f}
Dering I	0	757.60 ± 0.55^{a}	67.90 ± 0.10^{bc}	54.81 ± 1.10^{a}
	24	588.00 ± 5.45^{d}	69.20 ± 0.30^{b}	53.57 ± 1.10^{ab}
	48	569.20 ± 5.05^{f}	72.20 ± 0.90^{a}	52.19 ± 1.10^{bc}
	72	550.50 ± 4.60^{h}	71.80 ± 0.40^{a}	49.84 ± 1.10^{cde}

Values within the same column followed by different letters are significantly different ($p < 0.05$).

Table 3. Bulk density, whiteness, and yield recovery of corn flour pretreated with different soaking times.

Variety	Soaking time (h)	Bulk density (g/L)	Whiteness (%)	Yield recovery (%)
Local Sumenep	0	795.20 ± 1.10^{a}	50.90 ± 0.85^{a}	43.09 ± 0.14^{f}
	24	732.60 ± 3.27^{b}	51.80 ± 1.18^{a}	46.53 ± 1.65^{e}
	48	727.10 ± 1.81^{b}	48.90 ± 1.51^{b}	51.16 ± 1.39^{d}
	72	727.30 ± 6.36^{b}	51.30 ± 0.50^{a}	50.59 ± 0.88^{d}
HJ 21	0	787.40 ± 4.90^{a}	40.50 ± 0.65^{d}	56.45 ± 0.92^{c}
	24	712.00 ± 6.81^{c}	41.90 ± 1.76^{cd}	58.32 ± 0.92^{b}
	48	691.80 ± 7.40^{d}	42.90 ± 1.00^{c}	63.97 ± 0.35^{a}
	72	687.60 ± 9.12^{d}	42.70 ± 1.07^{c}	64.49 ± 0.45^{a}

Values within the same column followed by different letters are significantly different ($p < 0.05$).

Similarly, the whiteness of corn flour tended to increase with longer soaking time, even though it was not significant for the local variety. About 18% and 16% reduction of lutein and zeaxanthin were previously reported for 24-h soaking of corn seeds due to oxidation [87]. Also, a 7% loss of β-carotene, α-carotene, and β-cryptoxanthin was observed during 24-h soaking and subsequent wet milling [88] due to fatty acid oxidation and carotenoid bleaching associated with endogenous lipase and lipoxygenase activities [89]. In addition, soybeans and corn normally contain polyphenolic compounds [90], which may degrade during soaking, enhancing the flour brightness [91]. An increase in flour whiteness was also seen for pre-soaking the decorticated sorghum seeds due to a decrease in tannin content [39].

Different types and amounts of natural pigments, particularly the yellow pigment associated with the varietal/genetical origin of soybean, may also contribute to differences in flour whiteness.

This can be seen from the initial flour color of the improved variety (Dering 1) treated without soaking, which was whiter than that of local Sumenep, notably giving a whiter flour color. Conversely, corn flour prepared from the local Sumenep variety showed greater whiteness than that of the improved variety (HJ 21). This may be due to differences in the initial color of the seeds: light yellow for local Sumenep and orange for HJ 21.

Table 3 shows that the flour whiteness of both corn varieties tended to increase along with soaking time; however, it was not significant for the local Sumenep variety treated with 0, 24, and 72-h soaking. These results suggest that there is no significant change in the color of the corn flour produced from 0–72 h soaking treatments. The exception seen in the 48-h soaking may be due to differences in pigment intensity of the corn seed samples randomly taken from this treatment. Meanwhile, the flour of the HJ 21 variety prepared after 0, 24, and 48-h soaking presented similar flour whiteness, but it was significantly different after 72 h, suggesting that leaching or dissolution of the pigment (orange) into the soaking water occurred slowly.

The yield recovery of soybean flour significantly declined with longer soaking time, and higher values were obtained for Dering 1 relative to the local Sumenep variety (Table 2). This reduction in yield recovery may be related to the decrease in seed weight due to loss of protein, ash, and carbohydrate during soaking ($p < 0.05$) (Table 4). A previous study recorded a decrease in dried seed yield recovery from 77.80% to 70.71% after 9-h soaking [92]. According to economic calculations, high flour yield recovery would be more profitable, and minimal losses of flour nutrients during soaking are desired. Table 2 shows that the flour yield recovery for 24-h soaking was similar to that of 48-h soaking for both varieties; thus, 24 h is chosen as a proper soaking time for soybean seed with a value of 49.81% and 53.57% for the Local Sumenep and Dering 1 varieties, respectively. Gozalli & Nurhayati [93] reported slightly lower values of soybean flour yield recovery obtained from two improved varieties, namely Anjasmoro (48.50%) and Baluran (51.08%), in which the seeds were pretreated with 3 h of soaking.

Both corn varieties exhibited greater values of yield recovery with longer soaking time (Table 3). The HJ 21 variety showed higher values than those of the local Sumenep variety. Soaking changes the hard part of endosperm (horny endosperm) of the seeds to become soft (floury endosperm); thus, they are easier to grind and yield higher recovery [94]. Horny endosperm normally consists of 1.5%–2% more protein and exhibits a thicker protein matrix compared to the floury endosperm, which is softer and easier to break relative to the horny endosperm [95]. These differences in endosperm constituents are dictated by the separation capacity of the starch granules from the protein matrix. The adhesion level between the starch and protein matrix likely influences the corn hardness [95]. Soaking facilitates starch separation, followed by decreasing the seed hardness; thus, finer particles will be obtained during milling. Aini et al. [46] also reported a significant increase in corn flour yield recovery after pretreating the seeds with soaking for 60 h relative to 20 and 40 h. However, they observed a decrease in yield recovery after 80 h due to more leaching of the seed chemical components into the soaking water. In this study, the yield recovery after 48-h soaking was not significantly different from that of 72 h, and no difference in chemical composition was noted (Table 5); thus, 48 h was chosen as the optimal soaking time for corn seed. The yield recoveries found for 48-h soaking (51.16% and 63.97% for the local Sumenep and HJ 21 varieties, respectively) were greater than the value (49.50%) for 60-h soaking [46].

3.4. Chemical composition of soybean and corn flours

In this study, soaking facilitated the removal of the soybean seed coat, the pericarp, and the germ of the corn kernel. This may occur due to absorption or hydration of water by the seed until it achieves the equilibrium moisture content, and the texture becomes soft. Complete hydration for soybean seeds by soaking at 37 °C occurs after 6 h, with approximately 140% of the initial weight [96]. As a consequence, the moisture content of the soaked seed remarkably increases. After soaking for 12 h, chickpeas, lentils, and beans showed a moisture increase from 10.46%–12.22% to 66.78%–73.06% [97]. However, Tables 4 and 5 show that the longer the soaking time, the lower the moisture content of the flour, suggesting that both flours prepared from the soaked seeds had lower moisture content than the unsoaked seeds. Penetration of water into the intercellular space of the seeds, followed by solubilization and leaching of soluble solids into the soaking water, causes loss of the seed mass integrity [80]. In soybean seeds, this leaching process is mainly associated with the loss of soluble carbohydrates, such as sucrose and raffinose family oligosaccharides, which contributes to a reduced mass integrity and facilitates an effective moisture removal during drying. Thereby, the seed intercellular moisture would be more easily evaporated during subsequent oven-drying after soaking, giving a lower moisture content of the final flour. Similar findings were also obtained for soybean flour pretreated with seed soaking, which had a moisture content of 8.80%, 6.80%, 6.90%, and 6.70% for 0, 24, 48, and 72-h soaking, respectively [98], while it was similar for maize flour pretreated with 0-h soaking (10.10%) compared to 48-h soaking (10.50%) [75]. Another reason may be due to the occurrence of intermolecular cross-linking among hydrophilic molecules in the seeds due to higher temperature, resulting in reduced hygroscopic capacity of the flour [75].

In terms of variety, both soybean varieties showed similar flour moisture after 48-h soaking treatment (Table 4), while it was the 72-h soaking for both corn varieties ($p < 0.05$) (Table 5). Seed structure, shape, size, porosity, and coat thickness, as well as the chemical composition that dictates the water absorption and penetration during soaking [87], may determine the final moisture of the flour obtained after the oven-drying and milling process. The local corn variety had greater seed bulk density and hardness relative to the improved variety (Figures 1 and 2); thus, a longer time is likely required to absorb water and equilibrate, giving a higher moisture content after 48 h of soaking (Table 5).

The drying process of the soaked seeds also considerably determined the amount of moisture in the flour. As the oven-drying temperature and time applied in this study were the same, such seed physical and chemical characteristics may also affect the drying process (moisture evaporation) and dictate the flour moisture content. Low moisture content is essential to minimize the flour deterioration during storage due to microbial growth and chemical reactions, resulting in prolonged shelf life [99]. The flour moisture contents investigated in this study have met the national standard quality, with a maximum of 10% for soybean and corn flours [100,101], reflecting the effectiveness of oven-drying as one of the most economical and widely used methods in the food processing industry [102].

The ash contents of soybean flour significantly decreased following the soaking time, with the lowest value noted after 72-h soaking (Table 4). Slightly higher ash contents were seen in Dering 1 relative to the local variety (Table 4), according to the initial contents in their seeds (Table 1). Ash content represents the mineral composition of the seeds, and during soaking, some minerals are lost due to leaching into the soaking water. About 5%, 5%, and 4% reduction of Fe, Zn, and Ca, respectively, were noted during soaking of soybean for 12 h [103]. Another study also reported that the ash content of some legumes (peas, lentils, chickpeas, and beans) and cereals (oat and wheat) reduced by 6.91%–17.90% and 3.00%–6.90%, respectively, during 12-h soaking [97].

In contrast, corn flour showed a different response to soaking time. The ash content increased after 24 and 48 h of soaking for both corn varieties, followed by a decrease at 72 h (Table 5). The initial increase in ash content may be explained by a relative concentration effect, where the loss of soluble organic components during early soaking stages increased the proportion of minerals in the dry matter. However, prolonged soaking for 72 h likely enhanced mineral diffusion into the soaking water, resulting in a reduction in ash content. The relatively harder kernel structure of corn compared to soybean may have limited water penetration and mineral loss during the early soaking stages, delaying leaching effects until extended soaking occurred. Despite these changes, the ash contents of both soybean and corn flours remained below the maximum limits specified by national quality standards for soybean flour (6% ww) and corn flour (1.5% ww) [100,101].

The fat contents of soybean and corn flours slightly decreased after 48-h soaking, but then increased with prolonged soaking up to 72 h (Tables 4 and 5). Dering 1 soybean variety had a slightly greater amount of fat relative to the local variety, while it was similar for both corn varieties, following their initial values (Table 1). El–Safy et al. [97] also found a reduced fat amount in some legume seeds after soaking for 12 h due to lipase activity. However, Suri & Tanumihardjo [88] noted an increase in fat content of soybean flour from 22.60% up to 25.50% and 27.20%, respectively, after pretreating the seeds with 24 and 48-h soaking, as well as in maize flour from 11.40% up to 11.80% after 48-h soaking [75]. Leaching of solid materials into the soaking water may result in a greater proportion or concentration of fat per unit weight of the flour [75].

A significant decrease in protein content was noted for soybean flour pretreated with soaking, both for the local and Dering 1 varieties, which was about 4.80% and 11.40%, respectively, after 72 h (Table 4). Loss of soluble protein, particularly albumin, may occur during seed soaking, thereby decreasing the amount of protein [80]. Soybean protein predominantly consists of globulin (50%–70%) and albumin (8%–20%) [104]. Globulin, which is primarily not soluble in water, may also decrease during soaking, concerning its structure, which is facilitated with hydrophilic N-terminal amino acid groups on the molecule's surface, whereas hydrophobic groups exist inside the molecules. These hydrophilic properties promote water absorption up to 180% of the seed dry matter mass up to 12-h duration, resulting in swollen seeds. This physical change is subsequently followed by biochemical processes, including protein hydrolysis in relation to the activity of preexisting endoenzymes in the seeds, leading to the accumulation of albumin fraction and peptide residues [105]. As they are water-soluble, they would be easily released into the soaking water. In addition, natural fermentation may take place after 48 h of soaking, associated with the growth and activity of multiple microorganisms, resulting in variable metabolisms, including enzymatic hydrolysis of protein that could contribute to decreasing the protein content [98]. During soaking for 24 and 72 h, Agume et al. [98] also reported 5% and 22% reduction, respectively, in total protein of soybean flour.

Table 5 shows that the protein content of soaked corn flour is similar to that of unsoaked flour. However, the results show an increase in protein in the local Sumenep variety over time (48–72 h), while HJ-21 decreased at 24 h but increased at 48–72 h. The initial decrease in HJ-21 is likely due to the harder texture of corn kernels compared to soybeans, resulting in minimal protein release into the soaking water. Sayar et al. [80] reported only a 0.08% protein loss after 15 h of chickpea soaking and observed no significant increase in soluble protein in sorghum during soaking/fermentation, as the major corn proteins, namely prolamin (60%) and glutelin (34%), are water-insoluble. The increase in protein after 48 h in both varieties was due to enzymatic hydrolysis/depolymerization of proteins by microbial activity during spontaneous fermentation, resulting in higher soluble protein (0.9% dw).

Table 4 shows that the carbohydrate contents of both soybean flours significantly decreased during soaking, and lower values were seen in the improved variety (Dering 1). This decrease in carbohydrates is mainly due to starch (amylose) leaching into the soaking water. Sayar et al. [80] recorded 2.51% of total solid loss during 15-h soaking of chickpea, and carbohydrate accounted for 88% of such loss, followed by protein (3%). Meanwhile, Wang et al. [96] recorded a total solid loss of 10% after 24-h soaking of soybean. In addition, natural or spontaneous fermentation may occur, particularly after 24 h of soaking, due to the activity of molds and yeasts with amylolytic enzymes that hydrolyze starch into soluble sugars. These sugars are further fermented into lactic acid by lactic acid bacteria, which are typically present after 36 h of soaking [75,105]. This results in a lower carbohydrate content of the soaked soybean seeds. Sour taste/aroma, unclear soaking water, and pH reduction indicate the proliferation of lactic acid bacteria and their metabolic activities during soaking [39].

Table 4 presents a significant increase in amylose content of soybean flours by 1.00% during 72-h soaking, and slightly greater values were determined for Dering 1 relative to the local Sumenep variety. It is assumed that prolonged soaking may lead to starch hydrolysis, including depolymerization of the outer amylopectin branch chains, converting its structure into linear chains similar to amylose, thus increasing the apparent amylose content [106]. A previous study reported the presence of yeast, molds, and lactic acid bacteria as the primary microorganisms in soaking water at 15 and 35 °C [107]. Organic acids produced by these lactic acid bacteria also contribute to amylopectin depolymerization, resulting in linear residues. These linear chains form a significant blue color when reacting with iodine and are detected as amylose [108].

Conversely, the carbohydrate contents of corn flours derived from two varieties were likely not significant before and after pretreatment with soaking (Table 5). Ntso et al. [75] observed a decrease in pH from 6.54 to 6.39 during soaking of corn seeds for 48 h as a result of lactic acid bacteria activity, predominantly *L. fermentum* and *L. brevis*, that convert the soluble sugar into lactic acid through fermentation. Such soluble sugars are produced by molds and yeast, which were preliminarily present in the soaking water up to 36-h soaking [106]. The amount of soluble sugar was noted to be the same as the initial content up to 24-h soaking, but significantly decreased by 50% after 48 h. Nevertheless, such significant changes in carbohydrates were not seen in this study, which showed only a trace decrease in fat content and relatively similar protein content after soaking (Table 5).

The amylose content of the local variety of corn flour was not significantly different, although the 48-h soaking treatment resulted in slightly decreased values, while the average value was similar for all soaking treatments. The amylose content of corn in all soaking treatments was in the 18.32%–21.53% range. Similarly, in the improved variety HJ 21, soaking did not cause a difference in amylose content (Table 5). Arifin et al. [106] recorded a decrease of 1.15% in the amylose content of non-glutinous corn flour after soaking for 72 h. Following the carbohydrate content, it is likely that the dissolution of amylose and the debranching process of amylopectin into a linear starch structure (amylose) occurred at a lower rate for both corn flours compared to soybean flour.

3.5. Pasting properties of soybean and corn flours

The pasting properties of flour are essential for understanding its potential applications in commercial food processing. Table 6 presents the pasting properties of soybean and corn flours from both local and improved varieties pretreated with different soaking times. The first property is gelatinization temperature, which represents the temperature at which starch granules begin to swell, lose their crystalline structure, and increase the viscosity of the surrounding medium [109]. Soybean flour exhibited a higher gelatinization temperature, ranging from 85.40 to 93.00 °C, relative to corn flour (72.35–75.65 °C). This is related to a much higher content of protein and fat in soybean flour, while the amounts of carbohydrate and amylose were much lower compared to those of corn flour (Tables 3 and 4). During the gelatinization process, starch has an important role in water absorption and swelling of the granules. Therefore, the presence of non-starch components, particularly protein and fat in soybean flour, would interfere with its capacity to absorb water [65], thus requiring a longer time and higher temperature to be gelatinized. Protein, in particular, can compete with starch in absorbing water, resulting in a weak starch–water interaction [110]. Also, the formation of an amylose–lipid complex may inhibit the penetration of water into the starch granules, granule swelling, and solubilization of amylose [110].

Soybean flour prepared from local and improved varieties, as well as different soaking times, showed a varied gelatinization temperature. Soaking time likely accelerated the onset of gelatinization and increased the gelatinization temperatures in soybean flour slurry derived from Local Sumenep. However, such a phenomenon was not seen for the Dering 1 variety, even though the gelatinization temperatures were not detected for the flour that underwent 0 and 24-h soaking times. High protein and fat contents of the flour existing in these two soaking treatments may contribute to such findings, in addition to their differences in starch chain structure and composition (amylose and amylopectin) [111]. Aini et al. [46] revealed that the presence of fat would increase the gelatinization temperature as the amylose-fat complex tends to prevent excessive starch granule development. Thus, gelatinization might occur at a temperature higher than the range applied in this study, or no gelatinization actually occurs. Meanwhile, similar gelatinization temperatures of corn flours prepared from two varieties were noted for different soaking times, likely due to insignificant changes in chemical composition, particularly carbohydrate and amylose of the flour (Table 4). Higher gelatinization temperatures (81.70–88.50 °C) of maize flour pretreated with 20–80 h soaking time were reported by Aini et al. [46], suggesting that maize cultivar, origin, and flour processing method may contribute to such differences.

Peak viscosity (PV) refers to the highest viscosity attained during gelatinization and represents the ease of cooking and the strength of the starch gel formed from the flour during processing [94]. Table 6 shows that soybean flours had quite low peak viscosity, meaning that there was no change in viscosity during heating. This may be due to low contents of carbohydrate and amylose in soybean flour (Table 3) as well as the complexity of starch–fat–protein interaction, which may alter the starch pasting and gelatinization kinetics [98,110]. Similarly, no peak viscosity of both soaking treatments (0 and 24 h) for the Dering 1 variety can be visualized following their undetected gelatinization temperatures. This implies that no gelatinization or quite a low rate of gelatinization might occur during the heating of the soybean flour slurry.

Table 4. Chemical composition of soybean flour derived from two varieties and treated with different soaking times.

Variety	Soaking time (h)	Moisture (%)	Ash (% dw)	Fat (% dw)	Protein (% dw)	Carbohydrate (% dw)	Amylose (% dw)
Local Sumenep	0	7.25 ± 0.06^{a}	5.21 ± 0.07^{a}	19.22 ± 0.02^{f}	43.36 ± 0.24^{b}	32.12 ± 0.74^{c}	1.85 ± 0.03^{e}
	24	5.17 ± 0.01^{c}	4.48 ± 0.03^{e}	19.63 ± 0.04^{e}	40.84 ± 0.24^{c}	32.17 ± 0.13^{c}	2.36 ± 0.11^{cd}
	48	4.41 ± 0.08^{e}	4.40 ± 0.07^{ef}	20.82 ± 0.01^{c}	40.22 ± 0.14^{d}	30.89 ± 0.26^{d}	2.20 ± 0.13^{d}
	72	4.80 ± 0.03^{d}	4.30 ± 0.02^{f}	22.21 ± 0.11^{b}	38.53 ± 0.56^{e}	26.60 ± 0.13^{f}	2.86 ± 0.02^{b}
Dering I	0	$6.14\ 0.31^{b}$	5.10 ± 0.11^{ab}	18.97 ± 0.11^{g}	45.05 ± 0.50^{a}	33.03 ± 0.18^{b}	2.22 ± 0.03^{d}
	24	4.32 ± 0.01^{e}	5.05 ± 0.03^{bc}	17.79 ± 0.02^{h}	43.28 ± 0.48^{b}	35.36 ± 0.38^{a}	1.69 ± 0.17^{e}
	48	4.32 ± 0.06^{e}	4.95 ± 0.13^{c}	20.18 ± 0.06^{d}	39.00 ± 0.35^{e}	28.50 ± 0.48^{e}	2.45 ± 0.25^{c}
	72	5.13 ± 0.09^{c}	4.69 ± 0.01^{d}	22.88 ± 0.18^{a}	38.78 ± 0.16^{e}	23.45 ± 0.26^{g}	3.21 ± 0.04^{a}

Values within a column followed by different letters are significantly different ($p < 0.05$).

Table 5. Chemical composition of corn flour derived from two varieties and treated with different soaking times.

Variety	Soaking time (h)	Moisture (%)	Ash (% dw)	Fat (% dw)	Protein (% dw)	Carbohydrate (% dw)	Amylose (% dw)
Local Sumenep	0	7.30 ± 0.00^{c}	1.30 ± 0.04^{b}	4.60 ± 0.09^{bc}	8.47 ± 0.35^{d}	84.50 ± 0.25^{a}	20.04 ± 1.04^{ab}
	24	7.43 ± 0.23^{c}	1.36 ± 0.19^{ab}	4.17 ± 0.15^{d}	8.73 ± 0.26^{bcd}	84.60 ± 0.62^{a}	20.71 ± 0.17^{ab}
	48	7.20 ± 0.30^{c}	1.45 ± 0.08^{ab}	4.39 ± 0.19^{cd}	9.09 ± 0.65^{abcd}	83.18 ± 0.72^{b}	18.32 ± 3.21^{b}
	72	6.25 ± 0.21^{d}	1.35 ± 0.19^{ab}	5.07 ± 0.10^{a}	8.58 ± 0.10^{cd}	84.73 ± 0.30^{a}	21.01 ± 0.46^{a}
HJ 21	0	8.80 ± 0.01^{a}	1.40 ± 0.16^{ab}	4.65 ± 0.07^{b}	9.38 ± 0.20^{ab}	83.09 ± 0.32^{b}	19.87 ± 0.12^{ab}
	24	8.03 ± 0.58^{b}	1.48 ± 0.35^{ab}	4.25 ± 0.20^{d}	9.22 ± 0.50^{abc}	83.73 ± 1.07^{ab}	19.63 ± 1.57^{ab}
	48	6.58 ± 0.43^{d}	1.68 ± 0.25^{a}	4.66 ± 0.06^{b}	9.52 ± 0.40^{a}	83.03 ± 0.54^{b}	20.36 ± 0.72^{ab}
	72	6.37 ± 0.22^{d}	1.37 ± 0.09^{ab}	5.02 ± 0.16^{a}	9.61 ± 0.26^{a}	82.91 ± 0.56^{b}	21.53 ± 0.51^{a}

Values within a column followed by different letters are significantly different ($p < 0.05$).

Table 6. Gelling properties of soybean and corn flours pretreated with different soaking times.

Variety	Soaking time (h)	Gelatinization temperature (°C)	Peak viscosity (cP)	Hold viscosity (cP)	Final viscosity (cP)	Breakdown viscosity (cP)	Setback viscosity (cP)
Soybean:							
Local	0	85.40	2.50	-	25.00	-	22.50
Sumenep	24	77.50	2.50	-	20.00	-	17.50
	48	93.00	2.50	-	27.50	-	25.00
	72	92.80	2.50	-	30.00	-	27.50
Dering 1	0	-	-	-	-	-	-
	24	-	-	-	-	-	-
	48	92.60	2.50	-	25.00	-	22.50
	72	87.35	2.50	-	30.00	-	27.50
Corn:							
Local	0	75.65	192.50	662.50	2147.50	−470.00	1485.00
Sumenep	24	73.50	303.33	1725.00	4977.50	−1421.67	3252.50
	48	72.35	181.66	903.30	2476.70	−721.64	1572.70
	72	73.85	223.33	691.70	2181.70	−468.40	1490.00
HJ 21	0	75.50	117.50	960.00	3262.50	−842.50	2302.50
	24	73.75	201.67	947.50	2607.50	−745.83	1660.00
	48	72.35	126.67	506.70	1655.00	−380.03	1148.30
	72	74.10	143.33	422.50	1250.00	−279.17	827.50

In contrast, corn flours showed a decrease in peak viscosity with prolonged soaking, except for the 24-h soaking, which exhibited the highest value. Zaidul et al. [112] reported a negative correlation between peak viscosity and amylose content. Soaking leads to starch leaching, especially amylose, the amorphous starch constituent, as a result of enzymatic hydrolysis and starch degradation, causing a diminished peak viscosity [46]. Natural fermentation, including soaking, previously demonstrated a reduction in starch viscosity of corn flour [65]. A similar finding was also noted for fermented corn flour with *L. bulgaricus* and *L. casei* [94]. Modified corn flour with lower peak viscosity may broaden its application in various food products, including starch-based infant foods. In contrast, flour with high peak viscosity often exhibits weak paste stability as viscosity rises sharply to a peak and then rapidly declines due to the disruption of cohesive forces, leading to structural breakdown [113].

Hold viscosity (HV) shows the slurry viscosity measured at 95 °C, while breakdown viscosity (BV) is the difference between peak viscosity (PV) and hold viscosity (HV) when held at 95 °C for 10 min [114]. HV is the ability of starch paste to withstand shearing force at 95 °C. Table 6 shows the absence of HV and BV data for all soybean flours. Meanwhile, relatively high HV of both corn flours was noted, reflecting that the viscosity considerably increased after achieving peak viscosity. However, extending soaking time resulted in lower HV values of corn flours. HV is influenced by various physical changes occurring in the tested material. Soaking increases the water content of the material, causing the starch granules to become hydrated and easily break down when stirred at high temperatures. This resulted in a decrease in HV, which decreased with longer soaking times. Annealing during the soaking process causes the rearrangement of starch crystals; as a result, longer soaking times result in more organized starch crystals, which can result in lower HV. If fermentation occurs during soaking, degradation of amylose and amylopectin may take place, and heating reduces gel strength and consequently decreases HV. In soybean flours, HV was not detected due to the low carbohydrate content, which was insufficient to induce measurable viscosity changes during heating at 95 °C. Further heating at 95 °C for 10 min would normally weaken the swollen starch granules and partly break them into polymers and aggregates, leading to a decrease in viscosity due to amylose leaching and an increase in BV. Both flours markedly exhibited a decline in BV along with longer soaking time, showing the lowest value in the 72-h treatment (Table 5). A flour slurry with low BV normally has high stability during heating. Although it was not significant, slightly higher amylose content of both corn flours pretreated with 72-h soaking may contribute to such a finding [114].

Final viscosity (FV) measured at 50 °C normally shows an increase in viscosity, reflecting the slurry's ability to form a gel [115], while setback viscosity (SV) is the difference between FV and HV. SV exhibits the starch gel tendency to retrograde upon cooling and gel stability [114], suggesting that high SV would give a firm and stable gel. Soybean flours demonstrated extremely low SV, ranging from 17.50 to 27.50 cP (Table 6), reflecting that the gel formed was very weak and runny. As previously discussed, the presence of high amounts of protein and fat in soybean flour alters the starch gelatinization behavior. Soaking slightly increased the SV, which might be related to the higher content of amylose with longer soaking time (Table 3). Similar results of SV (6–26 cP) were also recorded by Agume et al. [98] for soybean flours that underwent 0–72 h soaking treatments. These findings suggest the limitation of single soybean flour application for gelatinized food products, such as porridge and infant foods, puddings, pasta, and bakery products. Therefore, soybean flour is better applied as a composite ingredient, blended with other starchy flours, like cereals, roots, and tubers, particularly to improve the nutritive value, functional properties, and sensorial attributes of the products [116–118].

Conversely, corn flours showed a significant increase in FV, resulting in a high SV (Table 6). Higher FV was observed for the local Sumenep variety relative to Dering 1, as illustrated in Figure 5, suggesting that the flour had strong retrogradation capacity and a more stable gel. The rate of retrogradation depends on many factors, including the amylose-to-amylopectin ratio, temperature, starch concentration, and the presence of organic and inorganic compounds [119]. Longer soaking time (0 up to 72 h) decreased the FV and SV of HJ 21 corn flour by 61.70% and 64.10%, respectively, resulting in lower thickening behavior of the gel compared to the unsoaked flour. This indicates that the HJ 21 variety benefits from extended soaking to improve the starch functionality. However, the values of FV and SV obtained from such soaking treatments were similar for local Sumenep corn flour (Table 6), suggesting that a prolonged soaking time of more than 72 h applied in this study was likely required to lower its FV and SV. Based on its gelling properties, corn starch can be used alone as an ingredient in starch-based food products, such as porridge, pudding, bread, and noodles. Nevertheless, differences in peak, hold, and final viscosities in relation to varietal/genetic factors might need further soaking time optimization. This is essential as soaking can also reduce cooking time, improve digestibility, and enhance product acceptability, which is particularly valuable for the utilization of local food crops in rural areas. Furthermore, the simplicity and cost-effectiveness of water soaking as a pretreatment support its economic feasibility.

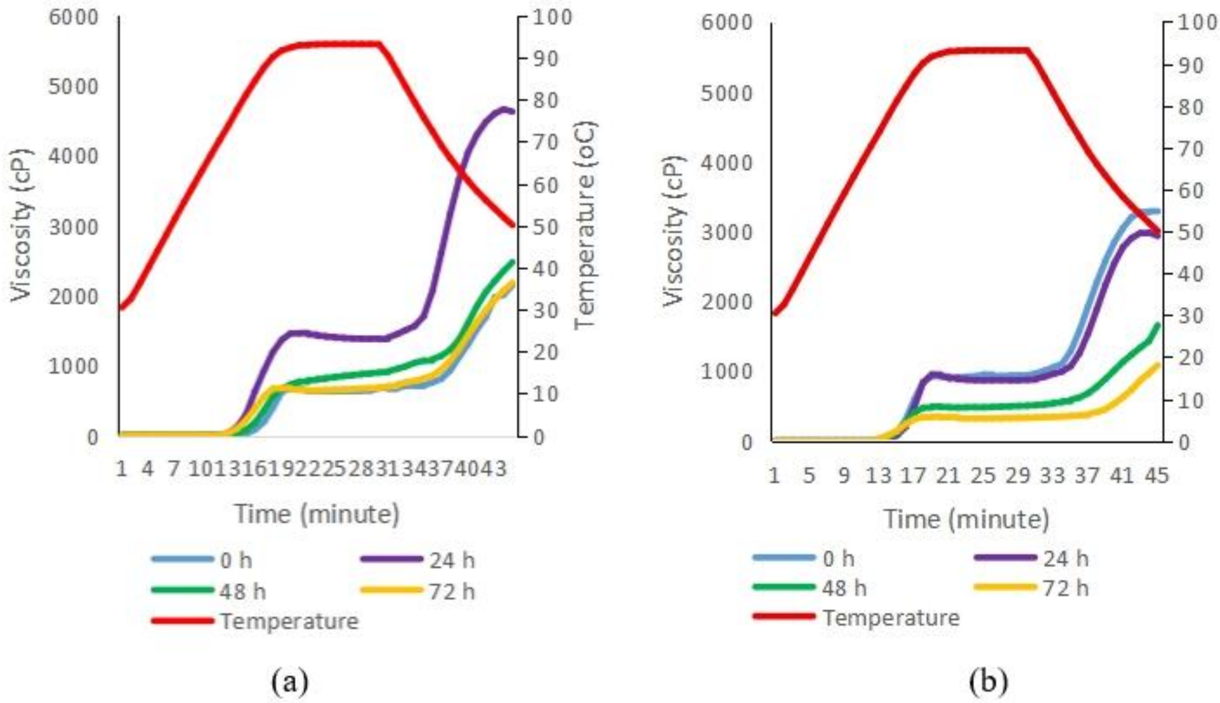

Figure 5. Visco-amylograph profiles of corn flour derived from the local Sumenep variety (a) and HJ 21 variety (b), pretreated with different soaking times.

3.6. Economic feasibility of soybean and corn flour processing

Table 7 shows the capital investment needed for purchasing the tools and machinery to produce soybean and corn flours at a home-scale processor. The largest cost component was associated with machinery procurement, particularly the cabinet dryer, which accounted for approximately 83.1%–85.0% of the total investment. A similar finding was reported by [120] for small-scale cassava flour production, in which approximately 80% of the total capital investment was allocated to the procurement of tools and machinery.

The total cost of soybean and corn flour production includes fixed and variable costs, where the variable costs consist of raw material expenses and other costs, such as packaging materials, electricity, water, and labor costs (Table 8). The highest proportion of standard production costs was attributed to the purchase of raw materials, accounting for 86.50% for soybeans and 78.30% for corn kernels. Based on the yield recovery of soybean flour presented in Table 2, we used the value obtained from Dering 1, an improved variety, for the proper 24-h soaking time (53.60%). Using a selling price of IDR 60,000 or 3.75 USD per kg at retail market price, the potential profit gained from normal soybean flour production with a capacity of 100 kg was approximately IDR 1,693,949 or 105.87 USD. The B/C ratio was 1.11, suggesting that soybean flour production can be developed as a profitable home-scale business, as for every IDR 1,000 spent on production costs, it will generate a profit of IDR 1,110.

Table 7. Capital investment for tools and machinery needed for running a home-scale production of soybean and corn flours.

Tools and machinery [1]	Price per unit (IDR000) [2]	Soybean flour				Corn flour			
		Normal investment		Adjusted investment (Sumenep case)		Normal investment		Adjusted investment (Sumenep case)	
		No. of unit(s)	Amount (IDR000)	No. of unit(s)	Amount (IDR000)	No. of unit(s)	Amount (IDR000)	No. of unit(s)	Amount (IDR000)
Manual soybean dehuller	2,631.50	1	2,631.50	1	2,631.50	-	-	-	-
Flour milling machine	3,185.00	1	3,185.00	1	3,185.00	1	3,185.00	1	3,185.00
Electric cabinet dryer (12 shelves)	13,935.00	1	13,935.00	0	0.00	1	13,935.00	0	0.00
Digital scale (40 kg)	205.00	1	205.00	1	205.00	1	205.00	1	205.00
Plastic sealer	234.00	1	234.00	1	234.00	1	234.00	1	234.00
80-mesh sieve	175.00	2	175.00	2	350.00	2	350.00	2	350.00
Drainer/strainer	52.00	5	52.00	5	260.00	5	260.00	5	260.00
Medium plastic tray	17.00	5	17.00	5	170.00	5	170.00	5	170.00
Big plastic basin	66.40	10	66.40	10	664.00	10	664.00	10	664.00
Big wood spoon	12.50	2	12.50	2	50.00	2	50.00	2	50.00
Bamboo tray	17.00	10	17.00	20	340.00	10	170.00	20	340.00
Plastic container box (150L)	250.00	6	250.00	6	1,500.00	6	1,500.00	6	1,500.00
Total investment (IDR000)			23,244.50		9,479.50		20,613.00		6,678.00

[1] Data for tools and machinery were collected during the preparation of flour.

[2] Based on the marketplace price when the study was conducted.

Table 8. Components of soybean and corn flour production cost and its economic feasibility [a)].

Description	Soybean flour						Corn flour					
	Standard production cost			Adjusted production cost (Sumenep)			Standard production cost			Adjusted production cost (Sumenep)		
	No. of units	Price per unit (IDR) [1)]	Amount (IDR)	No. of units	Price per unit (IDR) [1)]	Amount (IDR)	No. of units	Price per unit (IDR) [1)]	Amount (IDR)	No. of units	Price per unit (IDR) [1)]	Amount (IDR)
Fixed costs												
1. Depreciation cost [2)]	-	8,766 [4)]	8,766	-	4,235 [4)]	4,235	-	7,889 [4)]	7,889	-	3,244 [4)]	3,244
2. Maintenance cost [3)]	-	877	877	-	423	423	-	789	789	-	324	324
Total fixed costs (A)	9,643					4,658					8,678	3,258
Variable costs												
1. Soybeans (kg)	100	13,170 [5)]	1,317,000	100	13,170 [5)]	1,317,000	100	7,300 [5)]	730,000	100	7,300 [5)]	730,000
2. Packaging (1 kg)	65	313	20,345	65	313	20,345	57	313	17,841	57	313	17,841
3. Electricity and water	-	15,063	15,063	-	1,687	1,687	-	15,487	15,587	-	17,940	2,110
4. Labor	2	80,000	160,000	2	80,000	160,000	2	80,000	160,000	2	80,000	160,000
Total variable costs (B)			1,512,408			1,499,032			923,328			909,951
Total production costs (A + B)			1,522.051			1,503,690			932,006			913,209
Flour yield recovery (%)			53.6 [6)]			53.6 [6)]			64.0 [8)]			64.0 [8)]
Production (kg)			53.6			53.6			64.0			64.0
Price (IDR)			60,000 [7)]			60,000 [7)]			35,000 [9)]			35,000 [9)]
Revenue (IDR)			3,216,000			3,216,000			2,240,000			2,240,000
Income (IDR)			1,693,949			1,712,310			1,307,994			1,326,791
Revenue-cost (R/C) ratio			2.11			2.14			2.40			2.45
Benefit-cost (B/C) ratio			1.11			1.14			1.40			1.45

[a)] Calculated based on the capacity of 100 kg of soybean seeds or corn kernels per batch of production. [1)] Data collected from many sources throughout the study. [2)] Depreciation cost was estimated from the economic life of tools (1–5 years) and machinery (10–20 years) and respective price as listed in Table 7. [3)] Maintenance cost was calculated as 10% of depreciation cost. [4)] Assuming that the effective production time was 300 days per year. [5)] National average price for dry imported soybeans and corn kernel (for feed purpose) at a retail level in 2024 (Source: https://panelharga.badanpangan.go.id/) and converted into 1 USD at a rate of IDR 16,000. [6)] Soybean flour yield recovery of Dering 1variety with optimal 24-h soaking time (Table 2). [7)] The price was collected from one of the online marketplaces (Tokopedia) for organic soybean flour produced by Moringa Pangan Aman, Sleman Regency, as of May 29, 2024. [8)] Corn flour yield recovery of HJ 21 variety with optimal 48-h soaking time (Table 3). [9)] The price of corn flour was collected from one of the online marketplaces (Tokopedia) for "Mugo" commercial corn flour, as of May 29, 2024.

Taking into account the relatively low socio-economic conditions of most soybean farmers in the Sumenep region, particularly those with limited capital for soybean flour processing, the initial investment cost can be reduced by replacing the oven-drying method with sun-drying. This allows the electric oven to be excluded from the process (Table 7). In addition to the limited investment capital, sun-drying is also more feasible in this region due to the environmental temperature, which can reach up to 35 ºC on sunny days, especially during the dry season (June–November) [121]. Under such conditions, the drying process takes 3–4 days to complete. This would consequently reduce the capital investment (Table 7) and the flour production cost, particularly the equipment depreciation and maintenance costs, as well as the electricity cost (Table 8). A higher profit margin can be obtained with an R/C ratio of 2.14 and a B/C ratio of 1.14 (Table 8), reflecting that soybean flour production would be profitable and feasible in the Sumenep region.

Table 8 also indicates that home-scale corn flour processing is economically feasible and profitable for development. Using the highest yield recovery of corn flour for HJ 21 (improved variety) with a soaking time of 48 h, ca. 64.0% (Table 3), and a selling price of corn flour at the retail level of IDR 35,000 or 2.19 USD per kg, it is estimated that the potential profit would be approximately IDR 1,307,994 or 81.75 USD. The B/C ratio was 1.40, reflecting a generated profit of IDR 1,400 for every IDR 1,000 spent on the production cost. Similarly to soybean flour processing, replacing oven-drying with sun-drying would reduce capital investment and production costs, resulting in higher profit margins, with an R/C ratio of 2.45 and a B/C ratio of 1.45 (Table 8). Consequently, corn flour production represents a profitable and feasible business opportunity in the study area.

Soybean and corn flours can be used alone or as composite flours and blended with other flours to produce diverse food products, such as noodles, porridge, cakes, and bread [121–125], thereby promoting utilization diversity and supporting the availability of nutritious, affordable foods derived from local sources. Increased demand for these flours would ultimately stimulate greater production of both crops to meet raw material requirements.

4. Conclusions

Soaking as a pretreatment for soybean and corn flour production influenced the physicochemical and pasting properties of both local and improved varieties. Improved varieties exhibited higher flour yields than local varieties. Based on nutritional, physical, and functional properties, a 24-h soaking pretreatment was optimal for soybean seeds, whereas a longer duration (48 h) was more suitable for corn. Home-scale production of soybean and corn flours is economically feasible and profitable, as indicated by favorable B/C ratios, highlighting the potential for developing soybean and corn flour–based food products in the study area.

AI tools declaration

No Artificial Intelligence (AI) tools used in the creation of this article.

Acknowledgement

The author sthank Ir. Zainal Arifin, MP; Ita Yustina, STP, MP, and Mr. Jumadi for their assistance in carrying out this research, their technical support and for preparing the publication manuscript. Thank you to the Indonesian Ministry of Agriculture for providing funding for this research.

Conflict of Interest

The authors report there is no conflict of interest to declare.

Author contributions

Sri Satya Antarlina: Conceptualization, methodology design, investigation, validation, writing the original draft, supervision, review, and editing. Joko Susilo Utomo: Formal analysis, validation, writing the original draft, supervision, review, and editing. Erliana Ginting: Conceptualization, methodology design, validation, writing the original draft, supervision, review, and editing. Dian Adi Anggraeni Elisabeth: Data curation, formal analysis, investigation, validation, writing the original draft, review, and editing. Aniswatul Khamidah: Data curation, formal analysis, investigation, validation, writing the original draft, review, and editing. Indrie Ambarsari: Data curation, formal analysis, investigation, validation, writing the original draft, review, and editing. Heni Puwaningsih: Supervision, investigation, validation, writing the original draft, review, and editing. Siti Dewi Indrasari: Supervision, investigation, validation, writing the original draft, review, and editing. Ulyatu Fitrorin: Writing the original draft, formal analysis, data curation, visualization, review. Alit Pangestu: Formal analysis, validation, writing the original draft, visualization, review, and editing. Fitri Nur Kayati: Data curation, writing the original draft, formal analysis, visualization, review. Yessy Anna Pratiwi: Data curation, formal analysis, writing the original draft. Sugeng Pondang Sugiharto: Data curation, formal analysis, writing the original draft, review. Hozin Aziz: Data curation, formal analysis, writing the original draft.

References

1. Rouf Shah T, Prasad K, Kumar P (2016) Maize–A potential source of human nutrition and health: A review. *Cogent Food & Agric* 2: 1166995. https://doi.org/10.1080/23311932.2016.1166995
2. Siyuan S, Tong L, Liu R (2018) Corn phytochemicals and their health benefits. *Food Sci Hum Wellness* 7: 185–195. https://doi.org/10.1016/j.fshw.2018.09.003
3. Basson AR, Ahmed S, Almutairi R, et al. (2021) Regulation of intestinal inflammation by soybean and soy-derived compounds. *Foods* 10: 774. https://doi.org/10.3390/foods10040774
4. Kim IS (2021) Current perspectives on the beneficial effects of soybean isoflavones and their metabolites for humans. *Antioxidants* 10: 1064. https://doi.org/10.3390/antiox10071064
5. Ali W, Ahmad M, İftakhar F, et al. (2020). Nutritive potentials of soybean and its significance for humans health and animal production: A review. *Eurasian J Food Sci Technol* 4: 41–53.

6. Alaswad AA, Bo Song, Nathan WO, et al. (2021) Development of soybean experimental lines with enhanced protein and sulfur amino acid content. *Plant Sci* 308: 110912. https://doi.org/10.1016/j.plantsci.2021.110912
7. Kuswantoro H, Ginting E, Yusnawan E, et al. (2023) Agronomic performance, seed chemical composition, and bioactive components of selected Indonesian soybean genotypes (Glycine max [L.] Merr.). *Open Agric* 8: 20220229. https://doi.org/10.3390/agronomy10091315
8. Ginting E, Yulifianti R, Kuswantoro H, et al. (2018). Protein, fatty acid and isoflavone contents of soybean lines tolerant to acid soil. *J Korean Soc Int Agric* 30: 167–176. http://db.koreascholar.com/ article.aspx?code=357239
9. Yu JK, Moon YS (2021) Corn starch: Quality and quantity improvement for industrial uses. *Plants* 11: 92. https://doi.org/10.3390/plants11010092
10. Oladapo AS, Adepeju AB, Akinyele AA, et al. (2017) The proximate, functional and anti–nutritional properties of three selected varieties of maize (yellow, white and pop corn) flour. *Int J Sci Eng Sci* 1: 23–26. https://doi.org/10.15580/gjas.2016.9.101516167
11. Dewanto FA (2025) Pola Produksi dan Konsumsi Jagung Indonesia (Indonesian corn production and consumption patterns). Available from: https://www.beritadaerah.co.id/index.php/2025/01/05/pola–produksi–dan–konsumsi–jagung–indonesia/.
12. BPS 2024a Luas panen dan produksi jagung di Indonesia pada tahun 2023 (Harvested area and maize production in Indonesia in 2023 (2025) Available from: https://www.bps.go.id/id/pressrelease/2024/03/01/2377/pada–2023–luas–panen.
13. BPS 2024b Analisis produktivitas jagung dan kedelai di indonesia 2023 (hasil ubinan) (Analysis of maize and soybean productivity in Indonesia in 2023 based on crop cutting survey results) (2025) Available from: https://www.bps.go.id/id/publication/2024/08/30/e2e46d52a9cc9f78422f77ad/analisis–produktivitas–jagung–dan–kedelai–di–indonesia–2023–hasil–survei–ubinan–.html.
14. Balitkabi (2016) Deskripsi Varietas Unggul Kacang–kacangan dan Umbi–umbian (Description of superior varieties of legumes and tubers). *Balai Penelitian Tanaman Kacang–kacangan dan Umbi–umbian*. Malang.
15. Balitkabi (2021) Deskripsi Varietas unggul Aneka Kacang dan Umbi (Description of superior varieties of legumes and tubers). *Balai Penelitian Tanaman Aneka Kacang dan Umbi*. Malang.
16. BPSI Tanaman Serealia (2024) Deskripsi Varietas Unggul Baru Jagung dan Sorgum (Description of new superior varieties of corn and sorghum). *Balai Pengujian Standar Instrumen Tanaman Serealia*. Maros.
17. Ramadhani F, Surmaini E, Dariah A, et al. (2024) Multisource spatiotemporal analysis of cropping patterns on dry upland: A case study in Rubaru Sub–district, Sumenep Regency. *The Egypt J Remote Sens Space Sci* 27: 403–415. https://doi.org/10.1016/j.ejrs.2024.04.008
18. Arifin Z, Tafakresnanto C (2019) Pengelolaan pola tanam berbasis kedelai dan jagung di lahan kering (Management of soybean- and maize-based cropping systems in dryland agroecosystems). *Buletin Palawija* 17: 83–93. https://doi.org/10.21082/bulpa.v17n2.2019.p83-93
19. Ekawati I (2009) Prospek budidaya kedelai sistem organik di Kabupaten Sumenep (Prospects for organic soybean cultivation in Sumenep Regency). Agri–Tek. *Jurnal Penelitian Ilmu–Ilmu Eksakta* 10: 70–77.
20. BPS Jawa Timur 2024 (2024) *Indikator Pertanian Provinsi Jawa Timur 2023* (East Java Province Agricultural Indicators 2023) 12: 184.

21. Amzeri A, Djunaedy AZMRASZ, Ardianzah D, et al. (2018) Uji daya hasil pendahuluan kandidat jagung hibrida Madura (Preliminary yield trial of Madura hybrid corn candidates). *Agrovigor: Jurnal Agroekoteknologi* 11: 120–127. https://doi.org/10.21107/agrovigor.v11i2.5080
22. Prasetyo DD, Fauziyah E (2020) Efisiensi ekonomi usahatani jagung lokal di Pulau Madura (Economic efficiency of local corn farming on Madura Island). *Agriscience* 1: 26–38. https://doi.org/10.21107/agriscience.v1i1.7505
23. Wati HD, Ekawati I, Ratna P (2022) Keragaman Genetik dan Heritabilitas Karakter Komponen Hasil Jagung Varietas Lokal Sumenep (Genetic diversity and heritability of yield component characters of local corn varieties in Sumenep). *Jurnal Pertanian Cemara* 19: 85–94. https://doi.org/10.24929/fp.v19i1.1985
24. Jamilah IN, Suprapti I (2022) Analisis nilai tambah marning jagung lokal madura (Studi Kasus: UD. Sinar Murni Kecamatan Manding Kabupaten Sumenep) (Analysis of the added value of local Madurese corn (Case Study: UD. Sinar Murni, Manding District, Sumenep Regency)). *Prosiding Seminar Nasional Hasil Penelitian Pertanian, Perikanan dan Kelautan 2(2021), Surabaya.* Universitas Trunojoya, Bangkalan, 201–207. Available from: https://ilmukelautan.trunojoyo.ac.id/wp–content/uploads/2022/05/Jamilah–dan–Suprapti.pdf.
25. Hajar I (2024) Nasi Jagung Menjadi Menu Favorit Buka Puasa (Corn rice becomes a favorite menu for breaking the fast). Available from: https://www.rri.co.id/kuliner/599209/nasi–jagung–menjadi–menu–favorit–buka–puasa.
26. Ekawati SH (2024) “Durnang” Kuliner Khas Daerah Melegenda ("Durnang" legendary regional culinary specialty). Available from: https://rri.co.id/kuliner/731871/durnang–kuliner–khas–daerah–melegenda.
27. Aziz F, Jansen IA, Liridla M (2020) Pengembangan home industry Tempe “Keraton” Desa Montorna. *J Food Technol Agroindustry* 2: 70–78. https://doi.org/10.24929/jfta.v2i2.961
28. Hasanah H, Rum M (2023) Analisis nilai tambah dan strategi pengembangan industri rumah tangga tahu di Kecamatan Guluk–Guluk, Kabupaten Sumenep (Analysis of added value and development strategies for the tofu home industry in Guluk-Guluk District, Sumenep Regency). *Agriscience* 3: 623–637. https://doi.org/10.21107/agriscience.v3i3.15744
29. Manaf AHA, Hidayatullah N, Utami VK (2023) Pengembangan industri tahu skala rumah tangga menjadi tahu sutera Desa Jaddung Kecamatan Pragaan Kabupaten Sumenep Abdisuci. (Development of the household scale tofu industry into silken tofu in Jaddung Village, Pragaan District, Sumenep Abdisuci Regency) *Jurnal Pengabdian dan Pemberdayaan Masyarakat* 1: 42–46. https://doi.org/10.59005/j-abdisuci.v1i1.92
30. Roziyanto IE (2025) Cemilan unik, kacang kedelai goreng gurih dan renyah (Unique snack, savory and crispy fried soybeans). Available from: https://www.rri.co.id/sumenep/kuliner/1112902/cemilan–unik–kacang–kedelai–goreng–gurih–dan–renyah.
31. Firdaus MW, Fauziyah E (2020) Efisiensi ekonomi usahatani jagung hibrida di Pulau Madura. (Economic efficiency of hybrid corn farming on Madura Island). *Agriscience* 1: 74–87. https://doi.org/10.21107/agriscience.v1i1.7624
32. Arifin Z, Tafakresnanto C (2019) Pengelolaan Pola Tanam Berbasis Kedelai dan Jagung di Lahan Kering (Management of soybean and corn-based cropping patterns in dry land). *Buletin Palawija* 17: 83–93. https://doi.org/10.21082/bulpa.v17n2.2019.p83-93

33. Rahmaniyah F, Rum M (2020) Analisis Daya Saing Jagung Hibrida Unggul Madura MH–3 di Kabupaten Bangkalan (Competitiveness analysis of the superior Madura hybrid maize MH-3 in Bangkalan Regency). *Agrisience* 1: 367–382. https://doi.org/10.21107/agriscience.v1i2.8020
34. Krismawati A, Arifin Z, Hermanto C, et al. (2021) Application of biochar to improve maize performance on volcanic and sediment soil based parent materials in dry land. *IOP Conference Series: Earth and Environmental Science* 648: 012177. https://doi.org/10.1088/1755-1315/648/1/012177
35. Krishnan HB, Jez JM (2018) Review: The promise and limits for enhancing sulfur–containing amino acid content of soybean seed. *Plant Sci* 272: 14–21. https://doi.org/10.1016/j.plantsci.2018.03.030
36. Zhao H, Shen C, Wu Z, et al. (2020) Comparison of wheat, soybean, rice, and pea protein properties for effective applications in food products. *J Food Biochem* 44: e13157. https://doi.org/10.1111/jfbc.13157
37. Oyeyinka SA, Adebayo AI, Oyeyinka AT, et al. (2020) Flour functionality, physicochemical and sensory properties of steamed and baked maize meal enriched with defatted soybean. *J Food Process Preserv* 44: e14389. https://doi.org/10.1111/jfpp.14389
38. Deshpande SD, Bal S (2001) Effect of soaking time and temperature on textural properties of soybean. *J Texture Stud* 32: 343–347. https://doi.org/10.1111/j.1745–4603.2001.tb01241.x
39. Antarlina SS, Estiasih T, Zubaidah E, et al. (2021) The physicochemical properties of white sorghum (Sorghum bicolor L.) flour in various particle sizes by soaking the seeds before and after dehulling. *Food Res* 5: 129–143. https://doi.org/10.26656/fr.2017.5(3).541
40. Teusink B, Molenaar D (2017) Systems biology of lactic acid bacteria: For food and thought. *Curr Opin Syst Biol* 6: 7–13. https://doi.org/10.1016/j.coisb.2017.07.005
41. Badan Pangan Nasional (2024) Peraturan Presiden (Perpres) Nomor 81 Tahun 2024 tentang Percepatan Penganekaragaman Pangan Berbasis Potensi Sumber Daya Lokal. Badan Pangan Nasional. Jakarta (Presidential Regulation (Perpres) Number 81 of 2024 concerning the Acceleration of Food Diversification Based on Local Resource Potential. National Food Agency. Jakarta). Available from: https://peraturan.bpk.go.id/Details/295850/perpres–no–81–tahun–2024.
42. Ginting E, Elisabeth DAA, Khamidah A, et al. (2024) The nutritional and economic potential of tofu dreg (okara) and its utilization for high protein food products in Indonesia. *J Agric Food Res* 16: 101175. https://doi.org/10.1016/j.jafr.2024.101175
43. Fauziah L, Anggraeni L, Latifah E, et al. (2023) Increased yield and quality of corn by inorganic fertilizers and utilization of corn as food to support food security. *IOP Conference Series: Earth and Environmental Science* 1253: 012129. https://doi.org/10.1088/1755-1315/1253/1/012129
44. Khamidah A, Antarlina SS (2022) Corn flour substitution at pastry production. *IOP Conference Series: Earth and Environmental Science* 1107: 012058. https://doi.org/10.1088/1755-1315/1107/1/012058
45. Fanzurna, CO, Taufik M (2020) Formulasi foodbars berbahan dasar tepung kulit pisang kepok dan tepung kedelai. *Jurnal Bioindustri* 2: 439–452. https://doi.org/10.31326/jbio.v2i2.629.g345
46. Aini N, Wijonarko G, Sustriawan B (2016) Sifat fisik, kimia, dan fungsional tepung jagung yang diproses melalui fermentasi (Physical, chemical, and functional properties of corn flour processed through fermentation). *Agritech* 36: 160–169. https://doi.org/10.22146/agritech.12860
47. Ndukwu MC (2009) Determination of selected physical properties of Brachystegia eurycoma seeds. *Res Agric Eng* 55: 165–169. https://doi.org/10.17221/14/2009-RAE

48. Kaur M, Singh N (2007) Relationships between various functional, thermal and pasting properties of flours from different Indian black gram (*Phaseolus mungo* L.) cultivars. *J Sci Food Agric* 87: 974–984. https://doi.org/10.1002/jsfa.2789
49. Balamaceda EA, Kim MK, Franzen, et al. (1984) Protein functionality methodology standard test. In: Regenstein J (Ed.), *Food Protein Chemistry: An Introduction for Food Scientist,* Academic Press Inc. New York.
50. AACC (2010) Approved Methods of Analysis (11th ed.). *Cereal & Grain Association*. Available from: https://www.cerealsgrains.org/resources/Methods/Pages/default.aspx.
51. Juliano BO (1971) A simplified assay for milled–rice amylose. *Cereal Sci Today* 16: 334–340. Available from: https://www.researchgate.net/publication/275886661.
52. Gull A, Prasad K, Kumar P (2018) Nutritional, antioxidant, microstructural and pasting properties of functional pasta. *J Saudi Soc Agric Sci* 17: 147–153. https://doi.org/10.1016/j.jssas.2016.03.002
53. Collado LS, Corke H (1999) Heat moisture treatment effect on sweet potato starch differing in amylose content. *Food Chem* 65: 339–346. https://doi.org/10.1016/S0308–8146(98)00228–3
54. Coskuner Y, Karababa E (2007) Physical properties of coriander seeds (*Coriandrum sativum* L.). *J Food Eng* 80: 408–416. https://doi.org/10.1016/j.jfoodeng.2006.02.042
55. Solomon WK, Zewdu AD (2009) Moisture–dependent physical properties of niger (*Guizoatia abyssinic* Cass.) seed. *Ind Crops Prod* 29: 165–170. https://doi.org/10.1016/j.indcrop.2008.04.018
56. Atmaka W, Amanto BS (2010) Kajian karakterikstik fisikokimia tepung instan beberapa varietas jagung (Zea mays L.) (Study on the physicochemical characteristics of instant flour from several maize (Zea mays L.) varieties). *Jurnal Teknologi Hasil Pertanian* 3: 13–20. https://doi.org/10.20961/jthp.v0i0.13614
57. Molenda M, Montros MD, Horabik J (2002) Mechanical properties of corn and soybean meal. *Trans Am Soc Agric Eng* 45: 1929–1936.
58 Soyoye BO, Ademosun OC, Agbetoye LAS (2018) Determination of some physical and mechanical properties of soybean and maize in relation to planter design. *IGR J* 20: 81–89. Available from: http://www.cigrjournal.org.
59 Kruszelnicka W, Chen Z, Ambrose K (2022) Moisture-dependent physical-mechanical properties of maize, rice, and soybeans as related to handling and processing. *Materials* 15: 8729. https://doi.org/10.3390/ma15248729
60. Da Silva AR, Leão-Araújo ÉF, Rezende BR, et al. (2018) Modeling the three phases of the soaking kinetics of seeds. *Agron J* 110: 164–170. https://doi.org/10.2134/agronj2017.07.0373
61. Besharati B, Lak A, Ghaffari H, et al. (2021) Development of a model to estimate moisture contents based on physical properties and capacitance of seeds. *Sens Actuators A: Phys* 318: 112513. https://doi.org/10.1016/j.sna.2020.112513
62. Altuntas E, Demirtola H (2007) Effect of moisture content on physical properties of some grain legume seeds. *N Z J Crop Hortic Sci* 35: 423–433. https://doi.org/10.1080/01140670709510210
63. Karimi M, Kheiralipour K, Tabatabaeefar A, et al. (2009). The effect of moisture content on physical properties of wheat. *Pak J Nutr* 8: 90–95. https://doi.org/10.3923/pjn.2009.90.95
64. Gunathilake DMCC, Bhat J, Singh IR, et al. (2019). Dynamics of the physical properties of soybean during storage under tropical condition. *Legume Res* 42: 370–374. https://doi.org/10.18805/LR-447

65. Cabañas-Ojeda JA, Nicolás JJ, Mejia-Abaunza, et al. (2023) Corn kernel hardness and drying temperature affect particle size post-hammer-milling and pellet quality in broiler and swine diets. *Anim Feed Sci Technol* 304: 115744. https://doi.org/10.1016/j.psj.2021.101395
66. Siddique AB, Wright D (2003) Effects of different seed drying methods on moisture percentage and seed quality (viability and vigour) of pea seeds (*Pisum sativum* L.). *J Agron* 2: 201–208. https://doi.org/10.3923/ajps.2003.978.982
67. Song Y, Ndolo V, Fu BX, et al. (2021) Effect of processing on bioaccessibility of carotenoids from orange maize products. *Int J Food Sci Technol* 56: 3299–3310. https://doi.org/10.1111/ijfs.15038
68. Reykdal Ó (2018) Drying and storing of harvested grain a review of methods. *Skýrsla Matís* 2018: 05–18.
69. Widowati S (2012) Keunggulan Jagung QPM (Quality Protein Maize) dan Potensi Pemanfaatannya dalam Meningkatkan Status Gizi (The advantage of quality protein maize and the potent of its utilization in improving nutritional status). *Jurnal Pangan* 21: 171–184. https://doi.org/10.33964/jp.v21i2.127
70. Ezeokeke CT, Onuoha AB (2016) Nutrient composition of cereal (maize), legume (soybean) and fruit (banana) as a complementary food for older infants and their sensory assessment. *J Food Sci Eng* 6: 139–148. https://doi.org/10.17265/2159-5828/2016.01.004
71. Jahreis G, Brese M, Leiterer M, et al. (2016) Legume flours: Nutritionally important sources of protein and dietary fiber. *Ernahrungs Umschau* 63: 36–42.
72. Zhang Q, Sun T, Wang J, et al. (2023) Genome-wide association study and high-quality gene mining related to soybean protein and fat. *BMC Genomics* 24: 596. https://doi.org/10.1186/s12864-023-09687-6
73. Chaudhary DP, Sapna MS, Mandhania S, et al. (2012) Inter-relationship among nutritional quality parameters of maize (Zea mays) genotypes. *Indian J Agric Sci* 82: 681. https://doi.org/10.56093/ijas.v82i8.23049
74. Guan X, Zhong X, Lu Y, et al. (2021) Changes of soybean protein during tofu processing. *Foods* 10: 1594. https://doi.org/10.3390/foods10071594
75. Ntso ASA, Njintang YN, Mbofung CMF (2017) Physicochemical and pasting properties of maize flour as a function of the interactive effect of natural-fermentation and roasting. *J Food Meas Charact* 11: 451–459. https://doi.org/10.1007/s11694-016-9413-1
76. Ciabotti S, Silva ACBB, Juhasz ACP, et al. (2016) Chemical composition, protein profile, and isoflavones content in soybean genotypes with different seed coat colors. *Int Food Res J* 23: 621–629. Available from: http://www.ifrj.upm.edu.my/23%20(02)%202016/(23).pdf.
77. Wang S, Wang J, Yu J, et al. (2014) A comparative study of annealing of waxy, normal and high-amylose maize starches: The role of amylose molecules. *Food Chem* 164: 332–338. https://doi.org/10.1016/j.foodchem.2014.05.055
78. Suarni S, Firmansyah IU, Aqil M (2013) Keragaman mutu pati beberapa varietas jagung (Variability in starch quality among several maize varieties). *Jurnal Penelitian Pertanian Tanaman Pangan* 32: 124615.
79. Wardhani APK, Wirnas D (2024) Keragaman genetik karakter agronomi dan amilosa populasi sorgum F3 hasil persilangan Pulut 3 x Soraya 3 (Genetic variability of agronomic traits and amylose content in the F3 sorghum population derived from the cross Pulut 3 × Soraya 3). *Buletin Agrohorti* 12: 52–59. https://doi.org/10.29244/agrob.v12i1.53055

80. Sayar S, Turhan M, Köksel H (2011) Solid loss during water absorption of chickpea (*Cicer Arietinum* L.). *J Food Proc Eng* 34: 1172–1186. https://doi.org/10.1111/j.1745-4530.2009.00409.x
81. Coffigniez F, Rychlik M, Sanier C, et al. (2019) Localization and modeling of reaction and diffusion to explain folate behavior during soaking of cowpea. *J Food Eng* 253: 49–58. https://doi.org/10.1016/j.jfoodeng.2019.02.012
82. Bayram M, Kaya A, Öner MD (2004) Changes in properties of soaking water during production of soy-bulgur. *J Food Eng* 61: 221–230. https://doi.org/10.1016/S0260-8774(03)00094-3
83. Kajihausa OE, Fasasi RA, Atolagbe YM (2014) Effect of different soaking time and boiling on the proximate composition and functional properties of sprouted sesame seed flour. *Niger Food J* 32: 8–15. https://doi.org/10.1016/S0189-7241(15)30112-0
84. Princewill OP, Ezinne OE (2014) The effect of soaking time on some engineering properties of brown–speckled African yam bean. *Int J Eng Technol* 4: 700–708.
85. Joshi AU, Liu C, Sathe SK (2015) Functional properties of select seed flours. *LWT-Food Sci Technol* 60: 325–331. https://doi.org/10.1016/j.lwt.2014.08.038
86. Mukherjee R, Chakraborty R, Dutta A (2019) Soaking of soybean meal: Evaluation of physicochemical properties and kinetic studies. *Journal of Food Measurement and Characterization*: 13, 390–403. DOI:10.1007/s11694–018–9954–6
87. Mazi BG, Yıldız D, Barutçu MI (2023) Influence of different soaking and drying treatments on anti–nutritional composition and technological characteristics of red and green lentil (Lens culinaris Medik.) flour. *J Food Meas Charact* 17: 3625–3643. https://doi.org/10.1016/j.foodchem.2024.139293
88. Suri DJ, Tanumihardjo SA (2016) Effects of different processing methods on the micronutrient and phytochemical contents of maize: From A to Z. *Compr Rev Food Sci Food Saf* 15: 912–926. https://doi.org/10.1111/1541–4337.12216
89. Li S, Tayie FA, Young MF, et al. (2007) Retention of provitamin A carotenoids in high β-carotene maize (Zea mays) during traditional African household processing. *J Agric Food Chem* 55: 10744–10750. https://doi.org/10.1021/jf071815v
90. Cho KM, Ha TJ, Lee YB, et al. (2013) Soluble phenolics and antioxidant properties of soybean (*Glycine max* L.) cultivars with varying seed coat colours. *J Funct Foods* 5: 1065–1076. https://doi.org/10.1016/j.jff.2013.03.002
91. Afify AEMM, El Beltagi HS, Abd El Salam SM, et al. (2012) Biochemical changes in phenols, flavonoids, tannins, vitamin E, β-carotene and antioxidant activity during soaking of three white sorghum varieties. *Asian Pac J Trop Biomed* 2: 203–209. https://doi.org/10.1016/S2221–1691(12)60042–2
92. Rani H, Zulfahmi Z, Widodo YR (2013) Optimasi proses pembuatan bubuk (tepung) kedelai (Process optimization for the production of soybean powder (flour)). *Jurnal Penelitian Pertanian Terapan* 13: 188–196. https://doi.org/10.25181/jppt.v13i3.187
93. Gozalli M, Nurhayati N (2015) Karateristik tepung kedelai dari jenis impor dan lokal (varietas Anjasmoro dan Baluran) dengan perlakuan perebusan dan tanpa perebusan (Characteristics of imported and local soybean flour (Anjasmoro and Baluran varieties) with boiling and non-boiling treatments). *Jurnal Agroteknologi* 9: 191–200.

94. Aini N, Hariyadi P, Muchtadi TR, et al. (2010) Hubungan antara waktu fermentasi grits jagung dengan sifat gelatinisasi tepung jagung putih yang dipengaruhi ukuran partikel (The relationship between the fermentation time of corn grits and the gelatinization properties of white corn flour as influenced by particle size). *Jurnal Teknologi dan Industri Pangan* 21: 18–24. https://journal.ipb.ac.id/index.php/jtip/article/view/2450
95. Singh N, Bedi R, Garg R, et al. (2009) Physico–chemical, thermal and pasting properties of fractions obtained during three successive reduction milling of different corn types. *Food Chem* 113: 71–77. https://doi.org/10.1016/j.foodchem.2008.07.023
96. Wang HL, Swain EW, Hesseltine CW, et al. (1979) Hydration of whole soybeans affects solids losses and cooking quality. *J Food Sci* 44: 1510–1513. https://doi.org/10.1111/j.1365-2621.1979.tb06474.x
97. El Safy F, Salem R, Ensaf Mukhtar YY (2013) The impact of soaking and germination on chemical composition, carbohydrate fractions, digestibility, antinutritional factors and minerals content of some legumes and cereals grain seeds. *Alexandria Sci Exch J* 34: 499–513. https://doi.org/10.21608/asejaiqjsae.2013.3112
98. Agume ASN, Njintang NY, Mbofung CMF (2017) Effect of soaking and roasting on the physicochemical and pasting properties of soybean flour. *Foods* 6: 12. https://doi.org/10.3390/foods6020012
99. Apaliya MT, Kwaw E, Osae R, et al. (2024) Effect of different drying methods on the rehydration kinetics, physiochemical and functional properties of unripe plantain (*Musa parasidiaca*) flour. *Food Chem Adv* 4: 100610. https://doi.org/10.1016/j.focha.2024.100610
100. BSN 2011 Standar Mutu Tepung Kedelai (SNI 7612:2011) (Soybean Flour Quality Standards (SNI 7612:2011). *Badan Standarisasi Nasional*. Jakarta.
101. BSN 2020 Standar Mutu Tepung Tepung Jagung (SNI 3727:2020) (Corn Flour Quality Standard (SNI 3727:2020)). *Badan Standarisasi Nasional.* Jakarta.
102. Suriya M, Baranwal G, Bashir M, et al. (2016) Influence of blanching and drying methods on molecular structure and functional properties of elephant foot yam (*Amorphophallus paeoniifolius*) flour. *LWT-Food Sci Technol* 68: 235–243. https://doi.org/10.1016/j.lwt.2015.11.060
103. Kumari S, Krishnan, V, Jolly M, et al. (2014) *In vivo* bioavailability of essential minerals and phytase activity during soaking and germination in soybean (*Glycine max* L.). *Aust J Crop Sci* 8: 1168–1174.
104. Qin P, Wang T, Luo Y (2022) A review on plant-based proteins from soybean: Health benefits and soy product development. *J Agric Food Res* 7: 100265. https://doi.org/10.1016/j.jafr.2021.100265
105. Samofalova LA, Donskaya MV (2021) Study of the effect of soybean and chickpea seeds watering on protein complex solubility. *IOP Conference Series: Earth and Environmental Science* 640: 022076. https://doi:10.1088/1755–1315/640/2/022076
106. Arifin R, Dewanti-Hariyadi R, Hariyadi P, et al. (2014) Profile of microorganisms and amylose content of white corn flours of two local varieties as affected by fermentation process. *IPCBEE* 77: 60–65.
107. Gong M, Zhou Z, Jin J, et al. (2020) Effects of soaking on physicochemical properties of four kinds of rice used in Huangjiu brewing. *J Cereal Sci* 91: 102855. https://doi.org/10.1016/j.jcs.2019.102855

108. Bello-Perez LA, Flores-Silva PC, Agama-Aceved E, et al. (2020) Starch digestibility: past, present, and future. *J Sci Food Agric* 100: 5009–5016. https://doi.org/10.1002/jsfa.8955
109. Wongsagonsup R, Pujchakarn T, Jitrakbumrung S, et al. (2014) Effect of cross-linking on physicochemical properties of tapioca starch and its application in soup product. *Carbohydr Polym* 101: 656–665. https://doi.org/10.1016/j.carbpol.2013.09.100
110. Donmez D, Pinho L, Patel B, et al. (2021) Characterization of starch-water interactions and their effects on two key functional properties: Starch gelatinization and retrogradation. *Curr Opin Food Sci* 39: 103–109. https://doi.org/10.1016/j.cofs.2020.12.018
111. Zhang J, Liu Y, Wang P, et al. (2025) The effect of protein-starch interaction on the structure and properties of starch, and its application in flour products. *Foods* 14: 778. https://doi.org/10.3390/foods14050778
112. Zaidul ISM, Nik Norulaini NA, Mohd Omar AK, et al. (2007) RVA analysis of mixtures of wheat flour and potato, sweet potato, yam, and cassava starches. *Carbohydr Polym* 69: 784–791. https://doi.org/10.1016/j.carbpol.2007.02.021
113. Mpili P, Vicent V, Rweyemamu L (2024). Evaluation of the proximate composition, functional, and pasting properties of ichipipi maize flour. *Appl Food Res* 4: 100408. https://doi.org/10.1016/j.afres.2024.100408
114. Chhabra N, Kaur A, Kaur A (2018). Assessment of physicochemical characteristics and modifications of pasting properties of different varieties of maize flour using additives. *J Food Sci Technol* 55: 4111–4118. https://doi.org/10.1007/s13197–018–3337–1
115. Polnaya FJ, Huwae AA, Tetelepta G (2018). Karakteristik sifat fisiko–kimia dan fungsional pati sagu ihur (Metroxylon sylvestre) dimodifikasi dengan hidrolisis asam (Physicochemical and functional characteristics of Ihur sago starch (metroxylon sylvestre) modified through acid hydrolysis). *Agritech* 38: 7–15. https://doi.org/10.22146/agritech.16611
116. Taghdir M, Mazloomi SM, Honar N, et al. (2017) Effect of soy flour on nutritional, physicochemical, and sensory characteristics of gluten-free bread. *Food Sci Nutr* 5: 439–445. https://doi.org/10.1002/fsn3.411
117. Julianti E, Rusmarilin H, Yusraini E (2017) Functional and rheological properties of composite flour from sweet potato, maize, soybean and xanthan gum. *J Saudi Soc Agric Sci* 16: 171–177. https://doi.org/10.1016/j.jssas.2015.05.005
118. Okafor JN, Obiegbuna JE, Agu HO (2021) Functional and pasting properties of composite flour from wheat, sweet potato and soybean. *Int J Environ Agric Res* 12: 1–9. https://doi.org/10.5281/ZENODO.5855102
119. Varghese S, Awana M, Mondal D, et al. (2022) Amylose-amylopectin ratio: Comprehensive understanding of structure, physicochemical attributes, and applications of starch. In: Thomas S, Ajitha AR, Chirayil CJ, et al. (Eds.), *Handbook of Biopolymers,* Singapore: Springer Nature Singapore, 1–30. https://doi.org/10.1007/978–981–16–6603–2_48–1
120. Elisabeth DAA, Utomo JS, Byju G, et al. (2022) Cassava flour production by small scale processors, its quality and economic feasibility. *Food Sci Technol* 42: e41522. https://doi.org/10.1590/fst.41522
121. Verma AK, Pathak V, Singh VP (2014) Comparative cost assessment of refined wheat and soy flour based chicken meat noodles. *Asian J Dairy Food Res* 33: 123–125. https://doi.org/10.5958/0976-0563.2014.00587.9

122. Saputra HDD (2022) Uji kualitas french baguette dengan tepung kedelai sebagai substitusi tepung terigu: Quality test of french baguette with soybean flour as a wheat flour substitute. *Jurnal Ilmiah Pariwisata dan Bisnis* 1: 1936–1954. https://doi.org/10.22334/paris.v1i8.132
123. Adityawati IS (2019) Formulasi Bubur Instan Untuk Pemenuhan Kebutuhan Asupan Nutrisi Ibu Menyusui Menggunakan Linear Programming (Instant porridge formulation to fulfill the nutritional intake needs of breastfeeding mothers using linear programming). Doctoral dissertation, Universitas Brawijaya. Available from: http://repository.ub.ac.id/id/eprint/181560
124. Arief RW, Asnawi R, Richana N (2015) Penganekaragaman pangan olahan jagung dan analisis kelayakannya secara ekonomi di Kecamatan Pekalongan Kabupaten Lampung Timur (Diversification of processed maize-based food products and economic feasibility analysis in Pekalongan District, East Lampung Regency, Indonesia). *Prosiding Seminar Nasional Pengembangan Teknologi Pertanian, Politeknik Negeri Lampung* 2015: 161–169. https://doi.org/10.25181/prosemnas.v0i0.526
125. Kusuma PTWW, Mayasti NKI (2014) Analisa kelayakan finansial pengembangan usaha produksi komoditas lokal: mie berbasis jagung (Financial feasibility analysis of local commodity production business development: corn-based noodles). *Agritech* 34: 194–202. https://doi.org/10.22146/agritech.9510