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Physicochemical, nutritional and oxalate concentration of taro tubers grown in North Sumatera, Indonesia: effect of soaking and boiling treatments

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Abstract The presence of anti-nutrients is considered unfavourable to consumers as they limit the utilization of nutrients present in foods when eaten by the consumers. Oxalate is among the most common anti-nutrients found in many agricultural products. This study investigated the effects of soaking in sodium chloride (NaCl) solution and boiling treatment on the physicochemical properties, nutrients and oxalate content in taro tuber samples grown in North Sumatera, Indonesia. The data showed that the physicochemical properties (colour and pH) of the samples were not significantly impacted by both treatments. From the aspect of proximate compositions, soaked samples did not vary significantly from the control. On the other hand, noticeable drop in the ash, protein, fat and fibre contents were observed in the boiled samples. Both soaked and boiled samples recorded higher carbohydrate contents than the corresponding control. The treatments led to a loss of 29.69% to 99.23% of total oxalates in the samples, with boiling treatment exhibiting the greatest effect. Moreover, both treatments showed positive correlation with the concentration of salt and treatment duration, where a higher concentration of NaCl and a longer duration resulted in a higher loss of oxalate. However, only T4 could be regarded as low-oxalate content Thus, further treatments need to be considered to lower the amount to a greater extent.

Keywords: Anti-nutrient, Boiling, Soaking, Oxalate, Taro

Introduction

The *Colocasia esculenta* (English: taro/ Indo: *talas*) is a dominant tropical crop that comes from the tropical area located between Indonesia and India (Matthews, 2004). Despite being the sixth largest exporter of taro in the world, the production of taro in Indonesia is still not satisfying, with only about 20

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tons/hectare (Syafiuddin *et al.,* 2023). However, taros are very well received by the Indonesians. The leaves and stems of taros are usually turned into a snack or side dish, whereas the tuber is processed as a staple food other than rice by the Indonesians. Taros have a very high potential economical value due to its high nutritional values. They are a good source of iron, calcium, zinc, magnesium, phosphorus, sodium, copper and a rich source of phosphorus. They are also low in fat and contain a protein content higher than that of cassava and yam (Temesgen and Retta, 2015). Besides, taros house an appreciable content of vitamin C and B complex, which are beneficial for human health (Kaushal *et al.,* 2015). Having a rich soure of carbohydrate, taro can be an energy supply to the consumers (Alcantara *et al.,* 2013). Nevertheless, it is always not advisable to consume taro as it contains calcium oxalate, a type of anti-nutritional fator, ranging from 187.6 -1,096.2 mg/100 g (Azene and Molla, 2017).

Anti-nutritional factors, also known as anti-nutrients are endogenous compounds capable of causing a reduction in the maximum utilization of nutrients, in particular, proteins, vitamins and minerals when consumed as foods, thereby causing a reduction in the nutritive values of the foods (Gemede and Ratta, 2014; Joshi *et al*., 2020). Oxalates are tasteless and odorless, but we consume this compound every single day because they exist naturally in human, fruits and vegetables, especially seeds and nuts (Siener *et al*., 2021). This compound is widely distributed in plants in two forms, namely water-soluble and water-insoluble forms, where the former contains sodium, potassium, and ammonium oxalate, while the latter consists of calcium, magnesium, and iron oxalate (Gemede and Ratta, 2014; Ormanji *et al*., 2020). According to Sinha and Khare (2017), the two mechanisms that help in balancing the content of oxalate in human body are renal excretion (up to 90%) and intestinal excretion (10%). The primary factor that makes excessive dietary intake of oxalates a significant health risk for the general population is their capacity to react with divalent cations like magnesium or calcium to form insoluble salt (Siener *at al*., 2006).

Most taro cultivars exhibit an acrid taste and the presence of calcium oxalate in plants can cause toxic mechanical injury to the consumers. Calcium oxalates in plants exist in a various sizes and shapes, such as bundles of double-pointed fingers known as raphides (Prychid *et al.,* 2008) and these nanocrystals are known to cause oral and upper respiratory injury as well as skin irritation (Norton, 2017). Apart from existing in the form of raphides, they also have an unclear role in the etiology of gut-associated illness (Norton, 2017) and have the potential to result in mechanical injury to mucosal linings of the alimentary canal, teeth (Danielson and Reinhard, 1998) and skin (Salinas *et al.,* 2001). These crystals are also responsible for the swelling of soft-tissue, salivation, significant pain, aphonia and dysphagia upon mucosal contact (Dip *et al.,* 2011). Yet, the most detrimental health effect of consuming large amounts of foods high in oxalates is the formation of calcium oxalate (CaOx) kidney stones (Ormanji *et al*., 2020). Over consumption of oxalates can induce hyperoxaluria, increase the risk of calcium oxalate stones, and even be fatal to humans (Siener *et al*., 2006). Humans should limit the intake of oxalate with a safety limit between 40 and 50 mg per day, especially patients with kidney stone problems, who are advised to have their daily intake of oxalate limited to below 10 mg according to American Dietetic Association (2005). Foods with oxalate content less than 10 mg/100g are classified as low oxalate-containing foods whilst foods having oxalate content more than 50 mg/100g are regarded as high oxalate-containing foods (Joshi *et al*., 2020). Therefore, determining the oxalate content of foods prior to their sale in marketplaces and reduction of the oxalate concentration in foods to a lower level are crucial. This study investigated and compared the physicochemical, nutritional and oxalate content of taro tubers subjected to two different treatments, namely boiling and soaking treatements at different conditions.

Materials and methods

Sample collection and preparation

The taro tubers were planted for 24 months and then harvested from a farm located at Tanjung Morawa, North Sumatera, at a latitude of 3.5300°N and a longitude of 98.8078°E. The samples were then taken to Medan Healthy Polytechnic Laboratory for pretreatment and ready for further analysis. The tuber samples were peeled with a stainless-steel knife to for the removal of peel up to 1.0 ± 0.1 cm in thickness. The peeled taros were rinsed with distilled water after being washed with tap water and subsequently, cut into small pieces. Treatment was done on the samples by soaking them in 5% sodium chloride (NaCl) for 30 min and 60 min, respectively. Another treatment was boiling for 10 min and 15 min, respectively. All treated samples were then rinsed with tap water and subjected to a drying process in the cabinet dryer set at 60°C until the moisture content of all the samples was reduced to 10%. Next, the samples were then ground and placed in a sieving machine to obtain samples in the form of 80-μm powder. All the samples were then measured for their weight to determine the yield recovery by using the following equation:

$$\text{Yield recovery (\%)} = \frac{\text{Weight of dried sample}}{\text{Weight of fresh sample}}\ X\ 100\%$$

Physicochemical mesurement

This physicochemical analysis was carried out on all the treated samples with a control. Parameters such as pH and colour (L*a*b*) were determined by using a pH meter and a Hunter Lab calorimeter, respectively. These tests were carried out in accordance with those as proposed by Agrawal and Karthikeyan (2014).

Proximate analysis

Proximate analysis was carried out on all the treated taros and control by referring to the AOAC (2000) method. The analysis included the determination of moisture, ash, crude protein, crude fat, crude fiber and carbohydrates. Carbohydrate content was calculated by subtraction 100 from the other five components

Determination of oxalate content

The taro samples were analyzed for total, soluble, and insoluble oxalate contents by using 0.50 ± 0.01 g of ground sample as demonstrated by Saleh (2019). The soluble oxalate extract was subjected to an incubation in a water bath for 15 minutes at 80 °C after it has been extracted from the samples by using 40 ml of nano-pure water. 40 ml of 0.2M HCl at 80 °C was used to extract total oxalate for 15 minutes. Analysis using a Rezex ROA ion exclusion organic acid column was done after the extracted supernatants were subjected to filtration in a 0.45-mm cellulose nitrate filter and then followed by a chromatographic separation.

Statistical analysis

All analysis were done in triplicate and the Statistical Package for Social Sciences (SPSS) version28 was used in analyzing all the collected data with significance level set at $p<0.05$.

Results

Recovery yield of golden taro samples

No significant difference ($p>0.05$) was detected in the recovery yields of all the samples. The yields were in the range of 15.21% - 15.78% as shown in Table 1, indicating that the treatments did not influence the recovery yields.

Table 1. Recovery yield (%) of golden taro samples treated with soaking in 5% NaCl and boiling treatment

Golden Sample	Recovery Yield (%)
Fresh flour	15.25 ± 0.32[a]
T1	15.21 ± 0.33[a]
T2	15.65 ± 0.31[a]
T3	15.82 ± 0.29[a]
T4	15.78 ± 0.15[a]

1/ T1- Soaking in 5% NaCl, 30 mins; T2 - Soaking in 5% NaCl, 60 mins; T3 - Boiling (100°C), 10 mins; T4 - Boiling (100°C), 15 mins.
2/ Values are expressed as mean ± standard deviation with different superscripts indicated significant difference.

Physicochemical properties

Physicochemical properties of the samples are depicted in Table 2. The data revealed that the pH and colour properties of every sample were not affected significantly ($p<0.05$) by soaking and boiling treatments. The pH values of the samples were in the range of 5.49 - 5.69. On the other hand, the L*, a* and b* values ranged from 35.35 - 36.14, 5.73 - 6.13, 30.34 - 30.47, respectively.

Table 2. pH and colour properties of fresh taro and treated samples

Taro sample	Physicochemical properties			
	pH	Colour		
		L*	a*	b*
Fresh flour	5.69±0.01[a]	35.33±0.05[a]	6.13±0.14[a]	30.47±0.11[a]
T1	5.55±0.01[a]	35.44±0.01[a]	5.98±0.09[a]	30.47±0.17[a]
T2	5.54±0.07[a]	35.35±0.13[a]	5.96±0.07[a]	30.34±0.32[a]
T3	5.49±0.05[a]	35.95±0.21[a]	5.81±0.04[a]	30.36±0.14[a]
T4	5.53±0.03[a]	36.14±0.06[a]	5.73±0.09[a]	30.37±0.33[a]

1/ T1- Soaking in 5% NaCl, 30 mins; T2 - Soaking in 5% NaCl, 60 mins; T3 - Boiling (100°C), 10 min; T4 - Boiling (100°C), 15 min.
2/ Values are expressed as mean ± standard deviation with different alphabet indicated significantly different.

Proximate values

Table 3 presented the proximate values of every sample. In general, ash, protein and carbohydrate contents were influenced significantly ($p<0.05$) by the pretreatments. Moisture content, fat and crude fibre in all samples showed no significant difference ($p>0.05$), ranging from 3.09 to 4.98%, 0.65 to 0.71% and 0.30 to 0.38%, respectively. The soaking and boiling treatments resulted in samples with slightly lower ash contents as compared to the control. As for protein and carbohydrate, the treatments caused fluctuations in these two components.

Table 3. Proximate values of fresh taro and treated samples

Proximate content (%, w/w)	Fresh flour	Treatment			
		T1	T2	T3	T4
Moisture	3.96 ± 0.35[ab]	3.11 ± 0.33[b]	3.09 ± 0.15[b]	4.98 ± 0.18[a]	4.94 ± 0.26[a]
Ash	1.81 ± 0.03[a]	1.71 ± 0.03[a]	1.65 ± 0.07[a]	1.41 ± 0.03[b]	1.36 ± 0.03[b]
Crude protein	3.36 ± 0.21[a]	3.28 ± 0.21[a]	3.33 ± 0.21[a]	2.89 ± 0.21[b]	2.72 ± 0.33[b]
Crude fat	0.65 ± 0.05[a]	0.67 ± 0.02[a]	0.66 ± 0.04[a]	0.56 ± 0.01[a]	0.53 ± 0.03[a]
Crude fibre	3.38 ± 0.01[a]	3.37 ± 0.01[a]	3.37 ± 0.02[a]	3.18 ± 0.01[b]	3.05 ± 0.02[b]
Carbohydrate	86.84± 1.91[a]	87.86 ± 2.23[a]	87.90±1.89[a]	86.98±2.32[a]	87.40±2.52[a]

1/ T1- Soaking in 5% NaCl, 30 mins; T2 - Soaking in 5% NaCl, 60 mins; T3 - Boiling (100°C), 10 min; T4 - Boiling (100°C), 15 min.

2/ Values are expressed as mean ± standard deviation with different alphabet indicated significantly different.

Oxalate content

Table 4 indicated that the oxalate contents in in the samples were significantly affected ($p<0.05$) by the treatments. A reduction of 73.31% - 99.23% was seen in the total oxalate contents of the treated taros. Insoluble oxalate, normally in the form of calcium salt, was higher in concentration as compared to soluble oxalate regardless of the treatments adopted. The lowest value of oxalate was detected in T4 which underwent 15 minutes of boiling treatment.

Table 4. Oxalate contents present in fresh and treated taro samples by soaking in 5% NaCl and boiling treatment

Sample	Total Oxalate (mg/100g DM)	Soluble (Na and K Oxalate) (mg/100g DM)	Insoluble (Ca oxalate) (mg/100g DM)
Fresh flour	1272.56 ± 38.32[a]	133.44 ± 4.63[a]	1138.10 ± 40.24[a]
T1	377.87 ± 22.33[b]	76.41 ± 28.28[b]	301.07 ± 23.22[b]
T2	149.10 ± 12.31[c]	40.67 ± 23.36[c]	108.43 ± 13.89[c]
T3	63.51 ± 9.92[d]	7.68 ± 2.71[d]	55.83 ± 6.31[d]
T4	9.77 ± 1.10[e]	1.56 ± 0.90[e]	8.21 ± 1.12[e]

1/ T1- Soaking in 5% NaCl, 30 mins; T2 - Soaking in 5% NaCl, 60 mins; T3 - Boiling (100°C), 10 min; T4 - Boiling (100°C), 15 min.

2/ Values are expressed as mean ± standard deviation with different alphabet indicated significantly different.

Discussion

Recovery yield of golden taro sample

Based on the yields obtained, the recovery yields of taro are considered consistent. This proves that both treatments did not impact heavily on the recovery yields of the samples. During drying treatment, free water in the sample will be evaporated after passing through the cell in capillary movement to the sample surface before hot air removes it into the environment through the evaporation process (Jayas, 2026).

Physicochemical properties

The pH data of soaked samples obtained here aligned with the finding from a previous study where the pH and colour intensity of yam flour were no significantly influenced by soaking treatment (Obadina *et al.,* 2014). The negligible change of pH in this study can attributed to the neutral characteristic of 5% salt solution, which is generally having a pH of 7 (Cui *et al.,* 2016). Hence, it will not impart heavily on the pH system. Boiled samples showed insignificantly ($p>0.05$) lower pH values than the raw sample. The obtained results resembled the research of Edema-Eye *et al.* (2023), where boiled water leaves, bitter leaves and fluted pumpkins also showed a reduction in their pH after being boiled. The slight drop in the acidity of boiled samples was probably due to the dissociation of water molecules into hydronium (H_3O^+) and hydroxide (OH^-) ions at high temperature, resulting in a lower pH value (Bo *et al.,* 2021).

Colour of foods is crucial in determining the purchasing decision of consumers as it plays a vital role in catching the attention of consumers (Poliszko *et al.,* 2019). All the treated samples exhibited slightly higher L* values than their raw flour, indicating slight colour fading due to the pretreatments. Boiling pretreatement, in particular, resulted in samples with the highest L* values. This can be caused by the degradation of certain coloured compounds present in taro, Ŷsuch as anthocyanins, which are responsible for the red, purple and blue colours in plants (Khoo *et al.,* 2017), that will degrade at temperature beyond 100°C (Rakkimuthu *et al.,* 2016). Consequently, boiled samples also recorded lower b* (less red) values than the raw and soaked samples, probably as a result of the degradation of anthocyanin pigments. On the other hand, soaking basically did not influence the color properties of the samples. Anyhow, both treatments only gave very little effect on the color properties of the samples, which can be regarded as trivial since no significant difference is seen in the L*a*b* values.

Proximate values

Soaking in salt solution resulted in a reduction of moisture contents of about 21.97 – 22.47%. This is because plants will release water on the addition of salt (hypertonic solution) for the maintenance of isotonic environment (Phisut *et al.,* 2013). The finding here agrees with a previous study, where the moisture contents of banana slices dropped gradually when immersed in concentrated sodium chloride (NaCl) and sucrose solution (Mirzayi *et al.,* 2018). On the contrary, increment in the moisture contents of boiled samples was observed. The same trend was seen in a past research where boiled yam recorded an increase of 5.95% of moisture content (Adepoju, 2012). The rise in moisture contents by boiling in this case can be credited greatly to the presence of starch in taros. Starch is the dominant carbohydrate found in taro, accounting for approximately 70 – 80% of the total carbohydrate in a taro (Nagar *et al.,* 2021). Starch has a strong hydrophilicity due to the existence of large quantities of hydroxyl groups which can bond with water through hydrogen bonds. Hence, starch can absorb water very well (Wang *et al.,* 2020). However, all the samples' moisture contents are still within the permissible limit of not exceeding 10% for the long-term storage of powder (Polycarp *et al.,* 2012).

The inorganic residues that remain after the ignition or complete oxidation of organic compounds in a foodstuff is referred to as ash. Such analysis is important as it represents the total mineral content in a foodstuff (Marshall, 2010). A past study by Nsa *et al.* (2011) also revealed a drop in the ash contents of castor oil seeds as the duration of soaking and boiling increased. All the treated samples showed lower ash content than their raw sample. This phenomenon is largely caused by the leaching of minerals into the surrounding medium. A higher leaching rate is achieved at a higher temperature (Faraji *et al.,* 2022), and this explains why boiled samples recorded the lowest ash contents in comparison to the raw and soaked samples.

Soaking in salt solution did not bring any substantial effect to the overall crude fat content of the samples as compared to the raw ones. This obervartion mimics a previous study where the difference of crude fat between soaked and raw yam flour is insignificant ($p>0.05$) (Obadina *et al.,* 2014). Though insignificant, but boiling lowered the crude fat content of the boiled samples. Moreover, the reduction of fat is dependent on the duration of boiling as depicted in Table 3. Similar result is also described by Cheong *et al.* (2022) where boiled sweet potatoes recorded a lower crude fat content that their raw forms. Oozing out of some fats into the surrounding medium and volatization of fat during boiling are believed to be the reasons behind the decrease in fat contents of boiled samples (Wanjekeche *et al.,* 2003; Mittal *et al.,* 2012).

Crude fiber is often given attention because consumption of this nutrient can help reduce the incidence of colon cancer, diabetes, heart attack and digestive-related diseases (Kumoro *et al.,* 2014). The finding here is higher than that of Boampong *et al.* (2019), which ranged from 1.02% to 2.12%. This phenomenon can largely be attributed to the geographical regions and soil properties which affect the nutrient uptake of plants (Mohammadi and Asadi-Gharneh, 2018). As shown in Table 3, the crude fibre contents of soaked samples remained similar to that of raw samples. Oppositely, a noticeable drop in the crude fibre content of boiled samples was detected. The changes can be related to the breakdown of food matrix (mainly formed of dietary fiber) (Arias-Rico *et al.,* 2020). A past study by Cheong *et al.* (2022) also revealed that boiling resulted in a drop of fibre content of sweet potato.

Protein can be denatured by salting and heat treatment (Zhao *et al.,* 2020). Nevertheless, only boiled samples were adversely affected from the aspect of protein content in this study. This shows that the concentration of sodium chloride (NaCl) solution employed in this investigation was not high enough to cause denaturation of proteins because salts can strip off the essential layer of water molecules from the protein surface, thereby causing protein denaturation (Sinha and Khare, 2014). Leaching of amino acids (Ezeocha and Ojimelukwe, 2012) and denaturation of proteins (Sinha and Khare, 2014) during boiling are believed to be the factors contributing to the loss of protein contents of boiled taros. A longer boiling time led to a greater loss of protein and same trend was observed in an investigation conducted by Ezeocha and Ojimelukwe (2012) on water yams. After all, the protein content of raw taro obtained here matches with the one reported by Chino *et al.* (2021), ranging from 1.13% to 3.95%.

All the treated samples exhibited higher carbohydrate contents than their raw form. This observation resembles that of Ayo *et al.* (2018) which reported higher carbohydrate contents in soaked and boiled yam flours in comparison to the untreated one. The very high carbohydrate contents in all the samples indicates that carbohydrate is the most important chemical component in taros. This is proven in noodles incorporated with taro flour that had a higher carbohydrate content than the plain one. On top of that, taro is a good source of carbohydrates for consumers with gastrointestinal issues and diabetes as it has dietary fiber that is rich in essential nutrients, slow-digesting starch, and complex carbohydrates (Afifah *et al.,* 2023). This trait can improve its competitiveness against the other plants, enhance its application in the development of health-promoting products, and thereby increasing its marketing potential.

Oxalate content

Both soaking and boiling caused a significant reduction ($p<0.05$) in the oxalate contents of the treated samples. In this case, boiling treatment gave the best effect because the high temperature of cooking by boiling can result in the collapse of the calcium oxalate-containing cells and subsequently cause the breakdown of the structure of oxalate (Wang *et al*., 2018). Usually, a longer treatment time is beneficial in terms of oxalate removal as it has been shown in a study Bredariol *et al*. (2020) that a longer time of treatment at the same temperature resulted in a greater reduction of oxalate content. This is evidenced in this study since T4 showed a lower oxalate content than T3. Past research reported that oxalic acid could be best reduced when spinach was boiled at 100°C for 2 minutes as high temperatures can result in a better disintegration of spinach, and thus, improving the release of oxalic acid from the spinach (Wang *et al*., 2018). Hence, it can be said that in this study, boiling also disintegrated the structure of taros samples used, thereby resulted in a greater loss of oxalate.

Soaking is also another way in removing oxalic acid present in foods through leaching. However, it is not the best method in removing oxalic acid as this method only removes soluble oxalic acid that present in the foodstuffs. That is why this method is accompanied with the use of salt, as can be seen in this study. The addition of salt is able to remove oxalate in foods through the leaching of soluble derivatives into the aqueous solution formed from insoluble calcium oxalates in the foods (Rofi`ana *et al.*, 2018). Longer soaking time resulted in a greater reduction of oxalic acid as can be seen from the data where the total oxalate content of T2 is significantly ($p<0.05$) lower that of T1. A longer soaking time of the taro corm chips in the added calcium salt solution was a favourable condition for the leaching of the soluble oxalate. Generally, a higher rate of leaching of oxalates is seen in longer soaking time until the rate of leaching plateaus (Saleh, 2019). However, there is a drawback of using this method, which is the occurrence of saltiness in the end product due to the diffusion of salt solutes into the treatment sample.

The drop in the content of oxalate was also partly attributed to the removal of skin from the samples because skin contains large volume of oxalates. The skins of taros are usually higher in oxalate content than their centers (Kumoro *et al.*, 2014). Holloway *et al.* (1989) found that the skin of Samoan giant taro contained a higher oxalate content (451 mg/100g) than its center (84-182 mg/100g). Moreover, peeling also aided in the removal of oxalate. The effect is even more critical when it is combined with boiling as shown in research where boiling and peeling brought a loss of 77.96% oxalate content in taro corms (Joshi *et al*., 2020).

This research took the effort to look for possible ways to decrease the content of oxalate present in taros to achieve a higher utilization of nutrients when taros are consumed. In accordance to Abdel-Moemin (2014), foods are classified as having low oxalate content when containing oxalate less than 10 mg/100g and high in oxalate when the oxalate content is more than 50 mg/100g. Consequently, it can be drawn that only T4 is regarded as low-oxalate product, and the others are considered as high in oxalate. American Dietetic Association (2005) stated that humans should limit the intake of oxalate with a safety limit between 40-50 mg per day, especially patients with kidney stone problems, are advised to limit their total oxalate intake not to exceed 10 mg per day. So further treatments should be considered to further enhance the reduction of oxalate content in taros.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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