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# IMPROVEMENT OF PHYSICOCHEMICAL PROPERTIES OF GANYONG (CANNA EDULIS KERR) STARCH THROUGH CROSS-LINKING MODIFICATION USING A COMBINATION OF SODIUM TRIPOLYPHOSPHATE AND SODIUM TRIMETAPHOSPHATE

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## ABSTRACT

Ganyong (Canna edulis) is a local starch source with a naturally high starch content (about 88.10%), yet its industrial use remains limited because native ganyong starch is prone to gelatinization, retrogradation, and syneresis. This study modified native ganyong starch (NGS) through cross-linking using a combination of sodium tripolyphosphate (STPP) and sodium trimetaphosphate (STMP) to improve its physicochemical stability. A Central Composite Design (CCD) under Response Surface Methodology (RSM) was used to evaluate the effects of the STPP:STMP ratio and cross-linking temperature on swelling power, solubility, syneresis, Water Binding Capacity (WBC), and Oil Absorption Capacity (OAC). The STPP:STMP ratio was the most dominant factor: increasing the ratio decreased swelling power, solubility, syneresis, and WBC, while increasing OAC, consistent with the formation of distarch phosphate cross-links. The optimum condition was obtained at an STPP:STMP ratio of 19:1 and a temperature of 45.907°C, with a desirability value of 0.928. FTIR analysis showed no new ester group formation, confirming that the modification was physical in nature; SEM showed that granule morphology remained largely intact; and XRD confirmed that the B-type crystalline pattern was retained despite a change in the degree of crystallinity. Overall, cross-linking improved the thermal and structural stability of ganyong starch without altering its fundamental crystal structure.

**KEYWORDS:** canna starch, starch modification, STPP–STMP, cross-linking, physicochemical properties

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## 1. INTRODUCTION

Ganyong (Canna edulis Kerr) is one of Indonesia's potential local tuber crops, with a starch content of approximately 88.10%, easy cultivation, and strong resistance to marginal growing conditions [1]. Despite this potential, ganyong is still regarded as a secondary food source, with consumption largely limited to traditional preparations such as boiling, frying, or small-scale chip production [2]. National agricultural data indicate that ganyong contributes only a small fraction of Indonesia's tuber production compared with sweet potato, cassava, or taro [3], even though it contains high amylose and resistant starch levels associated with improved intestinal barrier function [4], a low glycemic index [5], and potential protective effects against colorectal cancer [6].

Native ganyong starch granules are fragile and tend to form a mucilaginous, low-viscosity paste upon heating, and are prone to retrogradation and syneresis during storage, which limits their application in modern food and industrial products [7]. Physical, enzymatic, and chemical modification methods have been developed to address these weaknesses, each with distinct advantages and limitations [8]. Chemical cross-linking is considered the most suitable approach because it produces starch with high thermal, shear, and acid stability [9] and consistent viscosity, which is important for functional food applications such as sauces and soups [10].

Sodium tripolyphosphate (STPP) is recognized as a safe food additive by the U.S. FDA; however, when used alone it increases granule hydrophilicity and swelling power, causing granules to rupture easily and produce a thinner paste with unstable viscosity during prolonged cooking. Combining STPP with sodium trimetaphosphate (STMP) provides a complementary effect: STMP strengthens granule resistance to rupture, stabilizing paste viscosity during heating, stirring, and under acidic conditions, while STPP maintains adequate swelling and solubility so the resulting paste does not become excessively rigid. A previous study on STMP/STPP cross-linked corn starch reported a synergistic increase in resistant starch content (30–40%) while maintaining a balanced viscosity profile [11].

Based on this background, the present study investigated the cross-linking modification of ganyong starch using a combination of STPP and STMP, focusing on the effects of the STPP:STMP ratio and reaction temperature on swelling power, solubility, syneresis, WBC, and OAC, together with structural characterization using FTIR, XRD, and SEM. The specific objectives of this study were: (1) to characterize the physicochemical properties of cross-linked ganyong starch; (2) to determine the effects of the STPP:STMP ratio and reaction temperature on these properties; and (3) to evaluate the structural and morphological changes resulting from cross-linking.

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## 2. MATERIALS AND METHODS

### 2.1 Materials and Equipment

Ganyong tuber flour was obtained commercially, and distilled water was produced using a Dipo Pure water purification unit. Analytical-grade 96% ethanol, 1 M sodium hydroxide, 1 M acetic acid, iodine–potassium iodide (KI) solution, sodium tripolyphosphate (STPP), sodium trimetaphosphate (STMP), sodium sulfate (Na2SO4), 1 M hydrochloric acid. Equipment used included a magnetic stirrer and hotplate for the cross-linking reaction, a pH meter for reaction monitoring, and a drying oven. Structural and functional characterization was carried out using a UV–Vis spectrophotometer, water bath, Fourier-transform infrared (FTIR) spectrometer, X-ray diffractometer (XRD), and scanning electron microscope (SEM).

### 2.2 Experimental Design

The effects of the STPP:STMP ratio and cross-linking temperature on the physicochemical properties of modified ganyong starch were evaluated using Response Surface Methodology (RSM) with a Central Composite Design (CCD) in Design-Expert software. The fixed variables were: starch mass per treatment (35 g, dry basis), total phosphate concentration (STPP + STMP, 12% w/w of starch), Na2SO4 mass (10% w/w of starch), starch-to-NaOH ratio during extraction (1:5, w/v), and cross-linking reaction time (3 h). The independent variables were the STPP:STMP ratio (1.5–19) and the cross-linking temperature (45–70°C), producing thirteen experimental runs. The resulting responses (swelling power, solubility, WBC, OAC, and syneresis) are summarized together with the design matrix in Table 1 (Section 3.2).

### 2.3 Determination of Initial Amylose Content

The amylose content of native ganyong starch was determined by an iodine–amylose colorimetric method. A 0.10 g sample of ganyong flour (dry basis) was dissolved in an ethanol–NaOH (1 M) mixture (1:9, v/v), heated in a boiling water bath for 10 minutes (~100°C) to promote complete gelatinization and dissolution, cooled, and diluted to 100 mL with distilled water to form a stock starch solution. A 2.5 mL aliquot was mixed with 25 mL of distilled water, 0.50 mL of 1 M acetic acid, and 0.50 mL of 0.0065 M KI solution, homogenized, and left for approximately 10 minutes to allow the blue amylose–iodine complex to form stably. Absorbance was measured at 620 nm using a UV–Vis spectrophotometer, and the amylose content was calculated from a linear regression standard curve.

### 2.4 Preparation of Native Ganyong Starch (NGS)

Dry ganyong starch was suspended in dilute NaOH solution (0.1–0.2% w/v) at a ratio of 1:5 (w/v) and stirred for 30–60 minutes at room temperature. The mixture was filtered, and the starch residue was washed with water until neutral pH was reached, settled, dried at 40–50°C, milled, and sieved to obtain native ganyong starch (NGS).

### 2.5 Cross-Linking Procedure

A total of 35 g of ganyong starch (dry basis) was weighed into a beaker. A mixture of STMP and STPP

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totaling 12% of the starch mass was added at the designated ratio, together with $Na_2SO4$ (10% of starch mass), and distilled water was added to form a stirrable slurry. The slurry pH was adjusted to approximately 12 with 1 M NaOH and maintained throughout the reaction. The slurry was then heated at 70°C using a hotplate with magnetic stirring, with the temperature and pH (~12) held for 3 hours to allow the phosphate groups of STMP and STPP to react with the hydroxyl groups of starch, forming phosphate bridges responsible for cross-linking. The reaction was terminated by cooling to 40–50°C and adding 1 M HCl dropwise until the slurry pH reached approximately 6.5. The neutralized slurry was centrifuged at 5000 rpm for 10 minutes; the supernatant was discarded, and the starch precipitate was washed with 100 mL of distilled water and re-centrifuged. This washing step was repeated five times to remove residual STMP/STPP, base, and dissolved salts. The washed starch was spread on stainless steel trays and dried overnight in an oven at 50°C, then milled and sieved (80 mesh) to obtain a uniform particle size of cross-linked ganyong starch (CGS).

### 2.6 Physicochemical Analysis

Syneresis was determined from a starch gel (3 g starch + 25 mL distilled water, heated 5.5 minutes) subjected to one freeze–thaw cycle (−20°C for 22 h, thawed at room temperature for 2 h), followed by centrifugation (1310 rpm, 10 min); syneresis (%) = (W1/W0) × 100, where W0 is the initial gel mass and W1 is the mass of separated liquid. Water Binding Capacity (WBC) was measured from 1.00 g of starch mixed with 10 mL of water at 37°C, stirred, and centrifuged (3000 rpm, 15 min); the bound water volume = $V_0$ − Vs. Oil Absorption Capacity (OAC) followed the same procedure using 10 mL of castor oil in place of water. Solubility was determined from 500 mg of starch heated in 20 mL of water (37°C, 30 min), centrifuged (3000 rpm, 15 min), and the dried supernatant residue mass was expressed as a percentage of the initial starch mass. Swelling power was calculated from the ratio of the wet sediment mass (from the solubility test) to the mass of insoluble starch.

### 2.7 Structural Characterization

Functional group changes in native and modified ganyong starch were analyzed using FTIR spectroscopy by comparing absorption band positions ($cm^{-1}$) and transmittance intensities (%T). Granule morphology was observed using SEM. Crystal structure was analyzed by X-ray diffraction (XRD) over a diffraction angle range of 10–80° (2θ) using Cu-Kα radiation (λ = 1.54060 Å), comparing peak positions (2θ) and relative intensities (%) between native and modified samples.

## 3. RESULTS AND DISCUSSION

### 3.1 Amylose Content of Native Ganyong Starch

The amylose content of native ganyong starch was determined using the iodine–amylose colorimetric method, with absorbance measured at 620 nm. A standard curve (Figure 2) was constructed using purified amylose solutions of known concentration, yielding the linear regression equation Y = 0.0460X + 1.0463

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with a coefficient of determination ($R^2$) of 0.92.

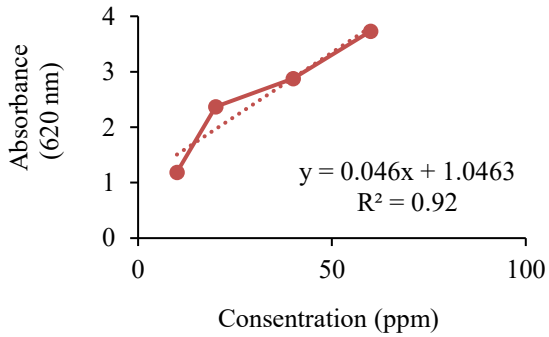



**Figure 2. Amylose standard curve**

The absorbance of the native ganyong starch sample was 1.549 at 620 nm, corresponding to an amylose concentration of 10.93 ppm from the standard curve, which was then converted to a percentage amylose content on a dry starch basis. The resulting amylose content is classified as high, consistent with reported values for ganyong (Canna edulis) starch: [12] reported 42.49% (dry basis), while [13] reported a range of 20–30%. Variation among studies may be attributed to differences in cultivar, growing conditions, extraction method, and analytical procedure. A high amylose content increases the tendency of the linear amylose chains to form intermolecular hydrogen bonds after gelatinization, promoting retrogradation, syneresis, and reduced storage stability — underscoring the need for cross-linking modification using STPP and STMP to improve the structural stability of ganyong starch.

### 3.2 Effect of STPP: STMP Ratio and Temperature on Physicochemical Properties

The physicochemical responses of cross-linked ganyong starch across the thirteen CCD runs are summarized in Table 1. Regression analysis using RSM produced the following empirical models (in actual factors, where A = STPP:STMP ratio and B = cross-linking temperature):

$$Swelling\ power\ (g/g) = 81.124 - 4.795A - 0.794B + 0.0245AB + 0.1054A^2 + 0.0023B^2 \quad (1)$$

$$Solubility\ (\%) = 144.55 - 7.93A - 2.57B + 0.02AB + 0.22A^2 + 0.01B^2 \quad (2)$$

$$WBC\ (mL) = 4.76 - 0.22A - 0.045B + 0.0031AB \quad (3)$$

$$Syneresis\ (\%) = 96.46 - 2.19A - 2.61B + 0.03AB + 0.004A^2 - 0.198B^2 \quad (4)$$

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**Table 1. RSM experimental design and physicochemical responses of modified ganyong starch**

| Run | Ratio STPP: STMP | Temp. (°C) | Swelling power (g/g) | Solubility (%) | WBC (mL) | OAC (mL) | Syneresis (%) |
|---|---|---|---|---|---|---|---|
| 1 | 10.25:1 | 57.5 | 20.47 | 8 | 1.75 | 2.30 | 8.82 |
| 2 | 19.00:1 | 57.5 | 20.89 | 20 | 1.20 | 2.70 | 5.58 |
| 3 | 10.25:1 | 45.0 | 21.60 | 24 | 1.77 | 2.00 | 11.92 |
| 4 | 19.00:1 | 45.0 | 17.03 | 6 | 1.55 | 2.45 | 7.74 |
| 5 | 19.00:1 | 70.0 | 14.12 | 18 | 1.90 | 1.70 | 14.55 |
| 6 | 10.25:1 | 70.0 | 15.97 | 22 | 1.40 | 2.60 | 12.38 |
| 7 | 1.50:1 | 45.0 | 39.25 | 58 | 2.70 | 1.60 | 17.00 |
| 8 | 1.50:1 | 57.5 | 18.88 | 36 | 2.20 | 1.90 | 13.16 |
| 9 | 10.25:1 | 57.5 | 14.65 | 16 | 1.72 | 2.28 | 8.85 |
| 10 | 10.25:1 | 57.5 | 14.82 | 18 | 1.76 | 2.32 | 8.82 |
| 11 | 1.50:1 | 70.0 | 29.20 | 52 | 1.70 | 2.20 | 9.45 |
| 12 | 10.25:1 | 57.5 | 15.10 | 14 | 1.75 | 2.30 | 8.76 |
| 13 | 10.25:1 | 57.5 | 14.60 | 16 | 1.73 | 2.26 | 8.79 |

As shown in Table 1 and the response surface plots in Figure 3, the STPP:STMP ratio was the most dominant factor affecting all five responses, consistently outweighing the effect of cross-linking temperature. Swelling power was highest at run 7 (39.25 g/g, low ratio of 1.5) and lowest at run 5 (14.12 g/g, high ratio of 19), indicating that a higher STPP:STMP ratio promotes more extensive distarch phosphate cross-linking, which restricts water penetration into the granule and limits swelling [14,15]. The same trend was observed for solubility, which decreased from 58% (run 7) to 6% (run 4), because cross-linking restricts leaching of amylose from the granule during heating [16].

WBC decreased with increasing STPP:STMP ratio, from 2.7 mL (run 7) to 1.2–1.55 mL at high-ratio conditions, because cross-linking consumes hydroxyl groups that would otherwise bind water [17,18]. In contrast, OAC increased with the ratio, from 1.6 mL (run 7) to 2.7 mL (run 2), as phosphorylation introduces steric hindrance that favors oil retention at the granule surface and within its pores, while cross-linking also stabilizes the granule against structural breakdown during processing [19,20]. Syneresis was lowest at a high ratio and moderate temperature (7.74% at run 4, ratio 19, 45°C) but increased again at 70°C (14.55–12.38% at runs 5 and 6), suggesting that excessive heating causes partial gelatinization and disruption of the cross-linked network, reducing the gel's capacity to retain water [21,22].

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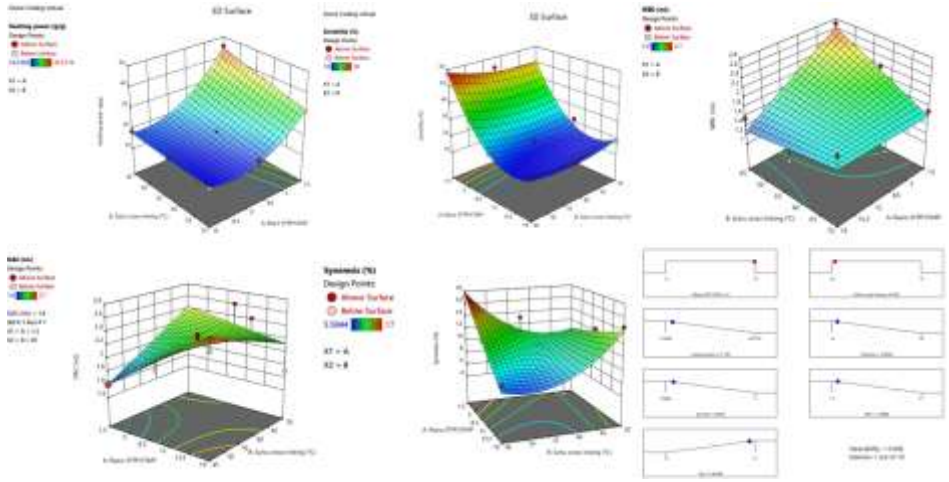


**Figure 3. Response surface plots of (a) swelling power, (b) solubility, (c) WBC, (d) OAC, (e) syneresis, and (f) desirability function, as functions of STPP:STMP ratio and cross-linking temperature**

### 3.3 Optimum Cross-Linking Condition

Simultaneous optimization of all five responses using the desirability function in Design-Expert (Figure 3f) — targeting minimum swelling power, solubility, WBC, and syneresis together with maximum OAC — identified the optimum condition at an STPP:STMP ratio of 19 and a cross-linking temperature of 45.907°C, with an overall desirability of 0.928. Under this condition, the predicted responses were: swelling power 17.764 g/g, solubility 16.84%, syneresis 6.60%, WBC 1.299 mL, and OAC 2.636 mL. A desirability value close to 1 indicates that this combination satisfies all target responses simultaneously to a high degree [23]. This result is consistent with previous findings [19], which reported that an STPP:STMP ratio of 19:1 produced the highest degree of cross-linking, while a moderate temperature (~46°C) was sufficient to drive phosphorylation effectively without causing thermal degradation of the starch structure [24].

### 3.4 Structural Characterization of Modified Starch

FTIR spectra of native and modified ganyong starch (Figure 4) show a strong, broad absorption band near 3273 $cm^{-1}$ corresponding to O–H stretching, characteristic of the hydroxyl groups in starch-based carbohydrates. A slight shift from 3273.18 $cm^{-1}$ (native) to 3273.64 $cm^{-1}$ (modified), together with a change in transmittance depth from 91.95%T to 93.59%T, indicates a small reduction in free O–H groups after modification, consistent with intermolecular interaction during cross-linking [25]. The sharpest peak, corresponding to C–O–C stretching of the α-1,4 glycosidic bond, appeared at 997.01 $cm^{-1}$ (native) and 995.48 $cm^{-1}$ (modified), with a notable intensity change from 78.56%T to 83.97%T, reflecting a change in structural order rather than a new chemical bond. Critically, no new absorption band appeared near 1720 $cm^{-1}$ (ester C=O), confirming that the modification did not introduce new covalent ester groups

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detectable by FTIR and supporting a physically-interpreted cross-linking mechanism (Table 2).

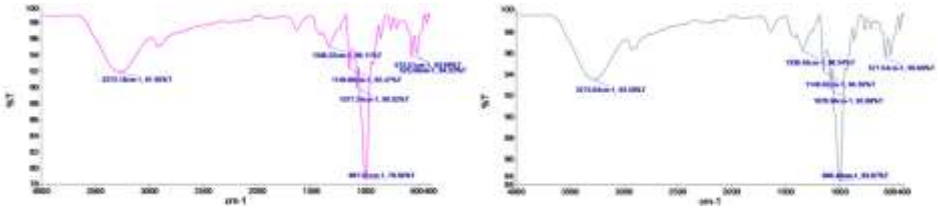


**Figure 4. FTIR spectra of (left) native and (right) modified ganyong starch**

**Table 2. FTIR absorption bands of native and modified ganyong starch**

| Functional group | Native ganyong starch ($cm^{-1}$) | Modified ganyong starch ($cm^{-1}$) |
|---|---|---|
| O–H stretching | 3273.18 | 3273.64 |
| O–H bending | 1336.22 | 1336.45 |
| C–O–C stretching | 1149.60 | 1149.52 |
| C–O stretching | 1077.24 | 1076.94 |
| C–O–C stretching | 997.01 | 995.48 |
| Skeletal vibration | 572.51 | 571.54 |
| Skeletal vibration | 525.58 | – |

SEM images of native and modified ganyong starch granules (Figure 5) show that both samples retain a similarly rounded-to-oval granule shape, indicating that cross-linking with STPP/STMP did not cause significant physical damage to the granules. Some minor changes were observed in the modified sample, including a reduced proportion of small granules, mild agglomeration among granules producing a more compact particle arrangement, and slight surface irregularities without evidence of cracking or granule rupture. These observations indicate that the cross-linking reaction occurred predominantly within the amorphous regions of the granule without disrupting overall granule morphology, consistent with previous findings [24,26], who reported that STPP/STMP-modified starch retained its granule shape and surface integrity after phosphorylation.

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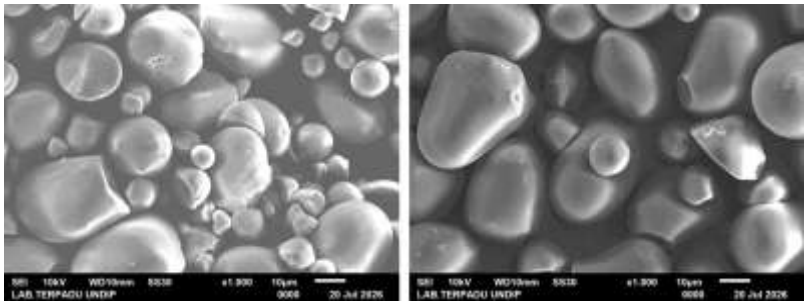


**Figure 5. SEM micrographs of (left) native and (right) modified ganyong starch granules (1000×)**

XRD diffractograms of native and modified ganyong starch (Figure 6) both show major diffraction peaks near 2θ = 15°, 17°, 18°, 23°, and 26° (Table 3), with the highest intensity peak at 17.18° (native) and 17.27° (modified), consistent with a B-type crystalline pattern typical of tuber starches [5,27]. A new peak appeared at 2θ = 11.47° (8.03% relative intensity) in the modified sample, which was not detected in the native sample, and relative intensities changed at several corresponding peaks — for example, an increase from 63.41% to 71.71% at ~15° and a decrease from 26.41% to 16.00% at 26.68°. The position of the major peaks did not shift significantly (< 0.3° difference), indicating that the fundamental crystal lattice was preserved while the degree of crystallinity and structural order changed as a result of cross-linking. This is consistent with the FTIR results, which similarly indicated a change in transmittance intensity at the 995–997 $cm^{-1}$ band without any shift attributable to a new chemical bond.

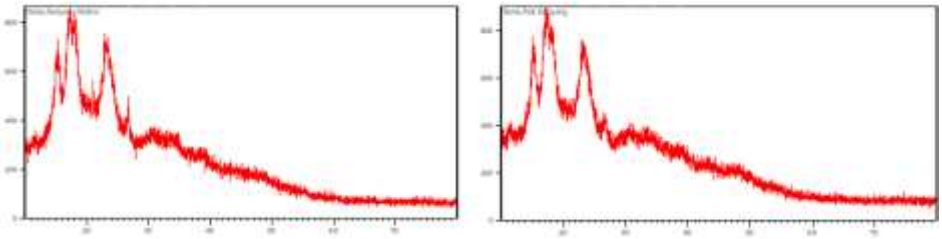


**Figure 6. XRD diffractograms of (left) native and (right) modified ganyong starch**

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**Table 3. XRD diffraction characteristics of native (NGS) and modified (MGS) ganyong starch**

| No. | NGS 2θ (°) | NGS Rel. Int. (%) | MGS 2θ (°) | MGS Rel. Int. (%) |
|---|---|---|---|---|
| 1 | – | – | 11.47 | 8.03 |
| 2 | 14.98 | 63.41 | 15.20 | 71.71 |
| 3 | 17.18 | 100.00 | 17.27 | 100.00 |
| 4 | 18.12 | 89.05 | 18.34 | 74.90 |
| 5 | 23.10 | 67.79 | 23.13 | 66.58 |
| 6 | 26.68 | 26.41 | 26.68 | 16.00 |
| 7 | 30.75 | 11.84 | 30.77 | 14.40 |
| 8 | 34.24 | 9.81 | 34.60 | 13.55 |
| 9 | 38.87 | 4.74 | 38.84 | 9.22 |

Overall, the FTIR, SEM, and XRD results are mutually consistent: the absence of new ester bands, the preservation of granule morphology, and the retention of the B-type crystal pattern together confirm that cross-linking modification of ganyong starch in this study was physical in nature, altering the degree of structural order without changing the fundamental granule or crystal structure.

## 4. CONCLUSION

Cross-linking modification of ganyong (Canna edulis Kerr) starch using a combination of STPP and STMP successfully altered its physicochemical properties compared with native starch, decreasing swelling power, solubility, and syneresis and changing WBC and OAC, confirming the formation of distarch phosphate cross-links that strengthen the granule structure and improve thermal and mechanical stability. The STPP:STMP ratio was the most dominant factor among the variables studied, with increasing ratio decreasing swelling power and solubility while increasing OAC; increasing temperature improved cross-linking effectiveness up to an optimum point, beyond which excessive heat (approaching 70°C) reduced modification effectiveness due to partial gelatinization. The optimum condition was obtained at an STPP:STMP ratio of 19:1 and a temperature of 45.907°C, with a desirability value of 0.928. FTIR, SEM, and XRD characterization confirmed that the cross-linking reaction proceeded as intended: no new functional groups (particularly the ester band near 1720 $cm^{-1}$) were detected, granule morphology remained largely round to oval without significant damage, and the B-type crystalline pattern characteristic of tuber starches was retained, with only a change in relative crystallinity. Because the success of the cross-linking reaction was inferred only indirectly, quantitative phosphorus content or degree-of-substitution analysis is recommended for future work, together with freeze–thaw stability testing over multiple cycles to evaluate the modified starch's suitability for cold-stored processed food products.

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## 5. REFERENCES

[1] Gabriel, A. A., Solikhah, A. F., Rahmawati, A. Y., Taradipa, Y. S., & Maulida, E. T. (2021). Potentials of edible Canna (Canna edulis Kerr) starch for bioplastic: a review. Industria: Jurnal Teknologi dan Manajemen Agroindustri, 10(2), 182-191.

[2] Noriko, N., & Pambudi, A. (2015). Diversifikasi pangan sumber karbohidrat canna edulis Kerr (Ganyong). Jurnal Al-Azhar Indonesia Seri Sains dan Teknologi, 2(4), 248-252.

[3] Sistem Informasi Pertanian Nasional. (2022). Data produksi umbi-umbian Indonesia. Kementerian Pertanian Republik Indonesia.

[4] Koida, A., Tanaka, M., Kosaka, R., Okuda, S., Takei, S., Ota, S., & Watanabe, H. (2024). Canna starch improves intestinal barrier function, inhibits allergen uptake, and suppresses anaphylactic symptoms in ovalbumin-induced food allergy in mice. Biomolecules, 14(2), 220.

[5] Tang, L., Wu, J., Aga, L., Wang, N., Li, Y., Li, H., & Wang, X. (2024). Structural analysis of type 3 resistant starch from Canna edulis during in vitro simulated digestion and its post-digested residue impact on human gut microbiota. Frontiers in Nutrition, 11, 1403497.

[6] Santoso, J. N., Soegijanto, S., Eldyjoe, A. G., Felicia, H., Jovita, G., Wiranti, R., & Astina, J. (2025). Canna (Canna edulis) flour's properties as Indonesian functional food to lower colorectal cancer risk. Indonesian Journal of Life Sciences, 7(1), 28–41.

[7] Lan, X., Liu, X., Yang, Y., Wu, J., & Wang, Z. (2017). The effect of lamellar structure ordering on the retrogradation properties of canna starch subjected to thermal and enzymatic degradation. Food Hydrocolloids, 69, 185–192.

[8] Marseno, D. W., Marsono, Y., Pranoto, Y., Ahmad, L., Harsanto, B. W., Pratama, B. P., et al. (2023). Teknologi Modifikasi Pati. UGM Press.

[9] Bangar, S. P., Sunooj, K. V., Navaf, M., Phimolsiripol, Y., & Whiteside, W. S. (2024). Recent advancements in cross-linked starches for food applications - a review. International Journal of Food Properties, 27(1), 411-430.

[10] Compart, J., Singh, A., Fettke, J., & Apriyanto, A. (2023). Customizing starch properties: A review of starch modifications and their applications. Polymers, 15(16), 3491.

[11] Ma, L., Liu, J., Cheng, Y., Frank, J., & Liang, J. (2025). Structural features, physiological functions and digestive properties of phosphorylated corn starch: A comparative study of four phosphorylating agents and two preparation methods. International Journal of Biological Macromolecules, 292, 139146.

ISSN: 2582-6271

Vol. 7, Issue.6, Nov-Dec 2026, page no. 18-30

[12] Harmayani, E., Murdiati, A., & Griyaningsih, G. (2011). Karakterisasi pati ganyong (Canna edulis) dan pemanfaatannya sebagai bahan pembuatan cookies dan cendol. *Agritech: Jurnal Fakultas Teknologi Pertanian UGM*, *31*(4), 92259.

[13] Santoso, B., Pratama, F., Hamzah, B., & Pambayun, R. (2015). Karakteristik fisik dan kimia pati ganyong dan gadung termodifikasi metode ikatan silang. Agritech, 35(3), 273–279.

[14] Kou, T., Song, J., Liu, M., & Fang, G. (2022). Effect of amylose and crystallinity pattern on the gelatinization behavior of cross-linked starches. Polymers, 14(14), 2870.

[15] Khikmah, N., Muflihati, I., et al. (2021). Optimasi modifikasi cross-linking pati ganyong menggunakan natrium asetat terhadap kekambaan bahan, kemampuan menyerap air dan minyak. Jurnal Sains dan Teknologi Pangan, 6(2), 115–123.

[16] Nor Sham, N. N. I., Yusoff, A., Ahmad, N., & Ab Mutalib, S. R. (2024). Response surface methodology for optimising cross-linking conditions of unripe banana (Musa balbisiana var. Abu) starch. Malaysian Journal of Analytical Sciences, 28(1), 127–140.

[17] Zhang, J., Tao, L., Yang, S., Li, Y., Wu, Q., Song, S., & Yu, L. (2024). Water absorption behavior of starch: A review of its determination methods, influencing factors, directional modification, and food applications. Trends in Food Science & Technology, 144, 104321.

[18] Wang, C., Fang, S., Ren, C., Huang, C., Zhu, H., Zhang, X., & Zhao, J. (2023). Cross-linked modifications of starches from colored highland barley and their characterizations, digestibility, and lipolysis inhibitory abilities in vitro. Food Research International, 174, 113493.

[19] Kumar, Y., Singh, S., & Saxena, D. C. (2025). A comprehensive review on methods, mechanisms, properties, and emerging applications of crosslinked starches. International Journal of Biological Macromolecules, 306, 141526.

[20] Wu, Z. W., Han, J. Y., Zhao, X. Y., Wei, Y. Y., Cai, X. S., Liu, H. M., et al. (2024). Impact of high temperature on microstructural changes and oil absorption of tigernut (Cyperus esculentus L.) starch: Investigations in the starch-oil model system. Carbohydrate Polymers, 328, 121711.

[21] Liu, Y., Chao, C., Yu, J., Wang, S., Wang, S., & Copeland, L. (2020). New insights into starch gelatinization by high pressure: Comparison with heat-gelatinization. Food Chemistry, 318, 126493.

[22] Shukri, A., & Cheng, L. H. (2023). The properties of different starches under the influence of glucono-delta-lactone at different concentrations. Foods, 12(9), 1770.

ISSN: 2582-6271

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[23] Mantegazini, D. Z., Nascimento, A., Mathias, M. H., Romero Guzman, O. J., & Reich, M. (2025). Optimization of rate of penetration and mechanical specific energy using response surface methodology and multi-objective optimization. Applied Sciences, 15(3), 1390.

[24] Malik, M. K., Kumar, V., Singh, J., Bhatt, P., Dixit, R., & Kumar, S. (2023). Phosphorylation of alkali extracted mandua starch by STPP/STMP for improving digestion resistibility. ACS Omega, 8(13), 11750-11767.

[25] Wahdaningsih, S., Untari, E. K., Fajriaty, I., & Hariono, M. (2022). Identifikasi gugus fungsi fraksi etil asetat dan fraksi n-heksan Hylocereus polyrhizus (F.A.C.Weber) Britton & Rose. Jurnal Pharmascience, 9(1), 113.

[26] Agvaandorj, E., Li, Y., Pan, Z., & Li, H. (2024). Effects of structural changes in cross-linked mung bean starch on freeze–thaw properties and in vitro digestibility. Foods, 14(689), 1–15.

[27] Gabriel, A. A., Rahmawati, A. Y., Taradipa, Y. S., Enomae, T., Fauzan, R. M. M. N., Thangunpai, K., Indramawarni, S., Halim, A., & Ihsanpuro, S. I. (2024). Canna edulis ker. starch-based biodegradable plastic materials: Mechanical and morphological properties.