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Correlation Study Between Modification Types and Characteristics of Cassava Starch (*Manihot utilissima*) Using Pearson Correlation

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Abstract:
Starch modification is a process that can improve the properties of starch, so that it has good characteristics. Research on the modification of cassava starch using various modification methods resulted in changes in the characteristics of cassava starch. There are various results regarding the type of modification and their resulting characteristic of modified starch. This research aimed to obtain certain characteristics of cassava starch that have the potential to be modified using certain types of starch modification. The data used in this research is secondary data through searching scientific publications. The type of starch modification was consist of pre-gelatinization, cross-linking, acid hydrolysis, HMT, and fermentation while the starch characteristics were swelling power, solubility, water absorption, peak viscosity, and breakdown viscosity. The data collected was analyzed using Pearson's correlation. The correlation between the type of modification and swelling power and WAC is moderate, while the correlation between type of starch modification and solubility, peak viscosity, and breakdown viscosity are very weak. Swelling power and WAC are the characteristics of cassava starch that have the most potential to be modified with predictable results, while changes in solubility, peak viscosity, and breakdown viscosity in various types of modification are difficult to predict, because many other factors are involved besides the type of modification.

Keywords: cassava; cassava starch; correlation; starch modification

1. Introduction

Cassava tubers are one of the local resources that are very widely available in Indonesia, in fact in Indonesia, cassava is included in the second-class commodity (secondary crops) after rice. Cassava tubers are also a plant that is very resistant to pest attacks and the planting process is not too difficult so cassava tubers are very easy to cultivate (Suryani and Nisa, 2015). The enormous potential of cassava should be developed so that its use is not limited to just being a food ingredient as has been the case so far (Hidayat et al., 2009).

Cassava (*Manihot utilissima*) is the main and highest starch producer compared to other plants such as rice and corn. Cassava tubers have an average starch content of 73.7-84.9% (dry basis). Cassava starch has very broad benefits in both the food and non-food industries. The use of cassava starch depends on the physicochemical properties of the starch, one of which is related to the proportion of amylose and amylopectin (Noerwijati, 2015).

Based on its use, cassava starch which is often used in the food industry can be divided into two, namely natural starch and modified starch. Natural starch is starch that still maintains its natural structure and characteristics. In the food industry, the use of natural starch is still limited because natural starch does not have certain desired functional properties. If heated, starch granules absorb water very easily, swell, form a gel, viscosity increases and decreases quickly. Modified starch is natural starch that has undergone changes in physical and chemical properties. Modifications are made to change the shape of the granules or change the composition of amylose and amylopectin. The modification aims to modify the gelatinization ability, reduce retrogradation, reduce the tendency of the paste to gel, improve the texture of the paste and gel, increase stability and improve adhesion between surfaces, and increase the clarity of the paste and gel (Noerwijati, 2015).

Starch modification is very important in overcoming the deficiencies in the functional properties of natural starch, so that modified natural starch can be used according to needs (Noerwijati, 2015). Some of the weaknesses of cassava starch are low stability and paste resistance because natural starch cannot withstand hot and acidic conditions (Singh et al., 2004). Starch modification is an alternative method that can improve the properties of starch polymers, so that they have good characteristics and stability so that they can be applied in the food industry (Young An, 2005).

According to Jayus et al. (2016) various methods that can be used to modify starch are chemical, enzymatic, physical and microbiological. Modified cassava starch can be used as a food ingredient with wider uses, including noodle products, bread, drinks and pudding. According to Sriroth et al. (2005) the most widely used methods for modifying starch are chemical modification using acids, oxidation and cross-linking as well as enzymatic modification. Kusnandar (2010) explains that chemical modification of starch is hydrolysis with acid. Starch modified by acid hydrolysis will produce starch with low viscosity which occurs during cooking. Enzymatic modification uses the α-amylase enzyme which produces starch with a stable viscosity at high and low temperatures. Physical modification of starch is carried out by heating starch at high temperatures, the resulting starch can be a change in the starch crystal structure where the starch crystals become resistant during gelatinization.

Research on cassava starch modification has been carried out using various modification methods. The results obtained show that several types of modifications can produce changes in certain parameters. For example, starch resulting from modification using an esterification process and cross-linking can increase starch stability (Effendy, 2016). Another example is modification using ozone (Maniglia et al., 2019) and acid (Chatpapamon et al., 2019) which is known to affect the viscosity of cassava starch. With the various results that have been published, a study is needed that can provide information about the relationship between the types of starch modification and the characteristics of cassava starch, so that it can be known which type of modification has the strongest relationship with one of the starch characteristic parameters. Literature study is an important step in building a theory, with the data obtained, through literature study it will provide answers to the problems raised. According to Bahry (1995) literature study is a series of processes for studying research results published by previous research to support the research being conducted. A similar opinion was expressed by Roselle and Spray (2012) that in general, literature studies are carried out to evaluate the research carried out, not just to build general knowledge.

2. Research Methods

Research Design

This research collected data and information with the help of book materials and other literature as the main object (Hadi, 1995). Literature studies can be obtained from various sources, including scientific journals or articles, books, documentation, the internet, and encyclopedias. The literature used in this literature study is research articles from the last 5-10 years with the selection of research results based on almost the same raw materials, variables and analytical tests. This aims to compare the results of one research with other research, so that it can be used as data, analysis, and conclusions can be drawn.

Sources and Data Collection Methods

The data used in this research is secondary data obtained through searching scientific publications. Searching scientific publications is carried out to obtain scientific publications of research results at both national and international levels. Scientific searches are carried out on the following databases:

1. Science direct (https://www.sciencedirect.com/)
2. Google scholar (https://scholar.google.com/)

The keywords used are "cross-linking cassava starch", "pregelatinized cassava starch", "HMT cassava starch", "acid hydrolysis of cassava starch", "fermentation of cassava starch", "HMT cassava starch", fermented cassava starch, and cross-linked cassava starch.” In this research, the scientific publications used are publications where articles are available in full text.

Article data collection was carried out by filtering based on predetermined criteria. The article data collection criteria can be seen in the table. 2 and 3.

The data analyzed for correlation in this research were the type of starch modification and the characteristics of cassava starch. Types of starch modification consist of pregelatinization, crosslinking, acid hydrolysis, HMT, and fermentation. The characteristics of cassava starch consist of swelling power, solubility, water absorption capacity, peak viscosity and breakdown viscosity.

Table 1. Inclusion criteria in literature review.

Criteria	Inclusion
Time Frame	- Publication dates for the last 10 years starting from 2011 to 2021
Languages	- Indonesian and English
Subject	- Types of Modification and Characteristics of Cassava Starch
Type of article	- Original article, such as a journal, proceedings thesis - Not just in abstract form - Article in full text form - There is suitability of writing keywords
Theme of the content of the article	- There is a connection between research results and discussion of potential types of modification to the characteristics of cassava starch

Table 2. Exclusion in literature review

Criteria	Exclusion
Testing Parameters	- There are some common testing parameters that are not performed - The units in the results of each test are different and cannot be converted
Method	- The method used is less understandable (not clear)
Article Identity	- The identity of the article is unclear

Table 3. Numbers of publication based on exclusion criteria.

Search engine	Keywords	Total article	Exclusion criteria	Articles used
Sciense direct	Pregelatinised of cassava starch	288 articles	➢ 251 articles cannot be downloaded. ➢ 8 articles do not match the year of publication. ➢ 21 articles do not match the title. ➢ 3 articles do not have the desired test. ➢ 1 article with unclear identity. ➢ 1 article with unclear numerical data.	3 articles
	Cross link of cassava starch	2.832 articles	➢ 2.741 articles cannot be downloaded. ➢ 2 articles do not match the year of publication. 83 articles do not match the title. ➢ 1 article do not have the desired test. ➢ 1 article with unclear identity.	6 articles
	Acid hydrolysis of casssava starch	4.653 articles	➢ 4.543 articles cannot be downloaded. ➢ 2 articles do not match the year of publication. ➢ 91 articles do not match the title. ➢ 2 articles did not include starch concentration ➢ 2 articles do not have the desired test. ➢ 1 article with unclear identity.	10 articles
	HMT of cassava starch	159 articles	➢ 136 articles cannot be downloaded. ➢ 2 articles do not match the year of publication. ➢ 16 articles do not match the title. ➢ 1 article do not have the desired test.	4 articles
	Fermentation of cassava starch	4.817 Articles	➢ 4.692 articles cannot be downloaded. ➢ 3 articles do not match the year of publication. ➢ 116 articles do not match the title.	3 articles

Search engine	Keywords	Total article	Exclusion criteria	Articles used
			➢ 2 articles do not have the desired test. ➢ 1 article with unclear numerical data.	
Google scholar	HMT cassava starch	198 articles	➢ 33 articles cannot be downloaded. ➢ 32 articles do not match the year of publication. ➢ 132 articles do not match the title.	4 articles
	Fermented cassava starch	4.100 articles, 150 articles taken	➢ 41 articles cannot be downloaded. ➢ 18 articles do not match the year of publication. ➢ 87 articles do not match the title.	4 articles
	Cross-linked cassava starch	186 articles	➢ 48 articles cannot be downloaded. ➢ 42 articles do not match the year of publication. ➢ 95 articles do not match the title.	1 article
Total				32 articles

Finally, 32 articles were found that met the inclusion criteria, while the other articles met the exclusion criteria. Of the 32 articles used in the research study of the correlation between the type of modification and characteristics of cassava starch, 17 articles for characteristics of cassava starch swinging power, 8 articles for characteristics of cassava starch WAC, 18 articles for characteristics of cassava starch solubility, 13 articles for characteristics cassava starch peak viscosity and 13 articles for cassava starch breakdown characteristics.

Data Analysis

The data collected was then analyzed using Pearson's correlation. Person correlation is used to determine whether there is a relationship between two variables and is one of the correlation measures used to measure the strength and direction of the linear relationship between two variables. The results of this analysis were carried out to find out the magnitude of the relationship between the type of starch modification and the characteristics of the starch and to find out how strong this relationship is. Correlation analysis is a statistical method used to measure the closeness of the relationship between two or more variables. Data analysis in this research uses the help of a statistical software application, namely SPSS 25 (Statistical Package for the Social Sciences version 25). From the correlation analysis carried out, a value is obtained which is called the correlation coefficient. The correlation coefficient (KK) is an index or number used to measure the degree of relationship, including the strength of the relationship and the form/direction of the relationship. For the strength of the relationship, the correlation coefficient value is between +1 and -1. For the form/direction of the relationship, the correlation coefficient value is expressed as positive (+) and negative (-), or ($-1 \leq KK \leq +1$) (Misbahudin and Hasan, 2013).

Table 4. Interval of correlation coefficient values

No	Interval Value	Strength of Relationship
1	KK = 0,00	No correlation
2	0,00 < KK ≤ 0,20	Very low or very weak correlation
3	0,20 < KK ≤ 0,40	Weak or low correlation
4	0,40 < KK ≤ 0,70	Moderate or fair correlation
5	0,70 < KK ≤ 0,90	High or strong correlation
6	0,90 < KK < 1,00	Very high or very strong correlation
7	KK = 1,00	Perfect correlation

Source: Misbahudin dan Hasan (2013).

3. Results and Discussion

Correlation between Modification Types and Characteristics of Cassava Starch

Based on the table above, it can be explained that the characteristics of cassava starch swelling power have a significance value of 0.00 and a correlation value of -0.45, WAC has a significance value of 0.00 and a correlation value of 0.50, meaning that the characteristics of cassava starch swelling power and WAC are significant to the type of starch modification with moderate correlation. While the characteristics of cassava starch, solubility has a significance value of 0.06 and a correlation value of 0.13, maximal viscosity has a significance value of 0.77 and a correlation value of 0.03 and breakdown has a significance value of 0.43 and a correlation value of -0.08, meaning that the characteristics of the starch Cassava solubility, maximum viscosity and breakdown are not significant to the type of starch modification with a very weak correlation. Therefore, manipulation of the characteristics of cassava starch in the form of swelling power and WAC is most potentially carried out through the starch modification process because changes in these starch characteristics can be predicted through starch modification, while the changes in the characteristics of solubility, peak viscosity and breakdown cannot be predicted through starch modification.

Table 5. Correlation between modification type and characteristics of cassava starch

Charcteristics	Correlation Coefficient	Significance
Swelling Power (gram)	-0,45	0,00
WAC (gram)	0,50	0,00
Solubility (%)	0,13	0,06
Maximal Viscosity (cP)	0,03	0,77
Breakdown (cP)	-0,08	0,43

Swelling Power

Swelling power is one of the important characteristics of starch which shows the ability of starch to expand during the heating process in the presence of water. Swelling power of starch is the maximum increase in volume and weight that occurs in starch in water. Swelling power shows the ability of starch to expand in water. Swelling power is calculated by weighing the gel produced after gelatinization (Dewi, et al., 2014). According to Leach, (1959) the swelling power value of starch can be calculated using the equation:

$$Swelling\ power = \frac{dry\ paste\ weight}{dry\ starch\ sample\ weight}$$

The analysis from 17 research articles shows that the type of starch modification and starch swelling power have a moderate correlation with a correlation value of -0.45. This is based on the opinion of Misbahudin and Hasan, (2013) who state that the percent correlation value ranges from 0.40 to 0.70, meaning the correlation is moderate or sufficient. The type of modification and characteristics of cassava starch swelling power have an inverse relationship, indicated by the percent correlation value which is negative. This means that the higher the value of the type of modification, the lower the value of the swelling power of cassava starch. The sequence used in this research is pre-gelatinization, crosslinking, acid hydrolysis, HMT and fermentation (Figure 4). The results of the correlation analysis will change if the sequence value of the type of modification is changed. The sequence of modification types that gives the highest correlation value to the swelling power characteristics of cassava starch is pre-gelatinization, crosslinking, acid hydrolysis, fermentation, and HMT with a moderate correlation value, namely -0.52. The correlation between the type of modification and the swelling power characteristics of cassava starch has a significance value of less than 5%, meaning that this correlation is significant.

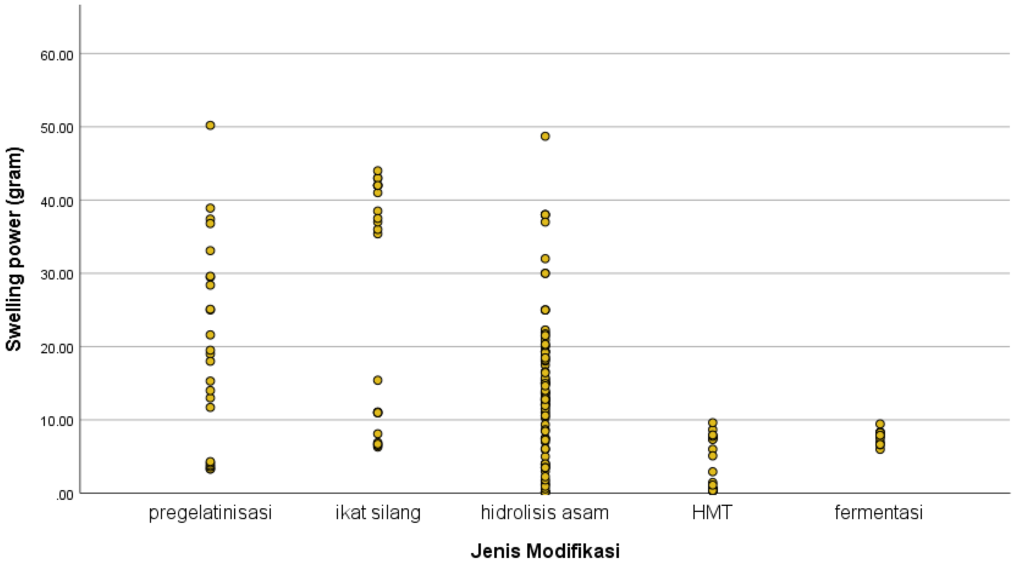

Figure 1. Correlation of modification type and swelling power of starch.

Table 6. Partial correlation of type of modification and swelling power of cassava starch.

No	Control variable	KK	P
1	Starch concentration (%)	-0,45	<0,05
2	Chemical Compound Concentration (%)	-0,47	<0,05
3	Time (Hours)	-0,57	<0,05
4	Temperature (^{0}C)	-0,19	<0,05

The use of control variables of starch concentration, concentration of chemical compounds, and time did not change the correlation value, but the use of the control variable temperature, changed the analysis results to a very weak correlation. This means that temperature is a factor that plays a role in determining the swelling power value. Based on the sequence, the following types of starch modification can reduce the swelling power of modified starch, namely starch modification by pre-gelatinization, cross-linking, acid hydrolysis, HMT and fermentation. Pregelatinized modified starch is starch that has undergone gelatinization and then drying. Heating starch paste in water will cause the water molecules around the granules to break hydrogen bonds, enter the granules and the granules will expand irreversibly (Wurzburg, 1989). Purnamasari et al., (2010) said that the larger the granule size allows the starch to absorb more water easily and therefore swell easily, causing the starch to undergo gelatinization more easily. The gelatinization process causes hydration and expansion of granules, loss of birefringent properties, increased clarity, increased consistency and achievement of peak viscosity (Pomeranz, 1991).

In contrast to pre-gelatinization, crosslinking is a modification of starch that connects one polymer chain to another polymer chain. Stevens, (2001) stated that cross-linking in a polymer can influence the degree of swelling power of starch. In the presence of a solvent, a cross-linked polymer will expand when the solvent molecules penetrate its network. The degree of this expansion depends on the degree of cross-linking and the affinity between the solvent and the polymer. Wenten, (1999) stated that the factor that influences the swelling character is the crosslinking agent ratio. The greater the crosslinking agent ratio, the tighter the copolymer structure will be, so that it is difficult for water molecules to enter the copolymer, this results in a reduced degree of swelling compared to the same copolymer with a lower crosslinking agent ratio.

Modification by acid hydrolysis is a process of inserting or replacing H atoms into the OH groups in starch to form chains that tend to be longer and can change the physicochemical and rheological properties of starch. When acid hydrolysis takes place, the amylose group will be reduced, this is because amylose molecules are easily broken down compared to amylopectin molecules (Pudjihastuti and Siswo, 2011). Sumardiono and Pudjihastuti, (2015) conducted research with modified cassava starch using lactic acid hydrolysis and UV, showing that the longer the UV lamp exposure, the higher the swelling power value, while the increasing concentration of lactic acid means the lower the swelling power value.

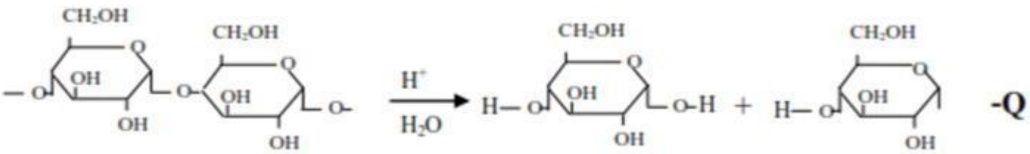

Figure 2. Starch hydrolysis reaction using acid (Pudjihastuti and Siswo, 2011).

One of the physical starch modifications currently being developed is heat moisture treatment, namely the process of modifying starch using high heat. The energy received by starch during heating allows the weakening of inter- and intermolecular hydrogen bonds of amylose and amylopectin in starch granules. This condition provides an opportunity for water to imbibe starch granules. Imbibition of water during the HMT modification process causes a rearrangement of the amylose and amylopectin molecules in the starch granules. The rearrangement of granule molecules has implications for changes in the physical and chemical properties of starch (Herawati, 2009). Changes in the volume of swollen starch granules (Collado and Corke, 1999).

Fermentation is a modification method using the help of microorganisms. The basic principle of fermentation is to activate certain microbial activities with the aim of changing the properties of the material so that something useful is produced. This change occurs because in the fermentation process the number of microbes is increased and their metabolism in the material is activated to a certain extent (Assegaf, 2009). Subagio, (2006) in his research concluded that the microbes that grow on cassava during the soaking process will produce pectinolytic and cellulotic enzymes which can destroy the cell walls of wood tubers resulting in the release of starch granules. The extracellular amylase enzyme is then produced by bacteria to break down the starch in cassava into simple compounds as energy for activity and growth. Extracellular amylase is an enzyme that is able to degrade amylose into a simpler compound, namely glucose. The degradation process results in more and more water being bound in the rehydration process, this causes the starch granules to swell and expand so that the swelling power increases. Fermentation assisted with the lactic acid bacteria starter Lactobacillus casei is considered to be able to improve the swelling power and level of cassava starch development (Kusumaningrum and Siswo, 2016).

Water Absorption Capacity (WAC)

Water absorption capacity of starch is the ability of starch to absorb water. Dewi, (2008) states that water absorption capacity is the product's ability to absorb water optimally. According to Kaisangsri et al., (2014) the water absorption capacity value of starch can be calculated using the equation:

$$\text{Water absorption capacity} = \frac{W1-W2}{W1}$$

The results of correlation analysis from 8 research articles show that the type of starch modification and the water absorption capacity of starch have a moderate correlation with a correlation value of 0.50. This is based on the opinion of Misbahudin and Hasan, (2013) who state that the percent correlation value ranges from 0.40 to 0.70, meaning the correlation is moderate or sufficient. The type of modification and water absorption characteristics of cassava starch have a unidirectional relationship, indicated by the percent correlation value which is positive. This means that the higher the value of the type of modification, the higher the value of the water absorption capacity of cassava starch. The sequences used in this research are pre-gelatinization, crosslinking, acid hydrolysis, HMT, and fermentation (Figure 3). The results of the correlation analysis will change if the sequence value of the type of modification is changed, the sequence of modification types that gives the highest correlation value to the characteristics of WAC cassava starch is acid hydrolysis, pre-gelatinization, crosslinking, fermentation, and HMT with a moderate correlation value of 0.52.

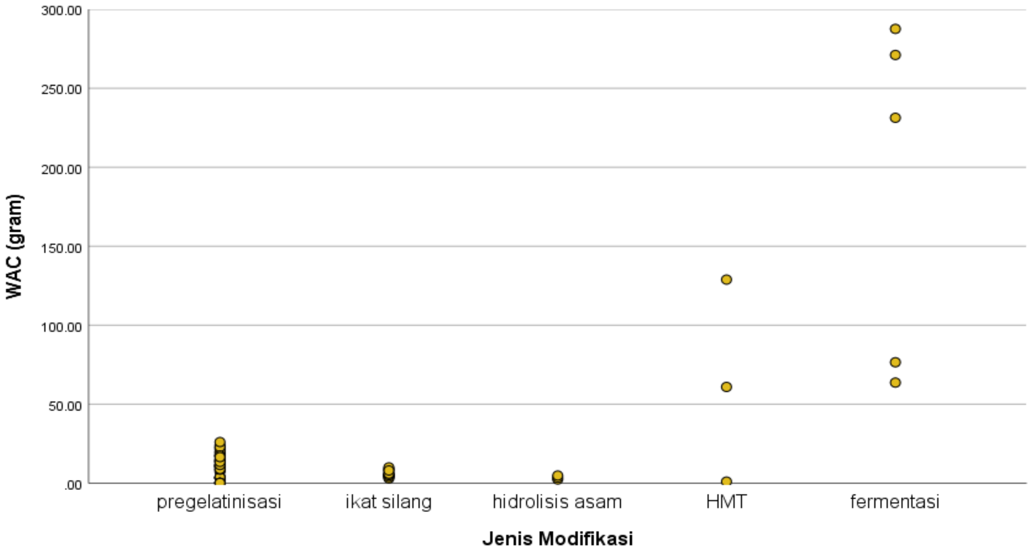

Figure 3. Correlation of modification type and WAC of starch.

Table 7. Partial correlation of modification type and WAC of cassava starch.

No	Control Variables	KK	p
1	Starch Concentration (%)	0,50	<0,05
2	Chemical Compound Concentration (%)	0,50	<0,05
4	Time (Hours)	0,32	>0,05
5	Temperature (^{0}C)	0,92	<0,05

The use of control variables for starch concentration and concentration of chemical compounds does not change the correlation value, however the use of the time control variable changes the analysis results to a weak correlation, and the use of the temperature control variable changes the analysis results to a very strong correlation. This means that time and temperature are factors that play a role in determining the WAC value. Based on the sequence, the following types of starch modification can increase the water absorption capacity of modified cassava starch, namely starch modification by pre-gelatinization, cross-linking, acid hydrolysis, HMT, and fermentation. Pregelatinized modified starch is starch that has undergone gelatinization and then drying. Hidayat et al., (2009) reported that the starch pre-gelatinization method has better water absorption characteristics than the sawut method. The higher water absorption value of cassava starch using the pre-gelatinization method is thought to be related to the hydrolysis of the starch and the formation of simpler components in the form of dextrin. According to Marchal et al., (1999) that starch derivative products have better water absorption capacity than original starch.

In contrast to pre-gelatinization, the starch modification method by crosslinking or what is usually called cross-linking is a starch modification that connects one polymer chain to another polymer chain. Yustiawan, et al., (2019) reported that the cross-linking method can increase the water absorption capacity of starch. The more phosphate compounds given, the more phosphate starch cross-linking will occur, and the more water will penetrate into the starch granules.

Modification by acid hydrolysis is a process of inserting or replacing H atoms into the OH groups in starch to form chains that tend to be longer and can change the physicochemical and rheological properties of starch. When acid hydrolysis takes place, the amylose group will be reduced, this is because amylose molecules are easily broken down compared to amylopectin molecules (Pudjihastuti and Siswo, 2011). Greenwood and Munro, (1979) explained that modification of starch by acid hydrolysis, where the acid will degrade the cell walls, causing damage and the integrity of the starch granules, causing the starch to absorb water. Sumardiono and Pudjihastuti, (2015) conducted research by modifying cassava starch using lactic acid hydrolysis and UV, showing that the longer the hydrolysis time, the less the starch chains and the starch chains tend to be shorter and absorb water more easily.

One of the physical starch modifications currently being developed is heat moisture treatment, namely the process of modifying starch using high heat. The energy received by starch during heating allows the weakening of inter- and intermolecular hydrogen bonds of amylose and amylopectin in starch granules. This condition provides an opportunity for water to imbibe starch granules. Imbibition of water during the HMT modification process causes a rearrangement of the amylose and amylopectin molecules in the starch granules. The rearrangement of granule molecules has implications for changes in the physical and chemical properties of starch (Herawati, 2009). Livia (2020) stated that the modification method of combining HMT with lintnerization can increase the water absorption value of starch.

Fermentation is a modification method that uses the help of microorganisms. The basic principle of fermentation is to activate certain microbial activities with the aim of changing the properties of the material so that something useful is produced. This change occurs because in the fermentation process the number of microbes is increased and their metabolism in the material is activated to a certain extent (Assegaf, 2009). Fermentation has varying impacts on the calculation of water absorption capacity. In general, the longer the fermentation, the more water absorption capacity increases. Fermentation causes the starch granules to break down so that when dried the starch easily absorbs water (Efendi, 2010).

Solubility

Solubility is an indication of the degree to which starch can dissolve in water (Janathan, 2007). According to Kiatponglarp, (2007) the solubility value of starch can be calculated using the formula:

$$\textit{Solubility}\ (\%) = \frac{\textit{weight of dissoloved solids}}{\textit{weight of dry starch sample}} \text{ x } 100$$

The results of correlation analysis from 18 research articles show that the type of starch modification and starch solubility have a very weak or very low correlation with a correlation value of 0.13. This is based on the opinion of Misbahudin and Hasan, (2013) who state that the percent correlation value ranges from 0.00 to 0.20, meaning the correlation is very weak or very low. The type of modification and the solubility characteristics of cassava starch have a unidirectional relationship, indicated by the percent correlation value which is positive. This means that the higher the value of the modification type, the higher the value of cassava starch solubility. The sequence used in this research is pre-gelatinization, crosslinking, acid hydrolysis, HMT, and fermentation (Figure 7). The results of the correlation analysis will change if the sequence value of the type of modification is changed, the sequence of modification types that gives the highest correlation value to the solubility characteristics of cassava starch is cross-linking, HMT, pre-gelatinization, fermentation, and acid hydrolysis with a weak correlation value of 0.31.

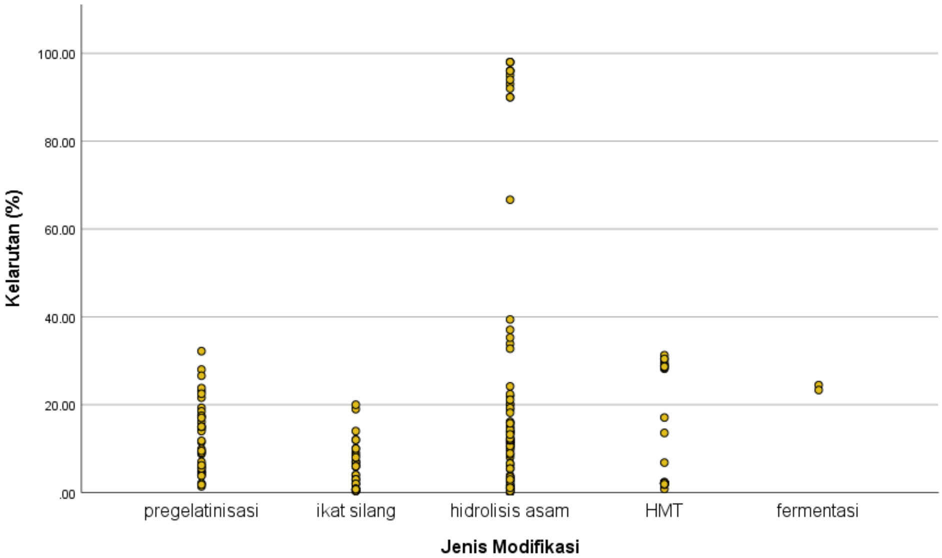

Figure 4. Correlation of modification type and starch solubility.

Table 8. Partial correlation of type of modification and solubility of cassava starch.

No	Control Variables	KK	P
1	Starch Concentration (%)	0,17	<0,05
2	Chemical Compound Concentration (%)	0,07	>0,05
4	Time (Hours)	-0,04	>0,05
5	Temperature (^{0}C)	0,32	<0,05

The use of control variables for starch concentration and concentration of chemical compounds does not change the correlation value, however the use of the time control variable changes the analysis results to a negative value, and the use of the temperature control variable changes the analysis results to a weak correlation. This means that time and temperature are factors that play a role in determining the solubility value. Based on the sequence, the following types of starch modification can increase the solubility of modified starch, namely starch modification by pre-gelatinization, cross-linking, acid hydrolysis, HMT, and fermentation. Pregelatinized starch is starch that has undergone gelatinization by heating the starch paste above its gelatinization temperature and then drying it. Gelatinization is heating starch paste in water which will cause the water molecules around the granules to break hydrogen bonds, enter the granules and the granules will expand irreversibly (Wurzburg, 1989). Luallen, (1988) stated that the level and technique of modification as well as the drying method are factors that cause variations in the functional properties of pregelatinized starch. According to Rogol, (1986) pregelatinized starch has the ability to dissolve easily in cold water compared to ordinary starch.

In contrast to pre-gelatinization, crosslinking is a modification of starch that connects one polymer chain to another polymer chain. The low solubility can be attributed to the presence of cross-links that prevent the amylopectin molecules from leaching, in addition to the inefficient oxidation process indicated by the lower carboxyl of the carbonyl. The abundant free radicals that are formed are destructive and cause the oxidation process to not run efficiently (Wang and Wang, 2003). Another opinion, Adebowale, et al., (2005) is that the increase in solubility can be associated with depolymerization and weakening of the starch structure due to the oxidation process.

Modification by acid hydrolysis is a process of inserting or replacing H atoms into the OH groups in starch to form chains that tend to be longer and can change the physicochemical and rheological properties of starch. When acid hydrolysis takes place, the amylose group will be reduced, this is because amylose molecules are easily broken down compared to amylopectin molecules (Pudjihastuti and Siswo, 2011). Erezka, et al., (2018) shows that hydrolysis with lactic acid increases the solubility of starch in water due to structure destruction which produces a simple and more hydrophilic product. The replacement of hydroxyl groups by more non-polar groups reduces the cohesive force between the molecules involved, causing an improvement in the flow properties of starch. The addition of lactic acid will reduce the pH value so that the size of the starch molecules becomes smaller so that the starch will easily dissolve in water.

One of the physical starch modifications currently being developed is heat moisture treatment, namely the process of modifying starch using high heat. According to Herawati, (2009) the energy received by starch during heating allows the weakening of inter- and intra-molecular hydrogen bonds of amylose and amylopectin in starch granules, this condition provides an opportunity for water to imbibe the starch granules. The limited amount of water causes the movement and formation of interactions between water and amylose or amylopectin molecules to be limited so that the solubility of starch in water does not increase during heating. Collado and Corke, (1999) stated that modification using HMT can cause changes in the solubility of starch.

Fermentation is a modification method using the help of microorganisms. The basic principle of fermentation is to activate certain microbial activities with the aim of changing the properties of the material so that something useful is produced. This change occurs because in the fermentation process the number of microbes is increased and their metabolism in the material is activated to a certain extent (Assegaf, 2009). Fermentation affects the solubility value of starch. Diniyah, et al., (2018) reported that the solubility value of starch tends to increase with longer fermentation time. This was explained by Choi and Keer (2004) that the cell liberation that occurs during fermentation will cut the bonds in starch so that its structure becomes simpler and some of it also changes to its basic structure, namely glucose, so that it becomes water soluble.

Peak Viscosity

Peak viscosity is the maximum point of viscosity of the paste produced during heating. (Glicksman, 1969). Viscosity indicates the condition where starch granules begin to gelatinize or reach maximum expansion until they burst. Viscosity can also be an indication of the water binding strength of a starch (Liu et al., 2017).

The results of correlation analysis from 13 research articles show that the type of starch modification and the peak viscosity of starch have a very weak or very low correlation with a correlation value of 0.03. This is based on the opinion of Misbahudin and Hasan, (2013) who state that the percent correlation value ranges from 0.00 to 0.20, meaning the correlation is very weak or very low. The type of modification and peak viscosity characteristics of cassava starch have a unidirectional relationship, indicated by the percent correlation value which is positive. This means that the higher the value of the type of modification, the higher the peak viscosity value of cassava starch. The sequences used in this research are pre-gelatinization, crosslinking, acid hydrolysis, HMT, and fermentation (Figure 8). The results of the correlation analysis will change if the sequence value of the type of modification is changed, the sequence of modification types that gives the highest correlation value to the characteristics of peak viscosity cassava starch is cross-linking, HMT, fermentation, pre-gelatinization, and acid hydrolysis with a weak correlation value of -0.28.

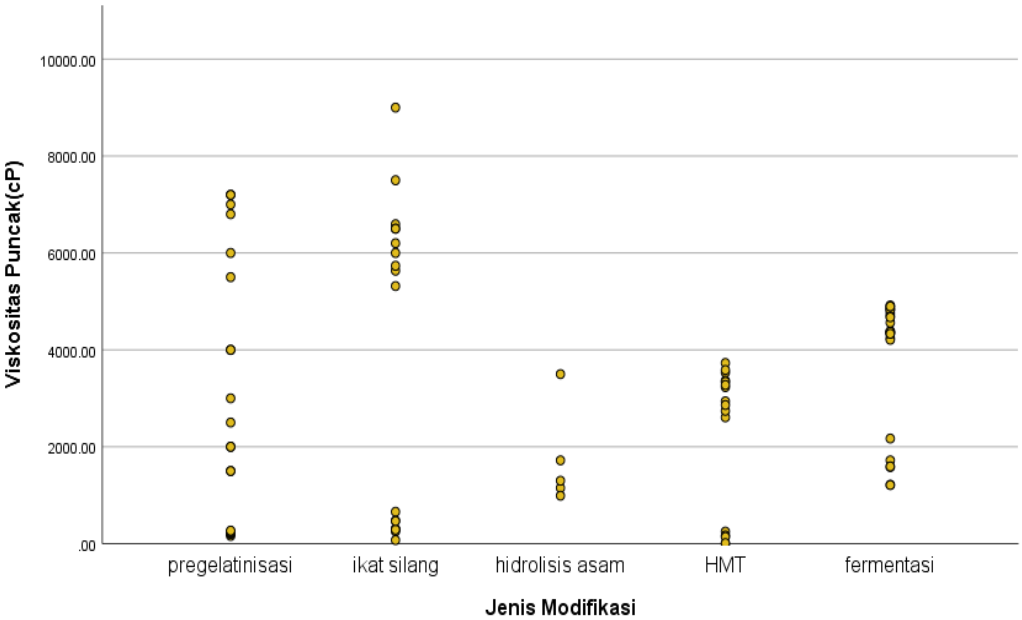

Figure 5. Correlation of modification type and maximum viscosity of starch.

Table 9. Partial correlation of modification type and maximum viscosity of cassava starch.

No	Control Variables	KK	p
1	Starch Concentration (%)	0,17	>0,05
2	Chemical Compound Concentration (%)	-0,07	>0,05
3	pH	-0,26	>0,05
4	Time (Hours)	0,87	<0,05
5	Temperature (^{0}C)	0,02	>0,05

The use of control variables for starch concentration and temperature does not change the correlation value, but the use of the control variable for chemical compound concentration changes the analysis result value to negative, pH changes the analysis result value to negative and weak, and the use of the time control variable changes the analysis result to a strong correlation. This means that the concentration of chemical compounds, pH and time are factors that play a role in determining the peak viscosity value. Based on the sequence, the following types of starch modification can increase the peak viscosity of modified cassava starch, namely starch modification by pre-gelatinization, cross-linking, acid hydrolysis, HMT, and fermentation.

Pregelatinized modified starch is starch that has undergone gelatinization and then drying. Wurzburg, (1989) explains the modification of pre-gelatinization where when heating the starch paste in water it will cause the water molecules around the granules to break hydrogen bonds, enter the granules and the granules will swell irreversibly, during the gelatinization process the amylopectin will remain in the granules, whereas amylose will be released and solubilized into the solution to form an intergranular matrix resulting in an increase in viscosity. The gelatinization process causes hydration and expansion of granules, loss of birefringent properties, increased clarity, increased consistency and achievement of peak viscosity (Pomeranz, 1991).

In contrast to pre-gelatinization, crosslinking is a modification of starch that connects one polymer chain to another polymer chain. According to Kusnandar, (2010) cross-linked starch is obtained by reacting starch with polyfunctional compounds that can react with OH groups in the amylose or amylopectin structure to form cross-links or bridges that connect one starch molecule with other molecules, with this cross-linking it will strengthen hydrogen bonds in starch chains. Castanha et al., (2017) said that dissolved ozone concentrations tend to increase peak viscosity. This is supported by the opinion of Satmalawati, et al., (2020) that viscosity may increase due to cross-linking effects and an increase in carboxylate groups, which are responsible for preventing molecular association and allowing granules to experience water absorption.

Modification by acid hydrolysis is a process of inserting or replacing H atoms into the OH groups in starch to form chains that tend to be longer and can change the physicochemical and rheological properties of starch. When acid hydrolysis takes place, the amylose group will be reduced, this is because amylose molecules are easily broken down compared to amylopectin molecules (Pudjihastuti and Siswo, 2011). According to Alsuhendra and Ridawati, (2009) acid can cause hydrolysis of starch chains, so that the gel formed is not strong. A number of acid-modified starches are thought to have been hydrolyzed, so that the gelatinization process occurs more quickly and the viscosity of the starch paste will also decrease due to dilution hydrolysis of the starch. Winarno, (1992) explained that a higher starch gelatinization temperature causes the starch granules to expand more slowly, which means that the viscosity is reached more slowly. Alsuhendra and Ridawati, (2009), reported that a low starch concentration automatically reduces the viscosity of the solution.

Starch modification using heat moisture treatment, namely the process of modifying starch using high heating. The energy received by starch during heating allows the weakening of inter- and intermolecular hydrogen bonds of amylose and amylopectin in starch granules (Herawati, 2009). It is generally reported that HMT can reduce peak viscosity (Eliasson, 2004). In HMT modification, increasing the addition of water content to starch can cause an increase in peak viscosity (Adebowale et al., 2005).

Fermentation is a modification method using the help of microorganisms. The basic principle of fermentation is to activate certain microbial activities with the aim of changing the properties of the material so that something useful is produced. This change occurs because in the fermentation process the number of microbes is increased and their metabolism in the material is activated to a certain extent (Assegaf, 2009). Adegunwa et al., (2011) reported that fermentation time affects the temperature and time of peak viscosity with increasingly higher values. This is thought to be due to the minor content, and amylopectin is increasing and amylose is decreasing. The minor content, amylose and amylopectin ratio are thought to influence the time (minutes) and temperature (oC) of peak viscosity. The higher the minor content, as well as the amylose and amylopectin ratio, the higher the time (minutes) and temperature (oC) of peak viscosity. Kartikasari et al., (2016) also reported that the longer the fermentation, the temperature and time of peak viscosity show higher values.

Breakdown Viscosity

Breakdown viscosity is a viscosity that describes the level of stability of starch paste during the heating process. Breakdown viscosity is obtained by the difference between the maximum viscosity and the viscosity of the starch paste after heating (Kusnandar, 2010). Breakdown or decrease in viscosity during heating indicates the stability of the starch paste during heating. Where the lower the breakdown, the more stable the paste formed is against heat (Lestari et al., 2015).

The results of correlation analysis from 13 research articles show that the type of starch modification and starch breakdown viscosity have a very weak or very low correlation with a correlation value of -0.08. This is based on the opinion of Misbahudin and Hasan, (2013) who state that the percent correlation value ranges from 0.00 to 0.20, meaning the correlation is very weak or very low. The type of modification and characteristics of cassava starch, breakdown viscosity, have an inverse relationship, indicated by the percent correlation value which is negative. This means that the higher the value of the type of modification, the lower the value of the breakdown viscosity of cassava starch. The sequences used in this research are pregelatinization, crosslinking, acid hydrolysis, HMT and fermentation (Figure 9). The results of the correlation analysis will change if the sequence value of the type of modification is changed, the sequence of modification types that gives the highest correlation value to the breakdown viscosity characteristics of cassava starch is pregelatinization, crosslinking, fermentation, HMT and acid hydrolysis with a weak correlation value of -0.29.

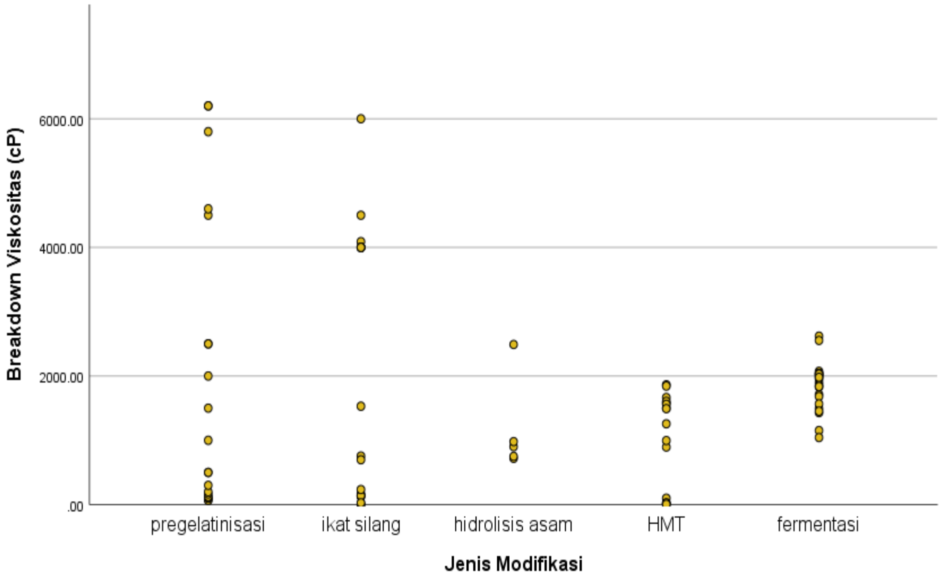

Figure 6. Correlation of modification type and breakdown viscosity of starch.

Table 10. Partial correlation of type of modification and breakdown viscosity of cassava starch.

No	Control Variables	KK	p
1	Starch Concentration (%)	-0,07	>0,05
2	Chemical Compound Concentration (%)	-0,23	>0,05
3	pH	-0,31	>0,05
4	Time (Hours)	0,65	<0,05
5	Temperature (^{0}C)	-0,14	>0,05

The use of control variables of starch concentration and temperature does not change the correlation value, but the use of control variables of concentration of chemical compounds, pH changes the analysis results to a negative correlation and time changes the analysis results to a moderate or sufficient correlation. This means that the concentration of chemical compounds, pH and time are factors that play a role in determining the breakdown viscosity value. Based on the sequence, the following types of starch modification can reduce the breakdown viscosity of modified cassava starch, namely starch modification by pre-gelatinization, cross-linking, acid hydrolysis, HMT, and fermentation. Pregelatinized modified starch is starch that has undergone gelatinization and then drying. Rahman's (2017) research results show that the starch pre-gelatinization method can increase the breakdown viscosity of starch paste. According to Imam et al., (2014), a high breakdown value during the heating process indicates that starch granules that have completely swelled have a brittle nature and are not resistant to heating.

In contrast to pre-gelatinization, crosslinking is a modification of starch that connects one polymer chain to another polymer chain. According to Kusnandar, (2010) cross-linked starch is obtained by reacting starch with polyfunctional compounds that can react with OH groups in the amylose or amylopectin structure to form cross-links or bridges that connect one starch molecule with other molecules, with this cross-linking it will strengthen hydrogen bonds in starch chains. The results of research by Wattanchant et al., (2003) on cross-linking of sago starch showed that the breakdown value of cross-linked hydroxypropylated sago starch was higher compared to natural starch, thought to be caused by a lack of cross-links formed, so it was not enough to reduce the breakdown value.

Modification by acid hydrolysis is a process of inserting or replacing H atoms into the OH groups in starch to form chains that tend to be longer and can change the physicochemical and rheological properties of starch. When acid hydrolysis takes place, the amylose group will be reduced, this is because amylose molecules are easily broken down compared to amylopectin molecules (Pudjihastuti and Siswo, 2011). Polnaya, et al., (2018) based on the results of their research using modified acid hydrolysis using HCl concentration, where the higher the HCl concentration, the lower the breakdown viscosity. This shows that the starch paste formed will be more stable against heat and mixing. The same results were also shown by Sandhu, et al., (2007) who said that acid modification using HCl would reduce the breakdown viscosity of starch.

Starch modification using heat moisture treatment, namely the process of modifying starch using high heat. Heat Moisture Treatment (HMT) is a method of physically modifying starch by providing heat treatment at a temperature above the gelatinization temperature with conditions of limited water content and a certain heating time (Collado et al., 2001). It is generally reported that HMT can reduce breakdown viscosity (Eliasson, 2004). In HMT modification, increasing the addition of water content to starch can cause an increase in breakdown viscosity (Adebowale et al., 2005).

Fermentation is a modification method using the help of microorganisms. The basic principle of fermentation is to activate certain microbial activities with the aim of changing the properties of the material so that something useful is produced. This change occurs because in the fermentation process the number of microbes is increased and their metabolism in the material is activated to a certain extent (Assegaf, 2009). Kartikasari, et al., (2016) reported that the longer the fermentation time, the breakdown value decreases. When starch granules swell and experience heat and shear, the starch experiences fragmentation and results in a reduction in viscosity which indicates starch breakdown. The higher the amylose content, the higher the breakdown viscosity (Bamfort, 2005).

Conclusion

Based on the results of the research that has been carried out, it can be concluded that the type of modification and characteristics of starch, swelling power and WAC of cassava starch have a moderate correlation ($p<0.05$). The type of modification and characteristics of starch solubility, maximum viscosity, and breakdown viscosity have a very weak correlation ($p>0.05$). Manipulation of the characteristics of cassava starch in the form of swelling power and WAC is most potentially carried out through the starch modification process.

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