JURNAL SYNTAX TRANSFORMATION

Volume 6, No. 5 May, 2025
p-ISSN 2721-3854 | e-ISSN 2721-2769

Effect of Hot Breaking and Cold Breaking on the Rheology of Tomato Paste (Lycopersicon Esculentum Mill)

Selpiah[1*], Salengke[2], Iqbal[3]
Universitas Hasanuddin, Indonesia[1,2,3]
*Corresponding Author: selpiahsrmddn@gmail.com

ABSTRACT
Tomato paste quality hinges on processing methods, with hot break (95°C) and cold break (65°C) treatments critically impacting rheology and shelf life. Prior studies lack comprehensive analysis of prolonged heating durations and storage effects on viscosity stability. This study examines how hot/cold break treatments influence tomato paste rheology, enzyme activity (PME, PG), and storage stability to identify optimal processing parameters. Tomatoes were heated at 65°C (cold break) or 95°C (hot break) for 5–15 minutes, processed into paste, and stored for 5 weeks. Rheological properties (flow index *n*, consistency coefficient *k*) were measured weekly using a viscometer (30–60°C), while PME/PG activities were assayed titrimetrically and via DNS. Hot break at 45°C with 10-minute heating yielded the highest viscosity stability (*n* = 0.3685, *k* = 1.478) and extended shelf life by reducing microbes. PG enzymes were more heat-resistant than PME, with cold break showing higher residual activity (27.72% PME, 35% PG after 5 weeks). Storage revealed pseudoplastic degradation, with 60°C treatments exhibiting drastic *k*-value declines (~50%). The 10-minute hot break at 45°C is recommended for industrial tomato paste production to balance viscosity and shelf life. Future research should explore hybrid thermal treatments to enhance nutritional retention, building on findings by Wang et al. (2023).
Keywords: Tomato, Hot break, Cold break, Rheology, Viscosity

INTRODUCTION

Tomatoes are an important commodity because they are traded globally in fresh or processed forms such as pasta, juice, and sauces. This is because processed tomato products are widely used in industry as the main ingredient in making food such as pizza, spaghetti and other processed foods. In addition, processed tomato products in the form of packaging facilitate handling, storage and transportation and have high economic value (Adeoye & Aderibigbe, 2021; De Meo et al., 2022). Currently, the consumption of processed tomatoes worldwide is estimated at around 40 to 42 million metric tons annually (World Processing Tomato Council).

Tomatoes contain a lot of bioactive compounds such as lycopene and functional vitamins C and E (M. Y. Ali et al., 2020). Therefore, tomatoes are considered a functional food because they can provide health benefits such as preventing cancer (Dundar Kirit & Akyıldız, 2022), nourishing the skin (Fajriyani et al., 2023), and boosting the immune system (Collins et al., 2022).

Tomato processing can be used to increase usability and reduce the rate of damage after harvest. Many researchers have reported that the characteristics of taste, aroma, texture, color and nutrition can be preserved through proper processing (Chang et al., 2024; Gomez et al., 2020; Wang et al., 2023). Therefore, post-harvest handling and processing are important to be carried out (Karki & Dawadi, 2022; Qasim et al., 2022). Tomato processing technology has a broad spectrum ranging from simple technology to advanced technology (Kundala et al., 2024).

One of the processed tomato products with the highest commercial value is tomato paste. Usually these products are processed using hot breaking and cold breaking methods (Gao et al., 2021; Sridhar et al., 2022). This method is known to be able to obtain processed tomato products with different characteristics (Syncora et al., 2024). Hot breaking is a heating method using a temperature of 85-95 °C for a period of 1-3 minutes. Meanwhile, cold breaking is a heating method using a temperature of 65-75 °C for 1-3 minutes. In the hot breaking process, tomatoes will be heated first and then separated between the meat, seeds and skin of tomatoes and tomato meat processed into a paste with high viscosity (M. Ali et al., 2024; Gao et al., 2021; Gouda & Li, 2025; Xu et al., 2018). The cold breaking process produces tomato paste with a lower viscosity (Gao et al., 2021; Najman et al., 2022).

The hot breaking method that uses high temperatures (85-95 °C) can inactivate enzymes quickly so that it can prevent pectin degradation which can produce a paste that has high viscosity. However, high temperatures can also damage the freshness and nutrients of tomatoes and can result in color degradation (Gundogan et al., 2024). The cold breaking method uses low temperatures (65-75 °C) so that it can produce fresh aromas and tastes, as well as maintain vitamin C and more volatile compounds. However, the cold breaking method can result in continued enzyme activity, resulting in lower viscosity and less suitable for use in thick products (Musa et al., 2024).

Various products produced using hot breaking and cold breaking methods have different rheological characteristics. In addition, the products produced from the two methods have different pectin content so that the texture produced is also different (Umeohia & Olapade, 2024). Rheological properties are one of the important properties because they affect the mouth feel when the product is consumed. The properties of rheology can be known by using several models, one of which is the power law. This model is the simplest model that describes the flow behavior of non-Newtonian fluids. It has been shown from various previous studies that the rheology produced from tomato paste products depends on the temperature and the length of time used during the heating process. Short periods of use during the heating process can result in high viscosity (Gao et al., 2021; Gouda & Li, 2025). Many researchers use a short period of time for tomato paste, but for a long and varied period of time, not many researchers have done so. Therefore, in this study, we tried to make tomato paste using hot breaking and cold breaking methods with a fairly long and varied time.

The purpose of this study is to study how the effect of hot breaking and cold breaking on the rheological properties of tomato paste. The current study advances existing research by systematically evaluating the rheological stability of tomato paste under both hot break (95°C) and cold break (65°C) treatments across extended heating durations (5, 10, 15 minutes) and storage periods (5 weeks), which prior studies (Gao et al., 2021; Sridhar et al., 2022) did not comprehensively address. Unlike earlier work focusing solely on viscosity or enzyme inactivation (Liu et al., 2023), this research integrates flow index (n) and consistency coefficient (k) measurements to quantify pseudoplastic behavior during storage, revealing that a 10-minute hot break at 45°C optimally balances viscosity and shelf life. Additionally, it demonstrates that PG enzymes are more heat-resistant than PME, corroborating Liu et al. (2023) but extending findings to industrial storage conditions. The study also contrasts with Basak & Annapure (2022), which emphasized pectin degradation, by providing empirical data on temperature-dependent viscosity fluctuations (e.g., 60°C treatments showed drastic k-value drops). Finally, it proposes hybrid thermal treatments as a novel future direction, bridging gaps in nutritional and sensory quality optimization highlighted by Wang et al. (2023).

METHOD

The tomatoes used in this study are vegetable tomatoes obtained from markets in Makassar, South Sulawesi. Processing and measurement are carried out at the Processing *Laboratory*, Agricultural Engineering Study Program, Department of Agricultural Technology, Faculty of Agriculture, Hasanuddin University.

The hot breaking and cold breaking process is carried out using a water bath using a temperature of 95 ºC (hot breaking) and a temperature of 65 ºC (cold breaking) with a heating time of 5, 10 and 15 minutes. After the process, the seeds, skin and meat are separated. Tomato meat is processed into paste by mashing using a blender and measuring the rheological properties and enzymes of PME (Pectin Methylesterase) and PG (Polygalacturonase). The resulting paste is stored for 1,2,3,4 and 5 weeks and the above parameters are measured weekly.
2.2 Measurement of Enzyme Activity

The activity of PME (Pectin Methylesterase) and PG (Polygalacturonase) enzymes in tomato products was carried out by enzyme extraction. Samples were mixed with a phosphate buffer buffer buffer buffer solution, pH 7.0 (PME) and sodium acetate buffer, pH 5.0 (PG) in a ratio of 1:1 (Liu et al., 2023). Mix in a centrifist at 10,000-12,000 rpm for 130 minutes at 4°C. Supernatants containing soluble enzymes (PME and PG) were collected for testing by:

PME enzyme testing uses the titrimetry method, where orange pectin (0.5% solution) is dissolved in water and lowered to pH to 7.0 using NaOH and then mixed with the extracted enzyme. The mixture is incubated at 30 °C for 30 minutes. Then it is titrated continuously with NaOH (0.01 M) to maintain a constant pH (7.0). The volume of NaOH used to maintain pH is recorded in units, where one unit is defined as the enzymes that cause NaOH consumption to be equivalent to 1 mL per minute under test conditions (Nguyen, 2024).

PG was tested using the DNS (Dinitrosalicylic Acid Test) method, where polygalacturonic acid (0.5% solution) was dissolved in a sodium acetate buffer (pH 5.0) and mixed the enzymes that had been extracted. The mixture is incubated at 40 °C for 30 minutes. The reaction is stopped by adding a DNS reagent (a solution of 3,5-Dinitrosalicylic acid). The mixture is heated with DNS reagents for color development (producing a red-brown color in the presence of reducing sugars) and absorbance is measured at 540 nm. Absorbance correlates with the concentration of reducing sugars, which indicates PG activity. PG enzyme activity is expressed as a unit, where one unit is the number of enzymes that release 1 μmol of reducing sugar (galacturonic acid) per minute (Nguyen, 2024).

Rheological measurements of materials were carried out using a DV-1 viscometer with heating temperatures of 30, 45 and 60 ºC using *a branded water bath* tool (B-ONE DWBC). This measurement is used at rpm 3, 6, 12, 30 and 60 and uses spindle 3 (Sjarif, 2020). The measurement of rheological properties is carried out by various methods, one of which is the mitschka method. Mitschka is used to calculate the average shear stress and average shear rate obtained from the brookfield viscometer.

Table 1. Conversion of Mitcshka Method Factors

Brookfield Spindle	1		2	3	4	5	6	7
$k_{\sigma\alpha}$		0,035	0,119	0,279	0,539	1,05	2,35	8,4
n =	0,1	0,728	1,431	1,457	1,492	1,544	1,366	1,936
	0,2	0,967	0,875	0,882	0,892	0,907	0,851	1,007
	0,3	0,705	0,656	0,656	0,658	0,663	0,629	0,681
	0,4	0,576	0,535	0,53	0,529	0,528	0,503	0,515
kNy	0,5	0,499	0,458	0,449	0,445	0,442	0,421	0,413
	0,6	0,449	0,404	0,392	0,387	0,382	0,363	0,346
	0,7	0,414	0,365	0,350	0,343	0,338	0,320	0,297
	0,8	0,387	0,334	0,317	0,310	0,304	0,286	0,261
	0,9	0,367	0,310	0,291	0,283	0,276	0,260	0,232
	10	0,351	0,291	0,270	0,262	0,254	0,238	0,209

The rheological properties of the material are calculated using the following formulas: Calculating the average shear stress using the equation (Yuan et al., 2023):

sa=Kas(C * *dial reading*) (1)

As = Voltage Confersion Factor (Pa);
Ksa = Voltage Confersion Factor (Pa)
C = Konstanta pegas viscometer
Dialreading = % torque displayed on *the Brookfield* Viscometer

Calculating the flow behavior index through the average slop of shear voltage at rotational velocity by using the equation (Alkouh et al., 2024):

$$n = (2)\frac{d\,(\log_{10}\sigma_{\alpha})}{d\,(\log_{10}\sigma_{\alpha\,N})}$$

n = flow index;
A = average shear stress
N = rotation speed (rpm)

Calculating *sheart rate* with equations (Gouda & Li, 2025; Yuan et al., 2023):

γa = KNY (*N*)

(3)

Where:
For the purposes of this Article = shear speed
KNY = Factor Conversion Shear Rate (min s^{-1}) *Spindle* on the flow index behavior
Calculating *the Viscosity Factor* (Mapp) with equations (Yuan et al., 2023):

$$happ = (4)\frac{\sigma a}{\gamma a}$$

Where:
Happ = *Apparen Viscosity*
As = Voltage Confersion Factor (Pa);
For the purposes of this Article = shear speed

2.4 Diagram Alir

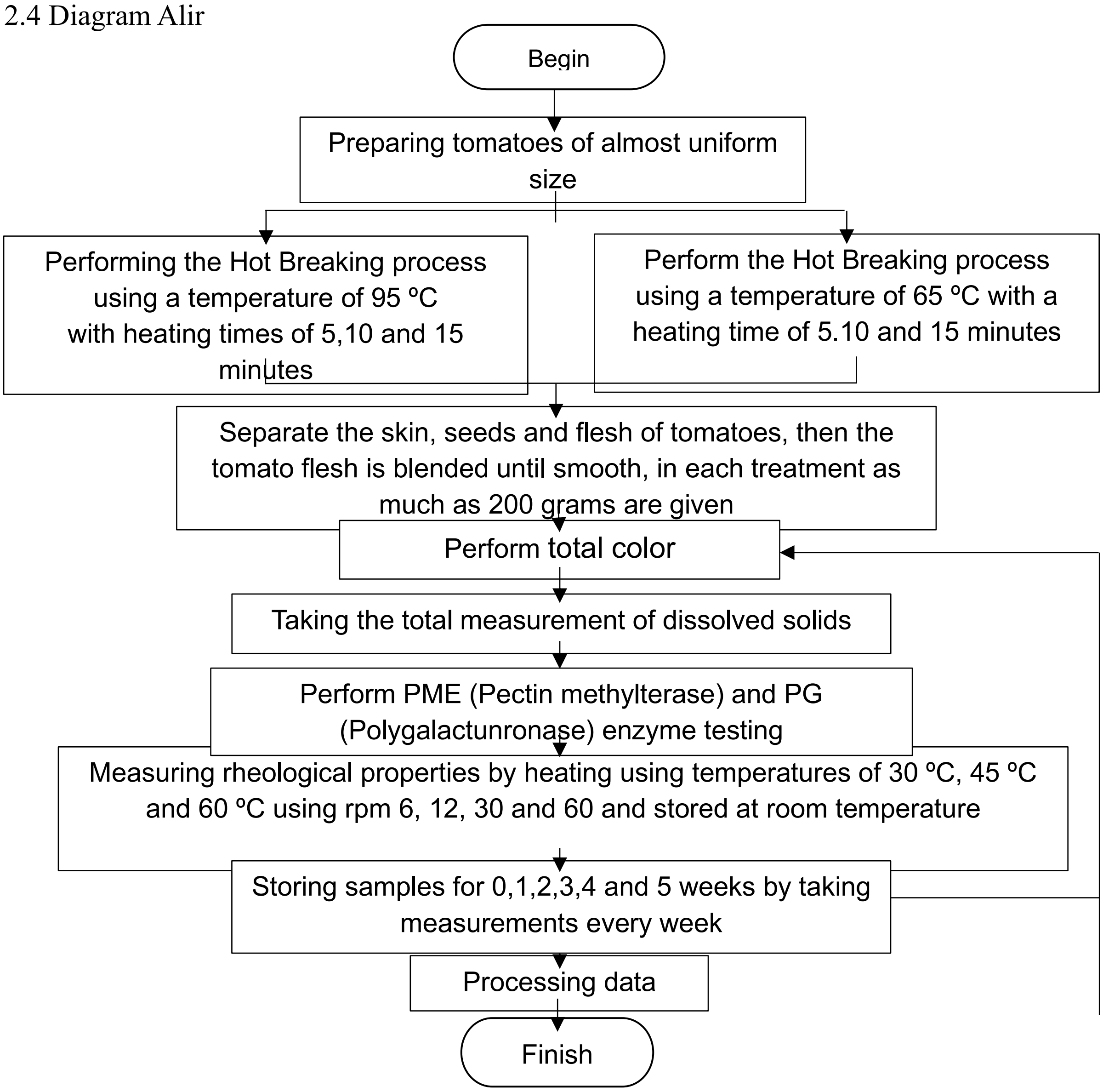


Figure 1. Research Flow Diagram

RESULTS AND DISCUSSION

Rheological properties of the material during storage

Table 2. Rheological Properties Calculation Results for *Cold Break* Treatment Temperature 65 for 5 minutes

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
30 ºC	0	0,1182	1,456	0,163161	0,279	1,457
	1	0,0235	1,8185	0,259713	0,279	1,457
	2	0,0393	1,8024	0,255851	0,279	1,457
	3	0,0925	1,6813	0,225645	0,279	1,457
	4	0,0735	1,54	0,187521	0,279	1,457
	5	0,0194	1,4562	0,163221	0,279	1,457
45 ºC	0	0,145	1,3491	0,130044	0,279	1,457
	1	0,0204	1,7707	0,248145	0,279	1,457

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
	2	0,0494	1,7498	0,242988	0,279	1,457
	3	0,1955	1,4803	0,17035	0,279	1,457
	4	0,1043	1,4825	0,170995	0,279	1,457
	5	0,1178	1,3434	0,128205	0,279	1,457
60 ºC	0	0,189	1,2352	0,091737	0,279	1,457
	1	0,1185	1,6075	0,206151	0,279	1,457
	2	0,0152	1,7889	0,252586	0,279	1,457
	3	0,0711	1,7586	0,245167	0,279	1,457
	4	0,0031	1,6296	0,212081	0,279	1,457
	5	0,1678	1,1215	0,049799	0,279	1,457

Table 2 can be seen the value n which shows the change in the rheological properties of the tomato paste during storage. In the first week, the paste is more stable and has a higher n-value, but due to pectin degradation, changes in water distribution and warming effects, the n-value decreases after the following week, then increases in the 3rd week and then decreases in the following week. A decrease in n value indicates an increase in the shear-tinning properties which affect the texture and quality of the product where the viscosity decreases when stirred or applied a sliding force. Heating of 30 and 45 ºC the k value tends to increase from week 0 to week 2 then decreases in week 3 to week 5, in contrast to *cold break* warming of 60 ºC the k value increases until week 3 but in week 5 it decreases very drastically. This is in accordance with the statement of Budaraga (2024), stating that a high flow index value indicates that tomato paste is biased to still have properties closer to Newtonian fluids where the change in shear stress is proportional to the change in the shear rate, while the lower value of n indicates the properties of psedoplastic (shear-thinning) where the viscosity decreases when given shear stress.

Table 3. Results of Rheological Properties Calculation for Cold Break Treatment Temperature 65 for 10 minutes

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
30 ºC	0	0,1142	1,4869	0,172282	0,279	1,457
	1	0,1155	1,6257	0,21104	0,279	1,457
	2	0,0284	1,7901	0,252877	0,279	1,457
	3	0,0039	1,7684	0,247581	0,279	1,457
	4	0,1069	1,4354	0,156973	0,279	1,457
	5	0,0309	1,7578	0,244969	0,279	1,457
45 ºC	0	0,1368	1,4209	0,152564	0,279	1,457
	1	0,0921	1,7371	0,239825	0,279	1,457
	2	0,4403	1,598	0,203577	0,279	0,53
	3	0,0589	1,6774	0,224637	0,279	1,457
	4	0,108	1,3716	0,137227	0,279	1,457
	5	0,0395	1,7498	0,242988	0,279	1,457
60 ºC	0	0,0967	1,4301	0,155366	0,279	1,457
	1	0,0918	1,7331	0,238824	0,279	1,457
	2	0,0633	1,7261	0,237066	0,279	1,457
	3	0,038	1,6057	0,205664	0,279	1,457
	4	0,0925	1,3988	0,145756	0,279	1,457
	5	0,1721	1,3618	0,134113	0,279	1,457

The results of the calculation of the values of n (flow index) and k (consistency coefficient) where the spindle used during the measurement process used spindles 3 brands brokfiled. Table 5 can be seen the value n which indicates the change in the rheological properties of tomato paste during storage. The value of n cold break heating of 30 ºC has a high flow index in the first week then decreases and increases again in the 4th week, as well as the heating of 45 ºC while in heating 60 it increases in the 5th week. The n-value in the cold break process tends to have a lower flow index, the length of the treatment heating time before making the paste can affect the physical and chemical properties of tomato paste. This is in accordance with the statement of Basak & Annapure (2022) stating that heating for longer periods of time can lead to the breakdown of pectin by pectinase enzymes or thermal hydrolysis which will decrease viscosity, however, if heating too quickly, the pectinase enzyme is likely not to be fully activated, which can accelerate the degradation of pectin during storage.

Table 4. Results of Rheological Properties Calculation for Cold Break Treatment Temperature 65 for 15 minutes

Sample Temperature	Week 1	n	K	log k	$k_{\sigma\alpha}$ Spindle 3	kNγ
30 ºC	0	0,1223	1,5242	0,183042	0,279	1,457
	1	0,1163	1,6221	0,210078	0,279	1,457
	2	0,0282	1,7731	0,248733	0,279	1,457
	3	0,0195	1,7531	0,243807	0,279	1,457
	4	0,0056	1,785	0,251638	0,279	1,457
	5	0,069	1,7824	0,251005	0,279	1,457
45 ºC	0	0,0645	1,5917	0,201861	0,279	1,457
	1	0,0186	1,7906	0,252999	0,279	1,457
	2	0,079	1,6985	0,230066	0,279	1,457
	3	0,0627	1,6296	0,212081	0,279	1,457
	4	0,1101	1,5099	0,178948	0,279	1,457
	5	0,1604	1,5347	0,186023	0,279	1,457
60 ºC	0	0,1223	1,5242	0,183042	0,279	1,457
	1	0,2408	1,4235	0,153357	0,279	0,882
	2	0,1481	1,5721	0,19648	0,279	1,457
	3	0,2001	1,4351	0,156882	0,279	0,882
	4	0,0401	1,5547	0,191647	0,279	1,457
	5	0,2102	1,3952	0,144636	0,279	0,882

Table 4 can be seen the value n which indicates the change in the rheological properties of the tomato paste during storage. The value of n cold break heating 30 ºC has a high flow index in the first week then decreases in each week, heating of 45 ºC at the beginning of storage decreases but in weeks 4 and 5 it increases, while in heating 60 ºC it increases in weeks 1, 3 and 5. Warming up 30 ºC the k value tends to increase from week 0 to week 2 then decreases in week 3 and increases in weeks 4 to week 5 in contrast to cold break warming up 45 increases until week 1 and the following week decreases, while warming up 60 minutes the k value decreases in weeks 1, 3 and 5. This is in accordance with the statement of Basak & Annapure (2022) stating that heating for longer periods of time can lead to the breakdown of pectin by pectinase enzymes or thermal hydrolysis which will decrease viscosity, however, if heating too quickly, the pectinase enzyme is likely not to be fully activated, which can accelerate the degradation of pectin during storage.

Table 5. Results of Rheological Properties Calculation for Hot Break Treatment at 95 Temperature for 5 Minutes

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
30 ºC	0	0,1163	1,5435	0,188507	0,279	1,457
	1	0,0422	1,8261	0,261525	0,279	1,457
	2	0,0025	1,8402	0,264865	0,279	1,457
	3	0,0926	1,5282	0,18418	0,279	1,457
	4	0,0989	1,3553	0,132035	0,279	1,457
	5	0,1084	1,3021	0,114644	0,279	1,457
45 ºC	0	0,331	1,1464	0,059336	0,279	0,656
	1	0,0281	1,7648	0,246695	0,279	1,457
	2	0,1782	1,4531	0,162296	0,279	1,457
	3	0,0427	1,6608	0,220317	0,279	1,457
	4	0,134	1,2018	0,079832	0,279	1,457
	5	0,1553	1,1771	0,070813	0,279	1,457
60 ºC	0	0,0295	1,4096	0,149096	0,279	1,457
	1	0,0546	1,7678	0,247433	0,279	1,457
	2	0,0946	1,594	0,202488	0,279	1,457
	3	0,1223	1,4185	0,151829	0,279	1,457
	4	0,1558	1,3096	0,117139	0,279	1,457
	5	0,2915	1,9621	0,292721	0,279	0,882

In Table 5, you can see the flow index (n) and consistency coefficient (k), the 30 ºC hot breaking treatment initially had a high value of 0.1163 then decreased and increased in the 5th week, heating 45 ºC had an initial higher n value of 0.331 than heating 30 ºC then the next week experienced a drastic decrease, while at 60 ºC heating had a low initial flow index of 0.00295 then increased until the 5th week. Heating of 30 and 45 ºC maintained high viscosity at the beginning but the following week experienced a decrease in contrast to heating of 60 ºC having low viscosity at the beginning but after storage the viscosity began to increase. The higher the temperature used during the heating process the enzyme will be faster it will be inactivated with time. Temperature can affect the stability of the paste during the storage process. This is in accordance with the statement of Yuniarti et al., (2022) stating that high fermentation can keep pectin intact at the beginning so that it can produce a thicker paste with a lower n value close to 0. Heating for too long can increase the flow index in the final weeks, causing the pasta to become thinner during long storage.

Table 6. Results of Rheological Properties Calculation for Hot Break Treatment at 95 Temperature for 10 minutes

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
30 ºC	0	0,2976	1,2102	0,082857	0,279	0,882
	1	0,0445	1,636	0,213783	0,279	1,457

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
	2	0,06	1,5473	0,189575	0,279	1,457
	3	0,0751	1,5199	0,181815	0,279	1,457
	4	0,0223	1,467	0,16643	0,279	1,457
	5	0,0983	1,4981	0,175541	0,279	1,457
45 ºC	0	0,3685	1,1337	0,054498	0,279	0,656
	1	0,067	1,5534	0,191283	0,279	1,457
	2	0,0661	1,5062	0,177883	0,279	1,457
	3	0,0784	1,4907	0,17339	0,279	1,457
	4	0,0202	1,478	0,169674	0,279	1,457
	5	0,1054	1,4724	0,168026	0,279	1,457
60 ºC	0	0,2644	1,1904	0,075693	0,279	0,882
	1	0,2113	1,3389	0,126748	0,279	0,882
	2	0,1769	1,2975	0,113107	0,279	1,457
	3	0,1638	1,2245	0,087959	0,279	1,457
	4	0,085	1,5747	0,197198	0,279	1,457
	5	0,1393	1,4659	0,166104	0,279	1,457

In Table 6, you can see the flow index (n) and consistency coefficient (k), the 30 ºC hot breaking treatment initially had a high value of 0.2976 at the beginning then decreased slowly until the 5th week, heating 45 ºC had an initial higher n value of 0.3685 than heating 30 ºC then the following week experienced a decrease every week, while at heating 60 ºC had a high flow index at the beginning which was 0.2644 then decreases in the same way as heating 30 and 45 ºC. Heating of 30, 45 and 60 ºC maintains high viscosity at the beginning but decreases the following week. The higher the temperature used during the heating process the enzyme will be faster it will be inactivated with time. Temperature can affect the stability of the paste during the storage process. This is in accordance with the statement of Yuniarti et al., (2022) stating that high fermentation can keep pectin intact at the beginning so that it can produce a thicker paste with a lower n value close to 0. Heating for too long can increase the flow index in the final week, causing the pasta to become thinner during long storage.

Table 7. Results of Rheological Properties Calculation for Hot Break Treatment Temperature 95 for 15 minutes

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
30 ºC	0	0,3464	1,1877	0,074707	0,279	0,656
	1	0,0817	1,7126	0,233656	0,279	1,457
	2	0,0831	1,6951	0,229195	0,279	1,457
	3	0,1056	1,6013	0,204473	0,279	1,457
	4	0,0398	1,6642	0,221206	0,279	1,457
	5	0,1106	1,6724	0,22334	0,279	1,457
45 ºC	0	0,3571	1,1388	0,056447	0,279	0,656
	1	0,132	1,5787	0,1983	0,279	1,457
	2	0,0352	1,7536	0,243931	0,279	1,457
	3	0,1022	1,6127	0,207554	0,279	1,457
	4	0,0885	1,6316	0,212614	0,279	1,457
	5	0,081	1,7591	0,245291	0,279	1,457

Sample Temperature	Week 1	n	k	log k	$k_{\sigma\alpha}$Spindle 3	kNγ
60 ºC	0	0,2713	1,1642	0,066028	0,279	0,882
	1	0,1615	1,5257	0,183469	0,279	1,457
	2	0,1205	1,5499	0,190304	0,279	1,457
	3	0,0892	1,5682	0,195401	0,279	1,457
	4	0,162	1,4483	0,160859	0,279	1,457
	5	0,1554	1,4985	0,175657	0,279	1,457

In Table 7, you can see the flow index (n) and consistency coefficients (k), the 30 ºC hot breaking treatment initially had a high value of 0.3464 then decreased and increased in the 3rd week, heating 45 ºC had an initial higher n value of 0.3571 than heating 30 ºC then the next week decreased and increased in the 3rd week, while heating 60 ºC has a high initial flow index, the same as heating of 30 and 45 ºC, which is 0.2713, then decreases. Heating of 30, 45 and 60 ºC maintained high viscosity at the beginning but declined the following week. The higher the temperature used during the heating process the enzyme will be faster it will be inactivated with time. Temperature can affect the stability of the paste during the storage process. This is in accordance with the statement of Yuniarti et al., (2022) stating that high fermentation can keep pectin intact at the beginning so that it can produce a thicker paste with a lower n value close to 0. Heating for too long can increase the flow index in the final weeks, causing the pasta to become thinner during long storage.

Appearen Viscosity (Mapp)

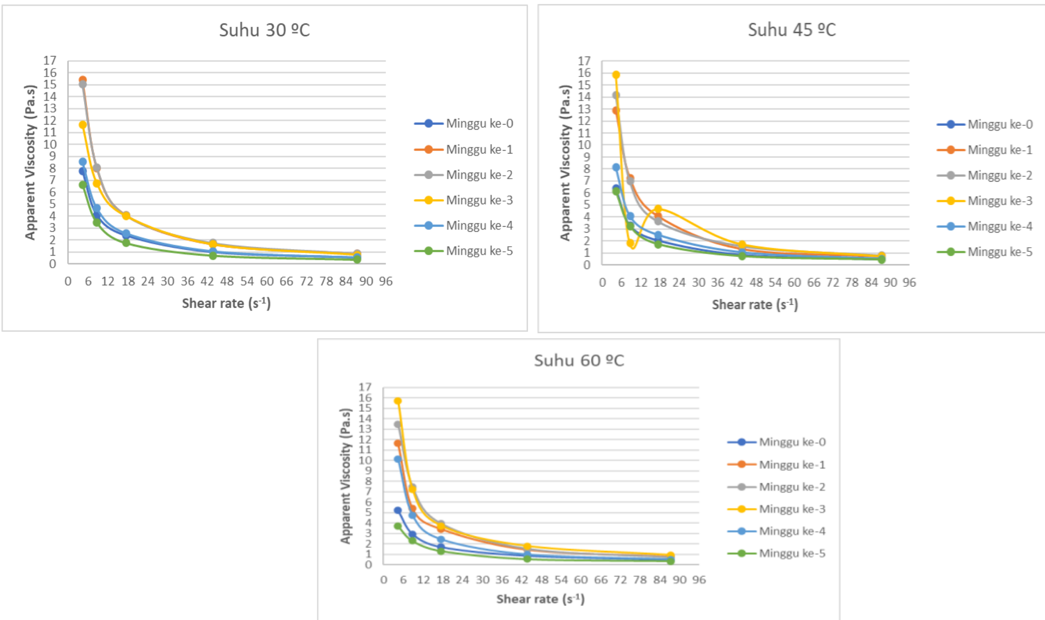


Figure 2. Viscosity Characteristics Graph for Cold Break Treatment of 65 ºC Temperature for 5 Minutes with Sample Temperatures of 30, 45 and 60 ºC.

In Figure 2, the sample temperature of 30 ºC has the highest viscosity appearance value in the 2nd and 3rd week, at the sample temperature of 45 ºC has the highest viscosity appearance value in the 3rd, 2nd week and 1st week but in the 3rd week the 3rd measurement increases and in the next measurement decreases. Meanwhile, at a sample temperature of 60 ºC, the viscosity appearance value is the same as the sample temperature of 45 ºC has the highest value in week 3, week 2 and then week 1. This is in accordance with the statement of Mazumder (2022) saying that the viscosity of fluids is affected by changes in temperature and pressure, if the temperature increases then the viscosity of the fluid will decrease, on the contrary, if the temperature decreases then the viscosity of the fluid will increase.

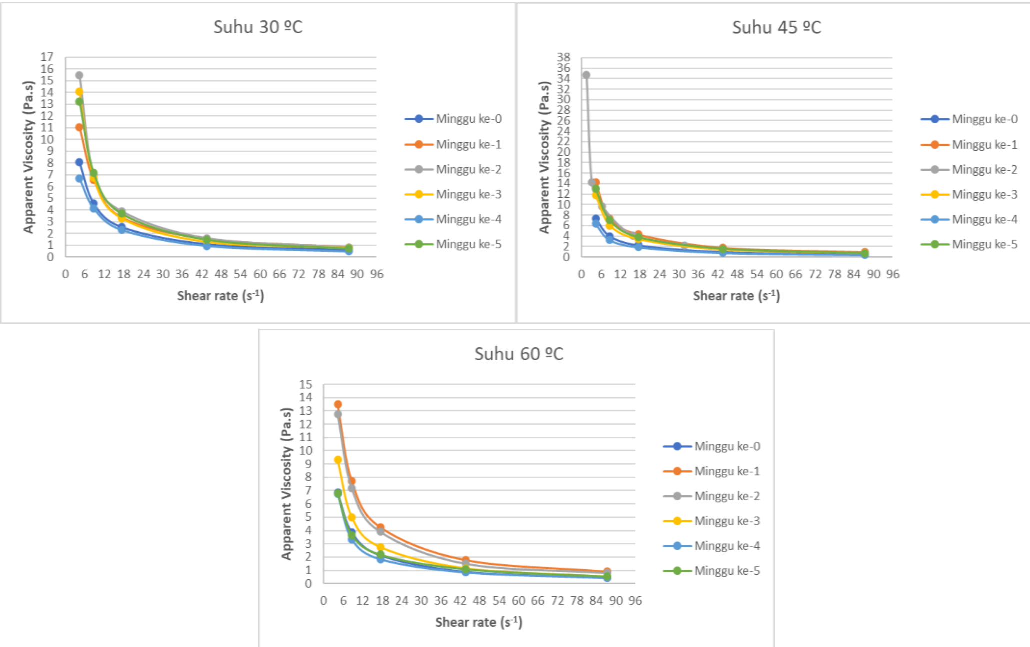
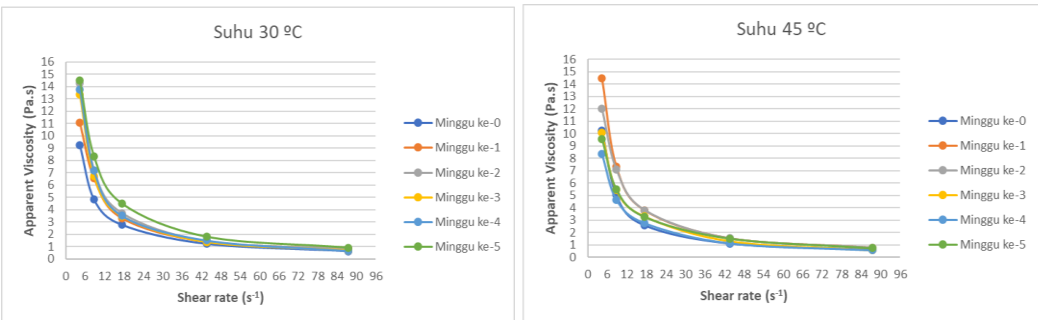


Figure 3. Viscosity Characteristics Graph for Cold Break Treatment of 65 ºC Temperature for 10 Minutes with Sample Temperatures of 30, 45 and 60 ºC.

In Figure 3 the sample temperature of 30 ºC had the highest viscosity appearance value in the 2nd and 3rd and 5th weeks, at the sample temperature 45 ºC had the highest viscosity appearance value in the 2nd week in the first measurement, which is quite far compared to the other weeks. Meanwhile, at a sample temperature of 60 ºC, the viscosity appair value had the highest value in week 1, week 2 and then week 3. At temperatures of 45 ºC and 60 ºC the sample had the lowest values at week 0 and week 5. This is in accordance with the statement of Mazumder (Mazumder, 2022) saying that fluid viscosity is affected by changes in temperature and pressure, if the temperature increases then the viscosity of the fluid will decrease, on the contrary if the temperature decreases then the viscosity of the fluid will increase.



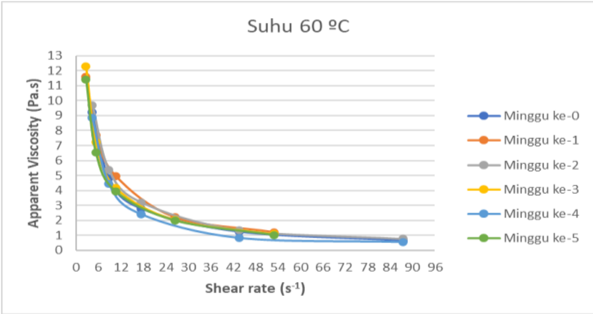


Figure 4. Viscosity Characteristics Graph for Cold Break Treatment of 65 ºC Temperature for 15 Minutes with Sample Temperature of 30, 45 and 60 ºC.

In Figure 4 the sample temperature of 30 ºC has the highest viscosity appearance value in the 5th and 3rd weeks, at the sample temperature 45 ºC has the highest viscosity appearance value in the 1st and 3rd weeks. Meanwhile, at a sample temperature of 60 ºC, the viscosity appair value is the same as the sample temperature of 45 ºC has the highest value in the 3rd week, the 5th week then the 2nd week, and in the 2nd and 4th weeks it has the highest shear rate value compared to other weeks. This is in accordance with the statement of Mazumder (2022) saying that the viscosity of fluids is affected by changes in temperature and pressure, if the temperature increases then the viscosity of the fluid will decrease, on the contrary, if the temperature decreases then the viscosity of the fluid will increase.

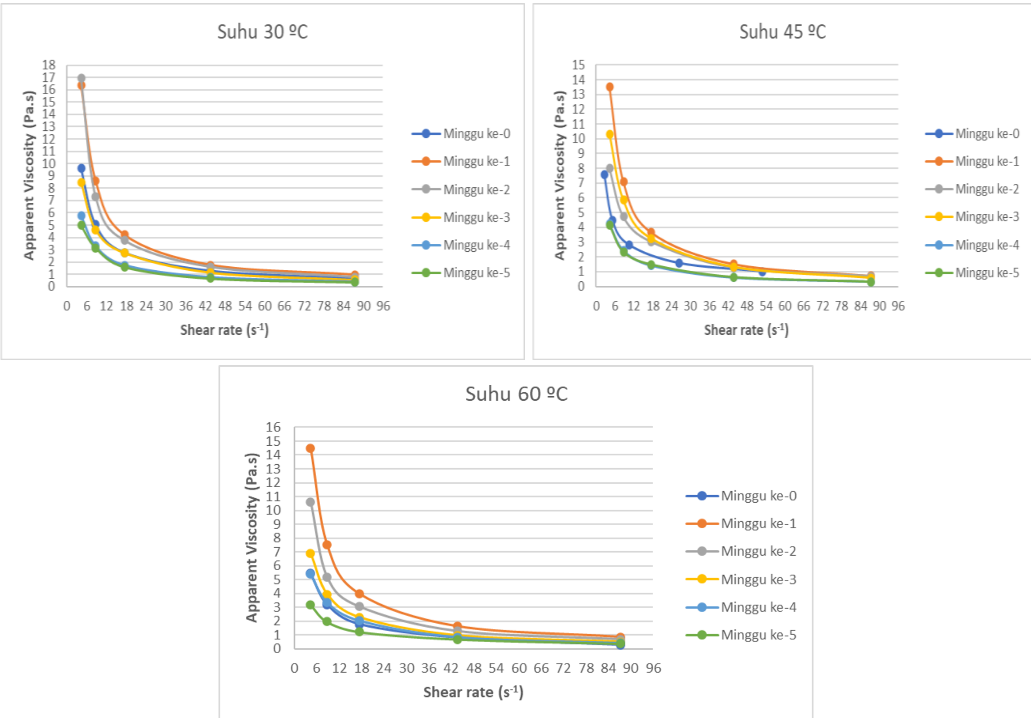


Figure 5. Viscosity Display Graph for Hot Break Treatment of 95 ºC Temperature for 5 Minutes with Sample Temperature of 30, 45 and 60 ºC.

In Figure 5 the sample temperature of 30 ºC has the highest viscosity appearance value in the 1st and 2nd weeks, at the sample temperature of 45 ºC has the highest viscosity appearance value in the 2nd and 3rd weeks. Meanwhile, at a sample temperature of 60 ºC, the viscosity appair value had the highest values in week 1 and week 2. At all temperatures, the sample had its lowest value at week 0. This is in accordance with the statement of Mazumder (2022) saying that the viscosity of fluids is affected by changes in temperature and pressure, if the temperature increases then the viscosity of the fluid will decrease, on the contrary, if the temperature decreases then the viscosity of the fluid will increase.

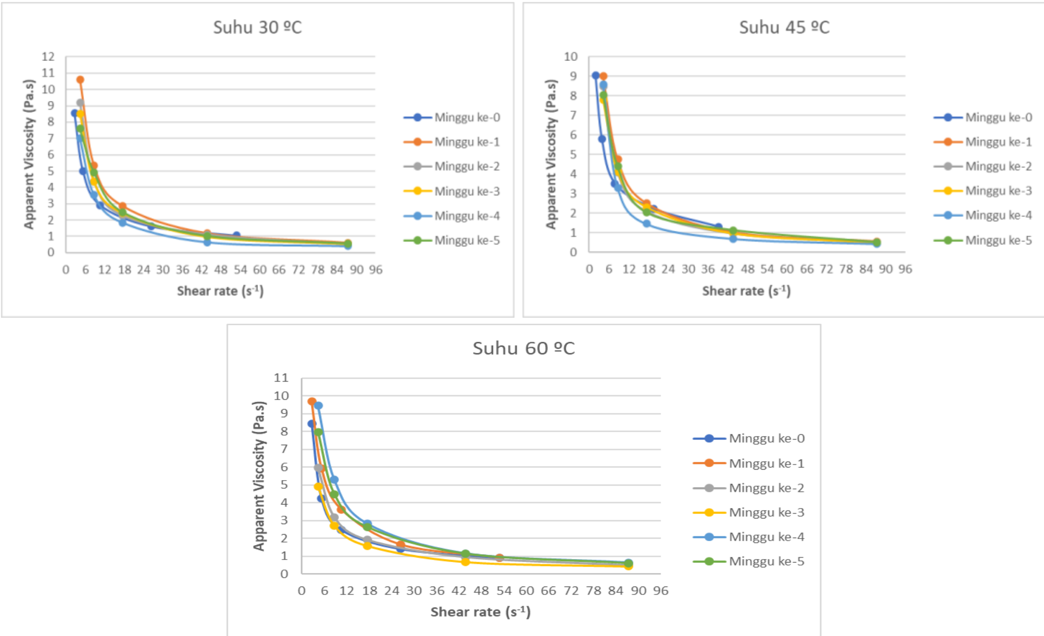
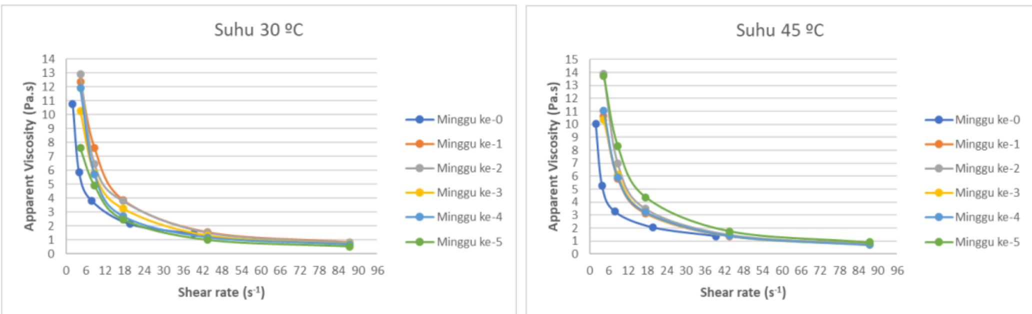


Figure 6. Viscosity Characteristics Graph for 95 ºC Temperature Hot Break Treatment for 10 Minutes with Sample Temperature of 30, 45, and 60 ºC

In Figure 6, the sample temperature of 30 ºC had the highest viscosity appearance value in the 1st and 2nd weeks, and the sample temperature of 45 ºC had the highest viscosity appearance value in the 1st and 4th weeks. Meanwhile, at a sample temperature of 60 ºC, the viscosity apparent value has the same highest value as week 4, namely in week 1 and week 4. At all temperatures, the sample had the lowest value in week 0, but at the sample temperature of 60 ºC, it had the lowest value in weeks 0 and 3. This is in accordance with the statement of Mazumder (2022) saying that the viscosity of fluids is affected by changes in temperature and pressure, if the temperature increases, then the viscosity of the fluid will decrease; on the contrary, if the temperature decreases, then the viscosity of the fluid will increase.



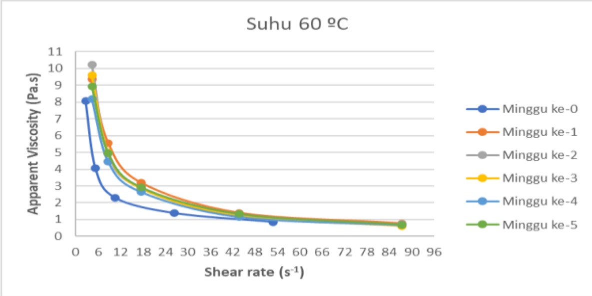


Figure 7. Viscosity Characteristics Graph for 95 ºC Temperature Hot Break Treatment for 15 Minutes with Sample Temperature of 30, 45 and 60 ºC.

In Figure 7 the sample temperature of 30 ºC had the highest viscosity appair values in the 2nd and 1st weeks, at the sample temperature of 45 ºC it had the highest viscosity appair values in the 5th and 4th weeks. Meanwhile, at a sample temperature of 60 ºC, the viscosity appair value had the highest value, namely in week 2 and week 3. At all temperatures, the sample had its lowest value at week 0. This is in accordance with the statement of Mazumder (2022) saying that the viscosity of fluids is affected by changes in temperature and pressure, if the temperature increases then the viscosity of the fluid will decrease, on the contrary, if the temperature decreases then the viscosity of the fluid will increase

Enzyme Test

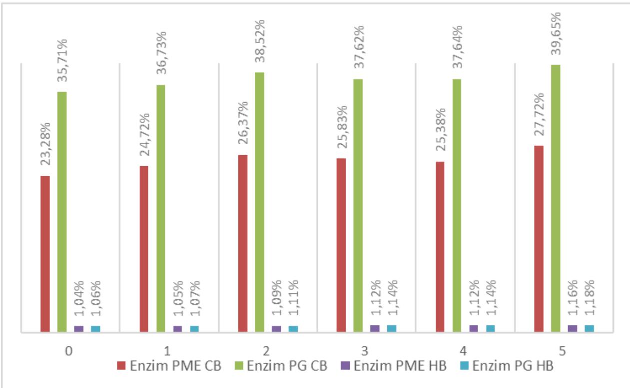


Figure 8. Cold Break Enzyme Testing and 5 Minute Heating Hot Break.

In Figure 8, the results of PME (*Pectin Methylesterase*) and PG (Polygalacturonase) enzyme testing results, PME enzyme activity in cold break treatment from week 0 to week 5 has increased, from 23.28% to 27.72%, as well as PG enzymes which have high values compared to PME enzymes. Meanwhile, in the hot break treatment, the activity of PME and PG enzymes had a very low value and in the last weeks there was a slight increase. This treatment also has a higher PG value compared to PME, this treatment still has enzymes because the heating time is quite short during the process of heating tomatoes before being turned into paste. This is in accordance with Liu et al., (2023) with the statement that PG is more resistant to heat and ultrasound than PME, which can be considered derived from the reversible PG configuration. The enzymes in cold break paste 65 are significantly higher than hot break paste 90. The results of the study showed that enzyme inactivation increased with increasing temperature Gao et al., (2021).

Figure 9. Cold Break Enzyme Testing and 10 Minute Heating Hot Break.

In Figure 9, the results of PME (*Pectin Methylesterase*) and PG (Polygalacturonase) enzyme testing are tested, PME enzyme activity in cold break treatment from week 0 to week 5 has increased, from 14.2% to 16.18%, as well as PG enzymes which have high values compared to PME enzymes. The enzyme results obtained are much smaller compared to the heating time of 5 minutes. Meanwhile, in the hot break treatment, the activity of PME and PG enzymes no longer contained enzymes in the first week, but after the 2nd week there was an increase in both enzymes, but the next week the growth of the enzyme was quite stable. This treatment also has a higher PG value compared to PME in the final weeks, this treatment has no enzymes in the early weeks due to the high heating temperature and a long heating time during the process of heating tomatoes before being converted into paste. This is in accordance with Liu et al., (2023) with the statement that PG is more resistant to heat and ultrasound than PME, which can be considered derived from the reversible PG configuration. The enzymes in cold break paste 65 are significantly higher than hot break paste 90. The results of the study showed that enzyme inactivation increased with increasing temperature Gao et al., (2021).

Figure 10. Enzyme Cold Break and Hot Break Heating 15 Minutes.

In Figure 10, the results of testing PME (*Pectin Methylesterase*) and PG (Polygalacturonase) enzymes, PME enzyme activity in cold break treatment from week 0 to week 5 has increased, from 11.27% to 15.26%, as well as PG enzymes which have high values compared to PME enzymes. The enzyme results obtained were much smaller compared to the duration of warming up and 10 minutes, the increase in enzymes from week 0 to week 5 had a difference that was not far enough because the length of time used was quite long. Meanwhile, in the hot break treatment, the activity of PME and PG enzymes no longer contained enzymes in the first week, but after the last weeks there was an increase in both enzymes, but the growth of the enzymes was quite stable. This treatment also has a higher PG value compared to PME in the final weeks, this treatment has no enzymes in the early weeks due to the high heating temperature and a long heating time during the process of heating tomatoes before being converted into paste. This is in accordance with Liu et al., (2023) with the statement that PG is more resistant to heat and ultrasound than PME, which can be considered derived from the reversible PG configuration. The enzymes in cold break paste 65 are significantly higher than hot break paste 90. The results of the study showed that enzyme inactivation increased with increasing temperature Gao et al., (2021).

CONCLUSION

The study found that 45°C is the optimal heating temperature for hot and cold break treatments in tomato paste production, balancing viscosity and storage stability, with a 10-minute hot break being most effective for maintaining viscosity and extending shelf life by reducing microbes. For future research, exploring hybrid thermal treatments (combining hot and cold breaks at varying conditions) could further improve viscosity, shelf life, and nutritional quality, while also assessing the impact on bioactive compounds (e.g., lycopene, antioxidants) and sensory properties to ensure both technical and consumer-oriented advancements in tomato paste processing.

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