Homogenization of tomato and apricot juice concentrate and a sensory analysis of its effect

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Abstract

Juice homogenization is mostly done to create smaller fiber particles, which reduces the sedimentation velocity to a lower level.

So far, fruit juice concentrate is diluted to juice before it is homogenized. The first aim of this research paper is a feasibility study regarding the homogenization of fruit juice concentrate before it is diluted to juice. That would save capacity and energy.

Secondly, besides the prevention of sedimentation it is unclear how the juice quality is affected from the consumer point of few. To get a better understanding of it a sensory analysis was conducted with different series of homogenized tomato and apricot juice regarding pressure and homogenized juice concentration

The results revealed that it is possible to homogenize fruit juice concentrate before diluting it. However, the increase in consistency, yield stress and apparent G’ modulus get smaller, the more of the concentrate was homogenized. The difference in the effect becomes smaller the higher the homogenization pressure was. The calculated particle size distribution from the Mastersizer and the visual analyzed microscope images had the same results. To get the same size distribution slightly higher pressure is needed when more concentrate is homogenized. The sensory analysis showed that the change in pressure is influencing all attributes asked to the respondents. Furthermore, the liking is affected by the juice type but not by the used homogenized concentrations. The tomato juice, which was homogenized with a pressure of 150 bar, had the best scoring for sweetness, flavor, mouthfeel and overall likeability. The homogenization of apricot nectar increased the liking for uniformity, sweetness and flavor. The preferred homogenization pressure range was between 50 and 150 bar.

It can be concluded that a higher juice concentration can be homogenized without affecting the quality properties. Furthermore, the ideal homogenization pressure is between 100 and 150 bar for the examined juices.

Contents

1 Context and Background

1.1 Apricot and Tomato

Apricots are classified as stone fruits ”*Prunus*” and its Latin species name is P.armeniaca (Bortiri, Sang-Hun, Jiang, & Baggett, 2001).

The apricot fruit consists of five layers: the outer layer is the epidermis, which consists of tightly packed, covered with a cuticle on the outside. This layer is covered with 135 hairs/mm², which are up to 100 µm long (Figure 1.1). Next, the hypodermal layer looks like the epidermal layer just without the cuticle. It can be seen on Figure 1.1 and Figure 1.2 that these two layers together have a thickness of approximately six cells. The largest fraction of fruit cells are the parenchyma cells. The parenchyma cells close to the hypodermal have an average diameter of 176 µm and are spherical shaped. The closer the cells are located to pit the smaller and longer they get with a final size of 57 µm (Compare Figure 1.2 - Figure 1.4). Around the pit are 1-4 layers of small, spherical cells (Figure 1.4 lower part).

The last group of cells are part of a network of vascular cell bundles shown in Figure 1.5 and 1.6, which are tightly packed cell and cross through the parenchyma layer (Archibald & Melton, 1987).

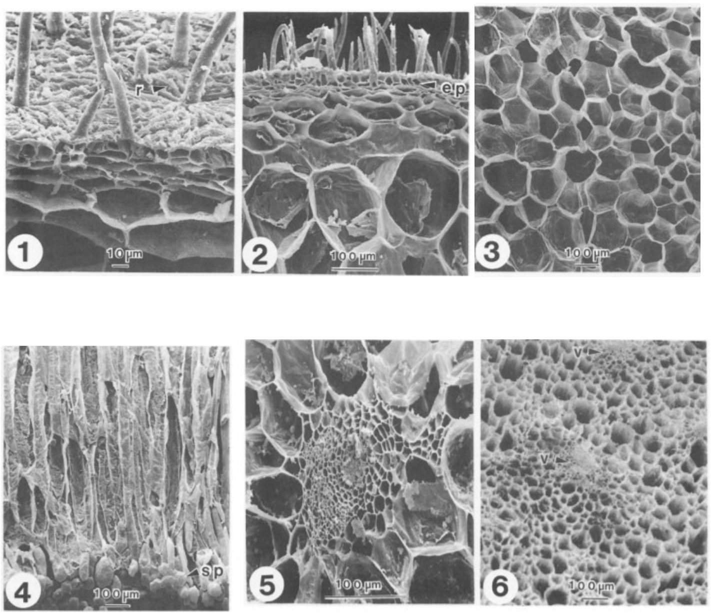


Figure 1 Microstructure of different types of apricot fruit cells and layers from outside to inside. Nr.1 and 2: Epidermis (Hairy cells, Hypodermis (small cells), Parenchyma cells (large cells); Nr.3 and Nr. 4upper part: Parenchyma cells. Nr.5 and 6: Vascular cell bundle) (Archibald & Melton, 1987)

Between 2014 and 2016, 3.9 million tons of apricots were produced globally in average per year. Almost every country along the equator is farming apricots industrially but by far the two top producers are Uzbekistan and Turkey, who produce together more than a quarter of the total apricots (FAO, 2017).

1.2 Tomato

The tomato is officially classified as a berry. As demonstrated in Figure 2 the structure of a tomato starts similar to the apricot with the epidermis outside followed by vascular bundles and a pericarp layer. Tomatoes vary with the number of locular cavities. The picture below is a common tomato with five locules whereas cherry tomatoes are usually bilocular. This segment of the tomato contains the seeds within a gelatinous membrane (Rost, 1996).

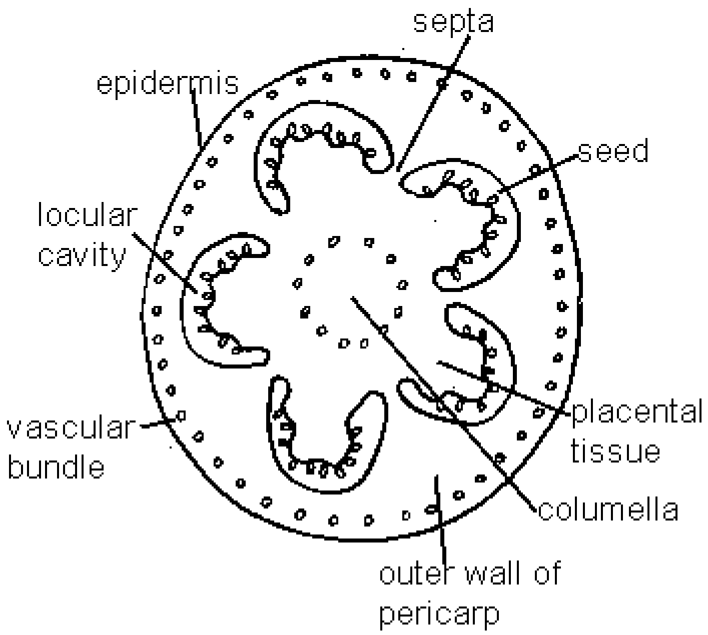


Figure 2 Scheme of a tomato from a transverse perspective (Rost, 1996)

As seen in Figure 3 the cell size of the tomato flesh varies with location. Close to the epidermis, the cell diameter can be less than 10 µm long whereas the cells in the middle of the outer pericarp wall are up to 500 µm long.

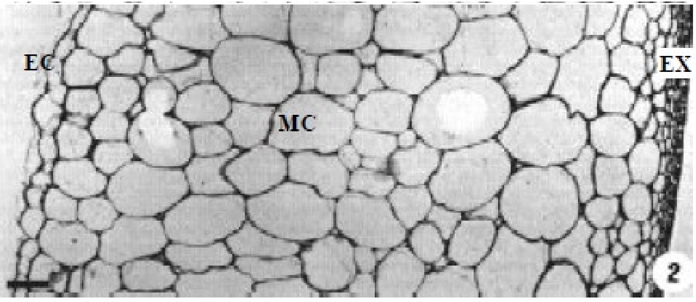


Figure 3 Light microscope image of the pericarp transversal section of a cherry tomato. Bar= 200µm (Stertz, Esperito Santo, & Bona, 2005).

The red appearance of a tomato is due to the content of lycopene in the chromoplasts (Rost, 1996) (see Figure 4).

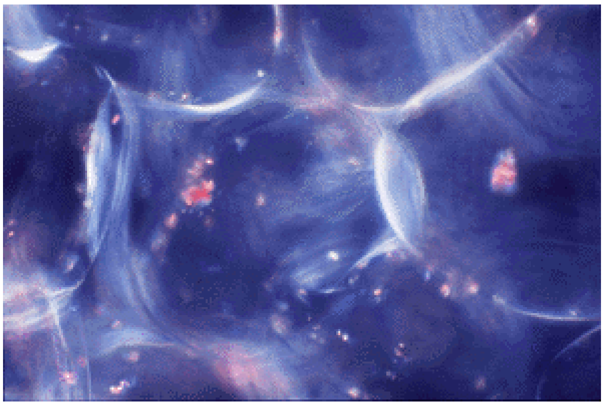


Figure 4 Light microscope image of tomato parenchyma cells (Rost, 1996).

There is a massive global production of tomatoes and it has increased steadily in the decade between 2006 and 2016 from 130 million ton to 177 million ton. China alone has contributed more than 55, 5 million tons in average between 2015 and 2016 (FAO, 2017).

1.3 Tomato and Apricot juice concentrate

After harvesting the tomatoes are transported to the processing facilitates. Since the composition of the tomatoes varies with the grade of ripening different ripening stages of tomatoes are mixed together to ensure the same properties of the final product. Before crushing which is also described as chopping or breaking the tomatoes are washed and defect ones are sorted out.

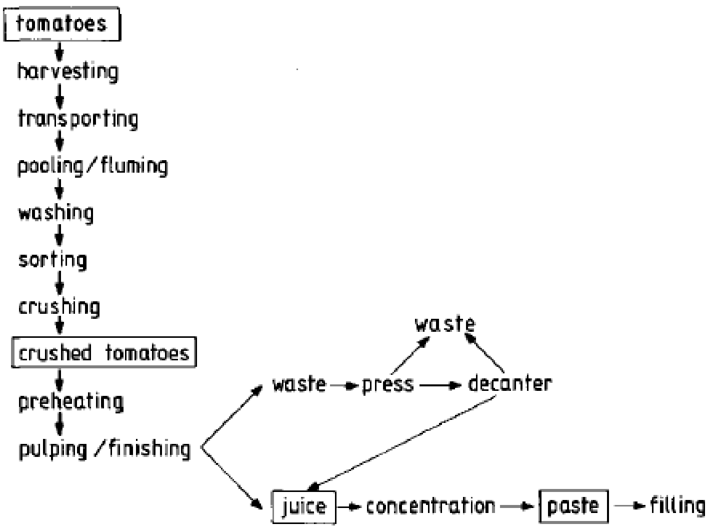


Figure 5 Production scheme of tomato concentrate (Heutink, 1985)

The preheating temperature and time has a strong influence on the final product. If the temperature is high, up to 115 °C the process is called ”hot break” which deactivates enzymes instantly and leads to a higher viscosity on the final product. It should be mentioned here that the correlation between the viscosity and enzyme activity is controversy discussed and the conclusions in more recent papers is that there are probably other reasons which have a greater impact on the change in viscosity.

For instance, the ripening stage of the tomato has probably major impact on the viscosity properties of the final product because not only water insoluble pectin is transformed to pectin during ripening but also the pH is increasing which influences the functionalities of the pectin (Dauthy, 1995).

1.4 The homogenizer

The high-pressure homogenizer was invented in 1899 and it was mainly used to create a stable milk emulsion. In principle, the liquid is pressed through a tiny gap (~0,1mm) between the so-called seat and a forcer. The seat and forcer together are called homogenizer head. Most of the used homogenizers consist of two heads in a row (Figure 6). The distance of the forcers can be changed which controls the exact gap size and the resulting pressure.

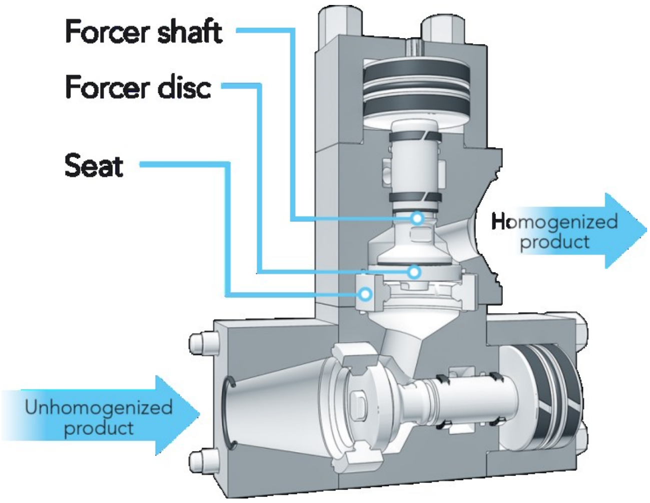


Figure 6 Illustration of a two stage homogenizer head (Tetra Pak, 2015)

After the liquid has passed the gap turbulences and cavitation is created which deforms and eventually breaks down the fat droplets. One theory about the purposes of the second stage is that it forces backpressure whereby cluster forming is avoided. In addition, the second stage is stabilizing the flow in the outlet pipe. (Tetra Pak, 2015). However, experimental studies concluded that cavitation does not play a significant role for neither drop fragmentation nor cell disruption. The effect on cavitation and turbulences could be visualized and showed that cavitation occurs mostly before the fluid is pressed through the gap whereas the turbulences take place in a relatively long stream after leaving the gap. By visualization of drop up fragmentation it can be seen that the break up occurs where the turbulences take place. Therefore, it can be assumed that these turbulences are also the main cause for the disruption (Håkansson, o.a., 2011). This finding is supported by a study where different geometries of the homogenizer seats where used. Square shaped seats did not have a higher cell disruption compared with conical ones although much more cavitation occurs in the former (Kleinig & Middelberg, 1996).

The physical effect of high-pressure homogenization on fruit juices, especially orange and tomato juices have been focused because of their commercial high volume. It can be concluded that the process leads to a cell break down and the viscosity is increasing proportional to the pressure. The aim is to break down the particles, which slows down their sedimentation and forms a stable state within the fluid, which is described as cloud. This cloudy state of dispersion is often desired by the consumer (Dauthy, 1995).

Fruits and their concentrates contain fruit cells that have a larger diameter than the gap in the homogenizer. It would be logical that these fruit cells break when they pass the gap. However, this effect could not be seen in the article by (Kleinig & Middelberg, 1996). Therefore, it is likely that the cells are very elastic and resistant against friction and the cell break up is caused by another mechanism.

Several studies, where light microscope images were used to compare the microstructure of fruit juices with different homogenization pressure confirm that the microstructure of the juices changes with their decrease is mean particle size. Un-homogenized juices contain whole cells including undamaged cell membrane and organelles. With an increase in homogenization, pressure the cells break and the size of cell particles decreases. The smaller the particles get the more fiber aggregates are formed (Kubo, Augusto, & Christianini, 2013)& (Tornberg, 2016).

In addition, (Bayod, 2008) explains the influence of shearing after the actual homogenization. A homogenized tomato suspension shows a wide spread network of fiber particles. However, the particles are already organized as described before (Figure 7, left). A new type of network is formed when the homogenized suspension was subsequently sheared (Figure 7, left).

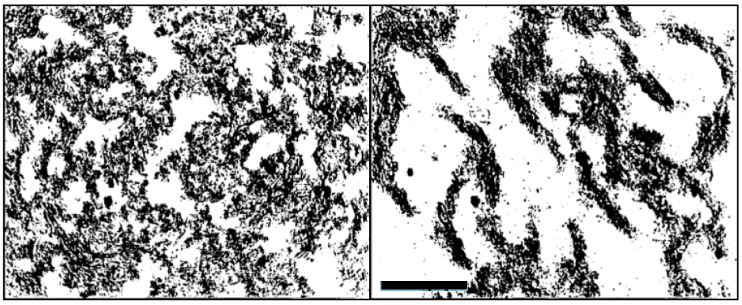


Figure 7 Binary images of 10% (w/w) cold break tomato paste suspension. Suspension was homogenized three times (pressure 90 bar). The scale is 250 µm. The images on the left and the right images show the suspension with and without subsequent shearing (Bayod, 2008).

The particles formed densely packed rod shaped aggregates, which were not as well connected to each other compared with the non-sheared suspension (Bayod, 2008).

As a result of the new formation the apparent G'-modulus is lower compared with the juice which was only homogenized (Tornberg, 2016).

1.5 Sensory analysis

The taste of a food product is influenced by many various factors like personal background, environment, appetite, age or food properties.

One important property is texture, which can be divided again in different attributes like thickness of a fluid or creaminess. Since texture is still a sensory attribute only humans can measure it. However, several studies are proven that there is a direct link between sensorial thickness and viscosity. However, other texture characteristics, which are more complex, require a combination of measurement techniques.

Another problem about the correlation between measurements and perception is that eating, and drinking is a continuous process with different steps starting from mastication and swallowing. Even for drinks, the liquid is pressed between the tongue and the palate so that there is a high variance in velocity and pressure. Furthermore, since prepared food is mostly either chilled or heated there is a temperature change in the mouth, which also affects the rheological properties of the food. As soon the food gets contact with the salvia, there is a change in food composition and depending on the food properties, the sensation can change from a dry to a creamy mouth feeling (Sala & Scholten, 2015).

The intensity of the basic tastes is also correlated to perception of typical fruit aromas. For instance, it was found that the highest tomato flavor intensity was scored when sugar and titrable acid were also present in a high amount. This effect was shown both in different tomato types with a variation in sugar and acid and experimentally by adding sugar and acid (Thakur, Singh, & Nelson, 1996)

2 Aim

So far, fruit juice concentrate is diluted to a normal juice level before being homogenized. The first goal of this Master thesis was to find out in which extent the fruit juice concentrate can be first homogenized and then diluted. This would save production energy and capacity and therefore had both an ecological and economical outcome.

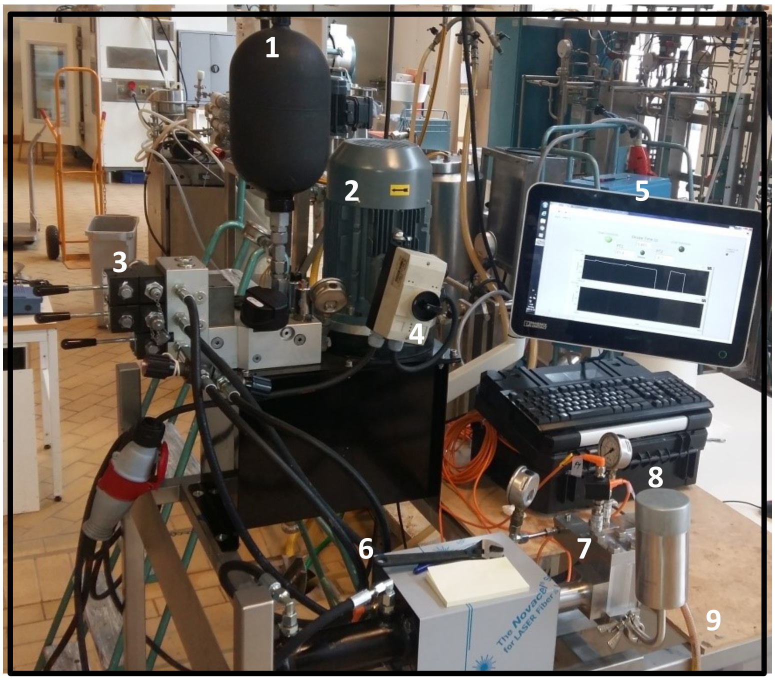
It is already known that an increasing in homogenizing pressure leads to smaller particle sizes within the juice dispersion. This increases the viscosity of the product and minimizes creaming/sedimentation. However, less in known about the sensory experience from the customer perspective. The second aim is to close this knowledge gap and find a correlation between homogenization pressure, homogenized concentrate and the optical, taste and mouthfeel sensation for the customer. To achieve this a sensory test will be performed on the different juices.

3 Material and Methods

3.1 Homogenizer

3.1.1 Bench top

Most of the experiments were conducted by using a prototype of homogenizer, the so-called bench top homogenizer (Figure 8). It has the benefits of a lab scale homogenizer requiring small quantities of samples because each piston stroke can be taken manually. One stroke has a volume of 38 ml and takes 0,45 s to get pushed through which results in a theoretical velocity of 304 L/min if the piston loading time is not taken into account. In addition, unlike typical lab scale homogenizer, its gap size between seat and forcer is the same as for the industrial homogenizer and therefore the experimental results can be transferred to an industrial size level.



1) Hydraulic air tank
2) Engine
3) Pressure setting system
4) On/Off button
5) Output system
6) Piston
7) Homogenization stages
8) Inlet tank
9) Outlet hose

Figure 8 Benchtop homogenizer connected to the computer. The actual homogenization pressures for both stages and the velocity are displayed on the screen (5).

3.1.2 Alex S05

It is important to see if the results from the Benchtop model can be reproduced in an industrial type of homogenizer. For this reason, the Alex S05 homogenizer was used. Like the Bench Top model, the Alex S05 has two hydraulic homogenization stages (see Figure 9). The homogenization head is identical with the Bench Top (Figure 9, black circle). However, this model is designed for a continuous production, which is driven by a 3-piston positive displacement pump that results in a capacity of around 300L/h (Tetra Pak, 2011).

Figure 9 Image of an Alex S05 homogenizer

For each series, the pressure had to be changed up to five times while the homogenizer was running. The juice between the changes had to be discarded. Therefore, for the sample preparation 0,5 L of homogenized juice was achieved for each sample. To be able to process the required amount of juice a Tetra Almix is used which can store and process up to 30-liter juice. Moreover, it has the advantage to mix and degas the juices in one-step.

In addition, to ensure a stable flow of the viscous raw material an additional centrifugal pump (Alfa-Laval, Sweden) between the mixer and the homogenizer was used.

3.2 Principal experiment plan

Since the goal is to find out if juice can be partially homogenized, meaning that the juice concentrate is first homogenized and then diluted to juice, first a standard juice made out of a concentrate was developed, produced and analyzed (Figure 10). To get insight of the homogenization effect, the common homogenization method was applied to produce homogenized juice samples. Finally, the partial homogenized juice samples were made and analyzed. These steps were done for both the apricot nectar and the tomato juice.

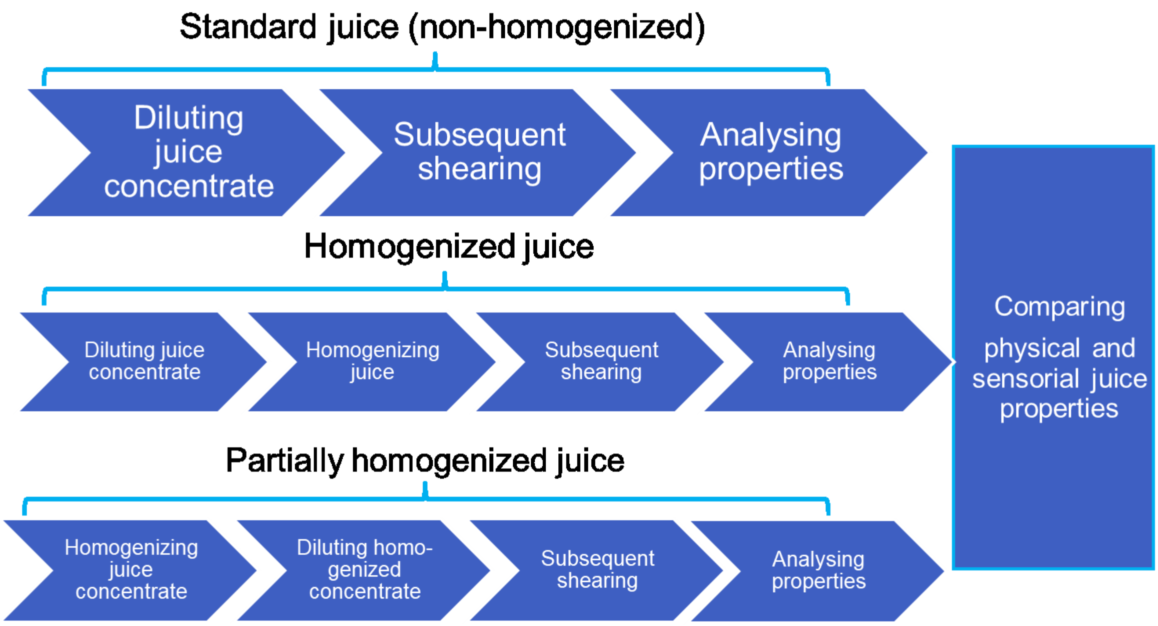


Figure 10 Overview of the experiment plan. The standard juice was not homogenized. The homogenized juice is the common homogenization method by the industry. The partially homogenized juice is the homogenized juice, where primarily juice concentrate was homogenized.

The rheological properties, particle size distribution and microstructure of these three different produced samples were compared to see how effective partial homogenization is. Furthermore, the results between apricot nectar and tomato juice were compared.

3.2.1 Preparing standard juice

Tomato juice (TJ)

Pre-trials with hot break tomato concentrate showed a too viscous consistency for the homogenized juices. Therefore, a cold break tomato concentrate was used for the experiments.

The tomato concentrate (Freshona, imported from Italy) was purchased at Lidl Lund between March and May 2018. The tubes have been stored at room temperature. The parameters of the product are listed in Table 1.

Table 1 Tomato puree nutritional value (Freshona, 2018)

Nutritional facts	
Dry Solids	28-30 % (double concentrated)
Fat	0,3 g
Carbohydrates	5,6 g
• Sugars	5 g
Proteins	1,7 g

For preparing the samples, the paste was gently mixed with cold tap water until a final Brix of 4,9(+-0,1) was reached, which was equivalent to 19 % (w/w) concentrate. For all next samples, this relative amount was used to prepare the TJ samples. However, the Brix was checked and adjusted after all trials.

Apricot Juice (AJ)

Apricot concentrate (Alpenfrucht, Italy) was chosen and provided by Tetra Pak. The raw material has been stored in a six ˚C tempered cool storage. The parameters of the product are listed in Table 2

Table 2 Apricot concentrate properties

Analytical Values	
Sol. Solids refractometer (Brix)	11,2
Total Acidity (as citric acid pH 8,1)	1,32
pH	3,42
Milling (mm)	0,5

Since according to the fruit juice experts of Tetra Pak, apricot nectar contains usually 35-50% apricot pure and the final product should have 12 Brix, the formulation on Table 3 was decided.

Table 3 Formulation for standard apricot nectar

Ingredient	**Amount (weight %)**
Apricot pure	50
Sugar	6
Tab water	44
Final Brix	12

The sugar was diluted in hot water and cooled down again. The used water was included in the juice recipe. The additional water, apricot concentrate and sugar solution were mixed with a common wire whisk. Finally, the nectar was degassed as described for the tomato juice.

3.2.2 Preparing homogenized juices

The same method was used for both AJ and TJ. Since the homogenization is the most crucial part of this thesis, it was important to be as precise as possible with the pressure settings.

Over the whole set of experiments the seats and forcer were checked regularly for fatigue damage and if necessary replaced. After each experiment the homogenizer were cleaned with water. At the end of each experimental series they were cleaned first with hot water, followed by a detergent solution and hot water again.

3.2.2.1 Homogenization: Benchtop

Before the homogenization, the juices were aerated with a Buechner flask. As a vacuum source, a water pipe was used. The juices were exposed to the vacuum until all air bubbles were busted. Next, the juices were gently transferred in clean flasks.

Most of the industrial homogenizer have two stages of homogenization. It is a common practice to use approximately 20 % of the pressure on the second stage. Although the actual benefit is not fully clear for the homogenization of fiber, the second stage is also used in these experiments because the aim is to simulate an industrial production.

According to the fruit experts in Tetra Pak, the most used pressure for fruit juice homogenization is 150 bar on the first stage and 30 bar (20%) on the second stage. Therefor the experimental pressure series were chosen around this one. The combinations can be seen in Table 4.

Table 4 Homogenization pressures for the experiments.

Pressure first stage (bar)	Pressure second stage (bar)
250	50
150	30
100	20
50	10
10	-
Not Homogenized (standard)	-

After setting and checking the suitable pressure one additional strike was discarded to get sure that no more juice from the previous setting was left over in the outlet pipe. Each sample was put in a sample flask and the used hydraulic and homogenizing pressures were documented.

3.2.3 Homogenization: Alex S05

To get comparable results the principal homogenization process is the same for the AlexS05 and Benchtop. However, in this case around 2-3 liter of juice is needed for one sample due to the relatively high production rate. Therefor the juice is prepared in a mixer connected to the homogenizer. The aim was to prepare the juice for the AlexS05 as similar as possible as for the Benchtop. Therefore, the mixer power was set to 3 % and the agitator to 75% that led to gentle mixing. The pressure was set to 160 mBar to aerate the juice. The mixing and degassing process was kept going for 10 minutes.

The centrifugal pump was set to a frequency of 30 Hz. To set the pressures for the homogenizer the second stage was set prior the second one since the used pressure is smaller and there is only one gauge for both stages.

First the second stage and then the first stage were set. The highest pressure-pair was set first followed by descending order.

Finally, the samples were transferred from the outlet pipe to clean plastic flasks and further to the sample container.

3.3 Preparing partial homogenized juice

3.3.1.1 Partial homogenized TJ

Since it was not clear to which extent the concentrate could be homogenized and to get an understanding in which way the homogenization of concentrate affects the final properties, different series of concentrate were conducted based on the percentage of concentrate used before homogenization. The chosen levels of concentrate were 38 % and 75 % (w/w). Higher concentration levels could not be carried out because the dispersion was too viscous to flow constantly in the homogenizer. Since the Brix is directly proportional to the percentage of concentrate, the mixtures could be checked with a Brix meter afterwards. The relation between Brix and concentrate can be seen in following table.

Table 5 Levels of TJ concentrate used before homogenization. TJ concentrate 19% represents the standard tomato juice

TJ concentrate	**19%**	**38%**	**(75%)**
Brix	**4,9**	**9,8**	**(21,1)**

The homogenization process was conducted as it is described for the standard TJ.

After the homogenization process the concentrates were diluted to 4,9 Brix with cold tap water. The formula $c1 \times V1 = c2 \times V2$ helped to estimate the needed additional water. However, all the samples were checked with a Brixmeter for their correct values. After the mixing, the juice samples were deaerated as described for the standard TJ

3.3.1.2 Partial homogenized AJ

Unlike the tomato concentrate, the viscosity of the apricot concentrate was obviously low enough to be processed undiluted. Therefore, for the partial homogenized AJ 100% of the AJ concentrate was homogenized. The partial homogenized AJ was deaerated and homogenized as the partially homogenized TJ.

After the homogenization, the AJ concentrate was diluted with a water-sugar solution to reach the standard concentration. The ratio was the same as it was used to produce the AJ.

3.4 Subsequent shearing

3.4.1 Methods for subsequent shearing

Unlike in a laboratory scale the product is still exposed to shearing forces after the homogenization process. Therefore, the samples were mixed after the homogenization process to break down apparent gel formations and to destroy fiber lumps that would probably also disentangled in a common production line. For the 60 ml samples, a Malvern Ultraturex with a screw-type stirrer has been used (see Figure 11).

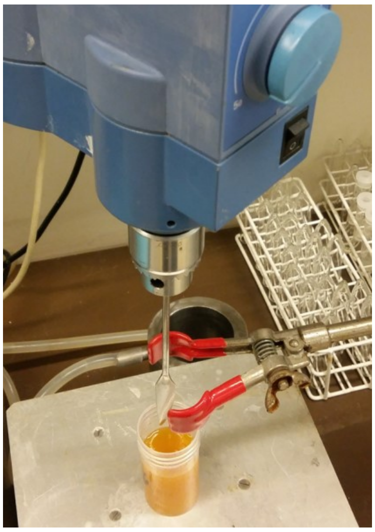


Figure 11 Instrument setting for samples with subsequent shearing: Ultraturex with a screw-type stirrer.

The speed was set to 1000 rpm and the duration was 60 seconds. For the sensory analysis samples, a common table mixer with a speed level of one was used.

3.4.2 Pretrial: Effect of subsequent shearing

After the first evaluation of the results between Bench Top and Alex S05 homogenizer it could be seen that the rheological properties were significantly different although the same particle size distribution could be achieved. It is known that shearing after the homogenization can decrease the viscosity. Therefore, it was assumed that the higher shearing forces after the homogenization caused by the longer outlet hose and the continuous flow of the Alex S05 influenced some of the rheological results. Consequently, pre-trials have been performed to confirm that the shearing caused the different results.

3.4.2.1 Viscosity

The black dashed line in Figure 12a shows the flow behavior index of the AJ. The black line represents the subsequently sheared AJ. By comparing these two series it can be seen that the partially homogenized AJ became more shear thinning when homogenized with low pressure. The red line and the red dashed line are the partially homogenized AJ and the subsequently sheared, partially homogenized AJ, respectively. The flow behavior decreased for both juices when low pressure was applied. The subsequently sheared, partially homogenized AJ was slightly less shear thinning at 250 bar. The grey and red points in the graph are the samples, which were homogenized with the Alex S05. It is clear to see that their flow behavior is identical with the subsequently sheared samples.

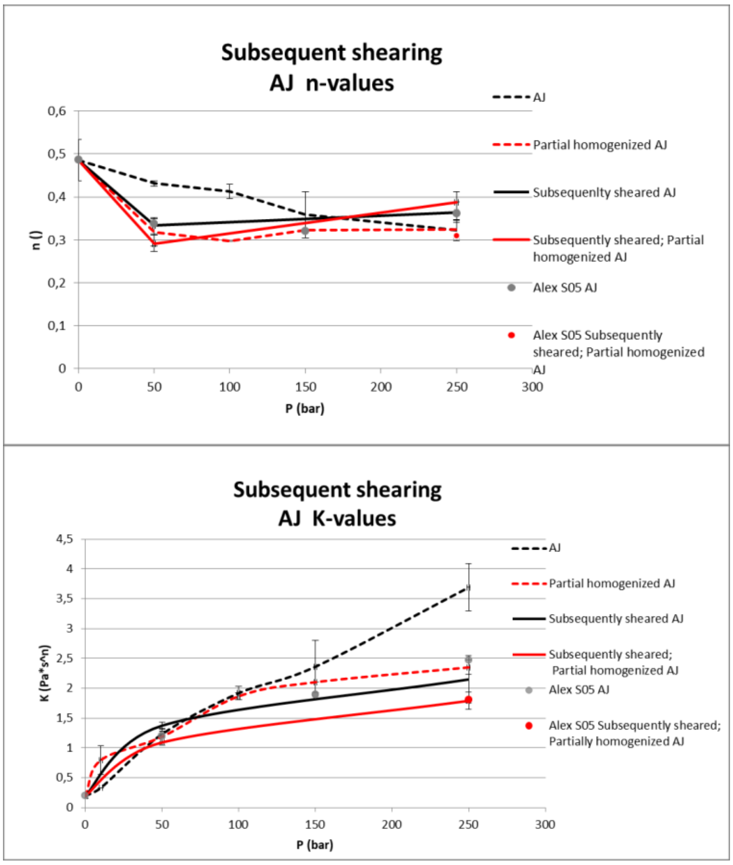


Figure 12 Partial homogenization effect on n- and K- values. Black lines are apricot nectars and red lines subsequently sheared AJ. Dashed lines show the viscosity values without subsequent shearing.

Figure 12 shows the consistency factor. All juices had a similar sharp increase in consistency for low pressure, followed by a steady increase until the maximum measured pressure. The homogenized AJ is the only series where the consistency factor increased sharply for high pressure. The AJ samples from the Alex S05 have similar consistencies as the subsequently sheared AJ samples from the Bench Top. This is the also the case for the partially homogenized AJ.

3.4.2.2 Yield stress

As it could be seen in the consistency values, the homogenized AJ series has a steady increase in yield stress whereas the slope of the subsequently sheared juice flattens after 50 bar, which leads to a decrease of 50 % in yield stress compared with the homogenized sample (see Figure 13). The results between the Alex S05 are almost identical.

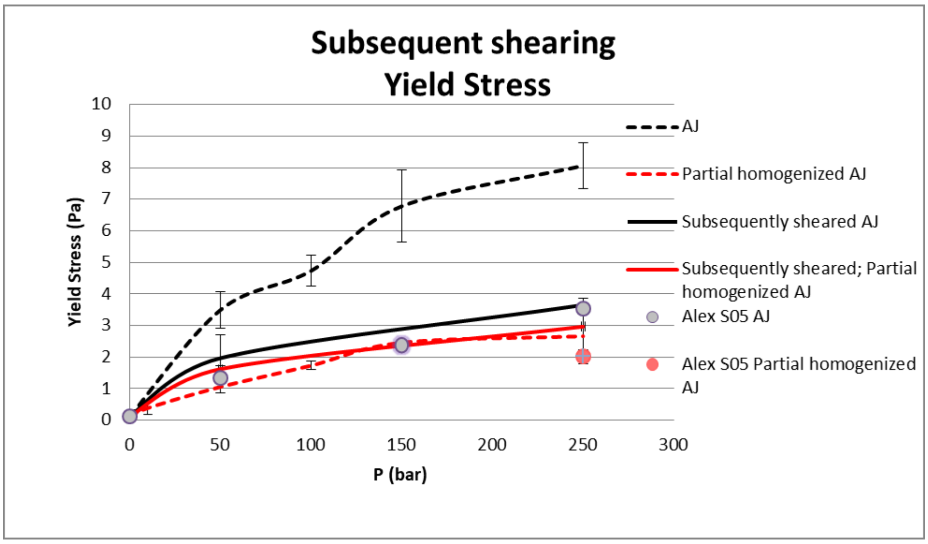


Figure 13 Effect of subsequent shearing on the yield stress of AJ.

Since all the measurements taken with the Alex S05 and the subsequently sheared samples taken with the Bench Top homogenizer have a very good match, it can be assumed that the two homogenizer accomplish the same results as long as the juice is subsequently sheared after homogenization. Therefore, all taken samples in this study were subsequently sheared.

3.5 Analytical method

3.5.1 Microscopy

An Olympus BX50 light microscope with a 50x magnification and an Olympus ILLK 200 stereo microscope with 10x and 63 x magnification were used to get images of the microstructure. With a pipette 0,15 ml of a gently stirred sample was transferred on a glass and covered with a cover glass. When putting the cover slip on the slide it can happen that small air bubbles are trapped. Although they can be neglected by the human eye and got erased for the image analyses these bubbles might cause slightly wrong interpretations for both the visual examination and for the image analysis.

The image software IC-Capture was used to improve the image quality and to safe images. The basic settings can be seen in Table 6 below:

Table 6 Settings for the image software IC-Capture

Light	102
Color strength	196
Color	170
Gamma	11

The image software ImageJ was used to set scale bars and to do further analyzing processes with the plugin DiameterJ 1-018.

The DiameterJ plugin that was programmed for analyzing micro fibers requires black/white images. In the first step, the program automatically uses 16 different segmentation algorithms to create a list of binary images. However, background, light and contrast corrections have been performed in a previous step to achieve better results.

The binary images must be compared with the original and the best fit can be selected for further manual correction and processing. In the second step the program analysis, several of different fiber characteristics (see Figure 14). For this thesis the fiber diameter means, or histogram mean, and the mean pore area are shown.

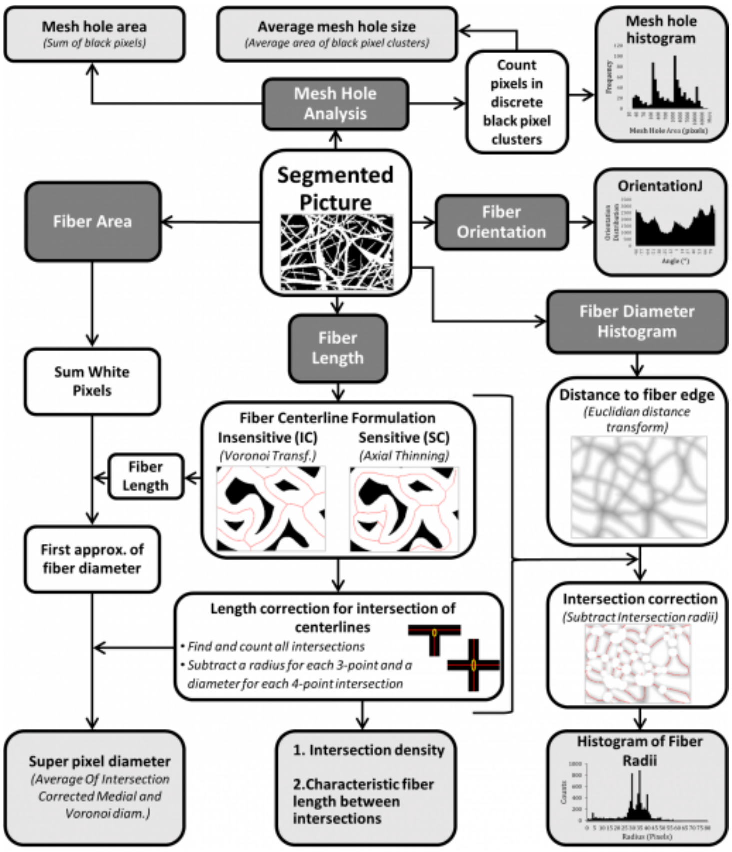


Figure 14 Overview of the image analysis outcome of the plugin DiameterJ

As a control, montage images for each sample are created which include the original image, an image of the centerline, an image of counted centerlines and an image with the detected pores (Hotaling, Bharti, & Kriel, 2015).

The image analyzing contains a high number of manual and automatic processing steps, so that the final numbers contain probably loaded with a high error. Furthermore, the complete analysis is time intensive although automatic tools were used when possible. That resulted in too less measured samples for a conclusion. However, in principal it is possible to analyze the images quantitative if the methodology is further improved regarding sampling and image preparation. Yet, it can be questioned if the effort justifies the possible outcomes because the visible change is probably highly correlated to the rheological properties, which are much easier to analyze.

3.5.2 Particle size distribution measurement

The particle size distribution was analyzed with the help of the Malvern Mastersizer2000. According to the literature (Gausman, Allen, & Escobar, 1974) the refractive index of plant cells is 1,42 with an absorbance of 0,1. The stirring speed was set to 1500 r/min. An acceptable obscureness range was chosen to be 10-15%. Only results were evaluated when the residual value was below 1 %, which indicates a good fit between the measurements and the theoretical values. To get reliable results the sample could disperse in the tank for one minute before the first measurement was taken. The SOP was set to take three measurements in a row and record both the individual results and the average of them. After each sample has been analyzed, the tank was flashed with deionized water and filled up with MiliQ water for the next measurement.

3.5.3 Rheology measurement

All rheological measurements were carried out with the *Malvern Kinexus Pro* viscometer and the data were obtained with rSpace software. The data were then exported to MS office and further processed.

The chosen upper geometry was a four bladed vane with a diameter of 21 mm. A normal cylindrical cup was used as a lower geometry with a diameter of 25 mm, which resulted in a gap size of 2 mm. This setting was describing in several papers where similar experiments were conducted to minimize the slipping effect of fruit juices.

To save time and avoid performing errors a sequence was set up which delivered both shear rate and oscillatory data and checked if the frequency sweep was performed within the linear region. The scheme of the sequence can be seen in Table 7 below.

Table 7 Overview of the generated sequence for the rheometer.

Process	Conditions
Sample insertion	Full cylinder (including vane), T = 20 °C, resting time: 5 min
Steady shear rate ramp	Shear rate: 0,1-10/s time span: 20 s per point; total point: 14
Rest	5 min (AJ), 10 min (TJ) to avoid thixotropic relaxation
Angular frequency sweep	0,1-100 rad/s; strain 0,1 %
Rest	5 min (AJ), 10 min (TJ) to avoid thixotropic relaxation
Strain sweep	Angular frequency: 10 rad/s; strain: 0,01- 10 %

The second resting step was necessary because a sudden vane spin could be sometimes observed at the end of the frequency sweep step.

3.5.3.1 Analyzing viscosity

The power law was used to determine the power law index n and consistency index K. To obtain that a plot between the log shear viscosity and log shear was created. It was crucial to use part of the linear region with the highest shear rate values because these results match best with the literature.

The green circle in Figure 15 illustrates the area where the power law index n and the consistency factor K were taken.

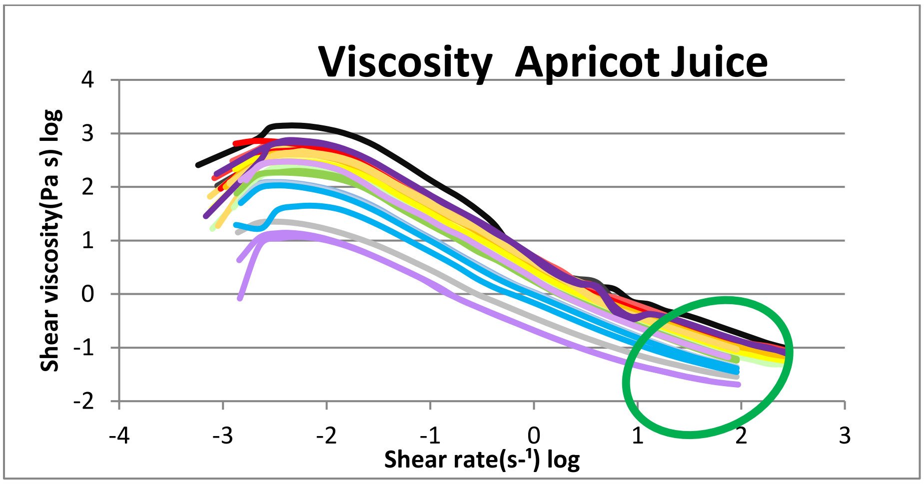


Figure 15 Examples of different linear regions depending on homogenization pressure and partial homogenization level

Note that the maximum shear rate was higher for samples with higher viscosity.

3.5.3.2 Analyzing yield stress

To obtain the yield stress a tangent analysis was used. As seen in Figure 16 the crossing point of the maximal horizontal shear viscosity has been crossed with the tangents of the linear slope.

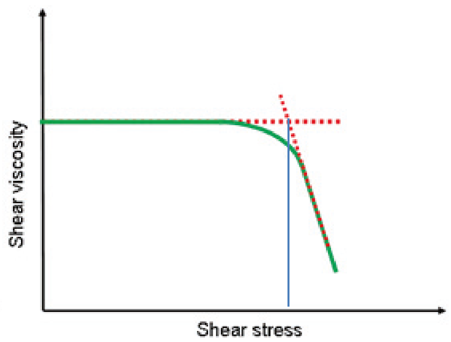


Figure 16 Yield stress determination by cross tangents analysis (Malvern Instruments, 2012).

For the used settings and samples, a standardized procedure could be used. The third to the eighth shear stress and shear viscosity measurement point from the shear rate ramp were isolated and different section of these slopes were compared on their standard deviation. Finally, the one with the lowest SD was selected (see Table 8).

Table 8 Standardized calculation of the yield stress based on the third to the eighth recorded measurement point. Yellow fields are the raw data; blue is the legend and green is the best-calculated regression and yield stress.

Shear stress	viscosity			full range		-Point3		-Point3,4		-Point3,8		-Point3,4,8		Best fit
0,08	22,41	Slope	Intercept	-182,80	37,53	-190,05	38,65	-194,01	39,29	-188,32	38,44	-192,92	39,13	
0,11	18,59	se(slope)	se(interce	3,76	0,52	2,06	0,30	1,66	0,26	2,59	0,36	2,93	0,43	1,66
0,13	14,43	r^2	se(y)	1,00	0,31	1,00	0,12	1,00	0,06	1,00	0,11	1,00	0,07	
0,15	10,56	F	df	2359,68	4,00	8483,09	3,00	13648,70	2,00	5295,44	2,00	4346,52	1,00	
0,16	7,47	y(max)	Yieldstress	24,68	0,07	24,68	0,07	24,68	0,08	24,68	0,07	24,68	0,07	0,08
0,1761	5,097													

To obtain the yield stress the maximum value of the whole range was the y-value and was inserted in the slope formula.

3.5.3.3 Analyzing Elastic behavior

An indicator of the strength of the network is to compare the elastic modules on a low frequency rate. For this purpose, the G'- values were isolated at a frequency of 0,1. These data can also support the results of the cross tangents analysis.

3.6 Sensory Analysis

The 40 participants were recruited directly or by email around the Food Technology department of Lund University.

A standardized 5-point hedonic questionnaire was established based on the sensory analysis described in Zhu, Sims, Klee, & Sarnoski, 2018 (see Appendix I). A brief introduction was given to all participants. The terminology of the attributes was explained. Furthermore, the respondents were asked to motivate their decision-making on the comment section of the questionnaire.

To get a better overview of the randomly chosen respondents, the questionnaire started with some demographic questions like gender, age group and juice drinking habits. Next, they rated uniformity (before tasting) and sweetness, flavor, mouthfeel and overall likeability (after tasting). Since the participants are not trained the questions were based on liking. The AlexS05 homogenizer was used to homogenize the samples. The juices were produced maximal two days before the first day of the analysis, vacuumed in plastic bags and stored in a cool storage. The investigated samples can be seen in Table 9.

Table 9 Table of the used samples for the sensory analysis with randomly generated codes. X marked cells were not considered in the sensory analysis.

Juice	Pressure (bar)	Concentrate concentration(%)
AJ	0,01	50
	50	50
	150	50
	250	50
Partially homogenized AJ	50	100
	250	100
TJ	0,01	19
	50	19
	150	19
	250	19
Partially homogenized TJ	50	38
	250	38

The 3-digit sample number and the order on the forms were randomly generated. The samples were filled in plastic cups maximal 30 minutes before the actual testing which leads to temperature of all samples between 5 and 20°C . The analysis took part in a sensory room with separated tables. Besides the samples, a neutral biscuit and tab water was provided to neutralize the flavor. Because of the high sample number, first only the AJ samples were served and after the participants have finished this part the TJ samples were served.

All the obtained data from the questionnaire was statistical evaluated with Minitab 18. Manova tests were performed between the demographic factors and the AJ and TJ attributes.

ANOVA tests compared with Dunnet post hoc tests were performed for each juice attribute.

4 Results & Discussion

4.1 The effect of homogenization pressure on AJ

4.1.1 Viscosity

The first research question was to what extent the partially homogenized juice concentrate differs from the homogenized juice. Therefore, first the data from the standard juice is needed to get a comparison. On all the graphs, the black line symbolizes the standard juice. AJ is used as an example to demonstrate the influence of homogenization pressure regarding the rheological properties of the juice.

Figure 17 shows both the flow behavior index and the consistency factor since the latter is always dependent on the flow behavior index. It can be seen that the un-homogenized AJ had an n-value of 0,5. When 50 bar homogenization pressure was applied the index dropped to 0,33 and was then almost constant through the entire series.

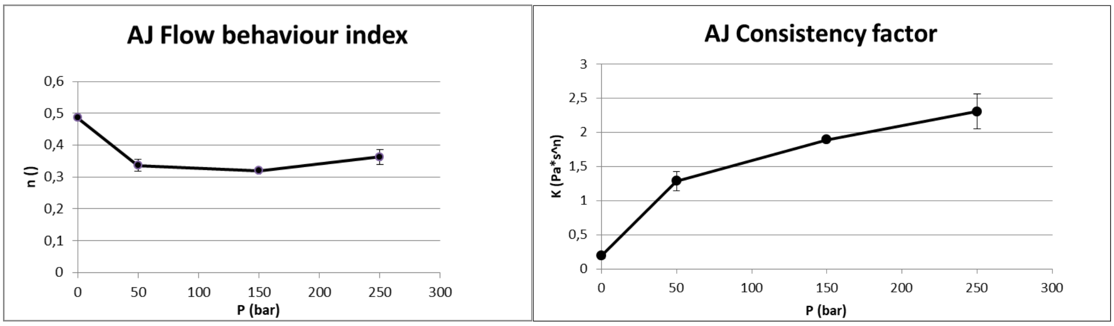


Figure 17 Flow behavior index (left) and the consistency factor (right) of apricot nectar as a function of pressure

The 50 bar homogenized AJ had a 6 time higher consistency factor than the standard juice. This value almost doubles when the juice was homogenized up to 250 bar.

A reason for the drop in flow behavior at the first 50 bar of homogenization pressure could be the breakup of the spherical cells in more spicular pieces, which tend more to rearrange their direction when shearing forces are applied. The increase in consistency as a function of pressure was probably due to a higher surface/volume ratio of the fibers, which created more possibilities for entanglements and collisions, eventually forming a network, which is suggested by the lower flow behavior index.

As seen in Figure 18 the yield stress of the un-homogenized AJ had almost no yield stress compared to the with 50 bar homogenization AJ. The yield stress continued to rise gradually with an increase in pressure.

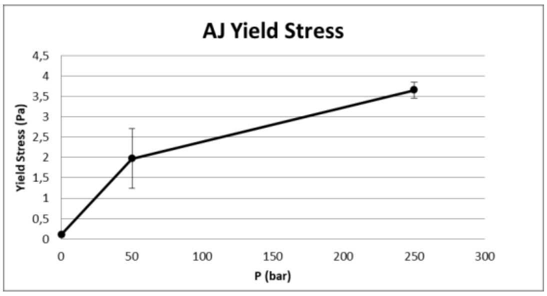


Figure 18 Yield stress of apricot nectar as a function of pressure

The reason for the increase in yield stress is likely to be similar to the one for the increase in consistency. The smaller fiber particles had an overall higher surface and the deformed shapes increased probably the ability to interact with each other and to form a network. Extra forces were required to break up these connections.

4.1.2 Elasticity

As expected, the stiffness is increasing when the juice is homogenized. Figure 19 shows the shear moduli for the standard AJ and the homogenized AJ. For both juices, the storage moduli were clearly larger than the loss moduli. Furthermore, the shown juices reached a gel break before 110 Hz. Therefore, independent from the homogenization the investigated AJ could be described as gels.

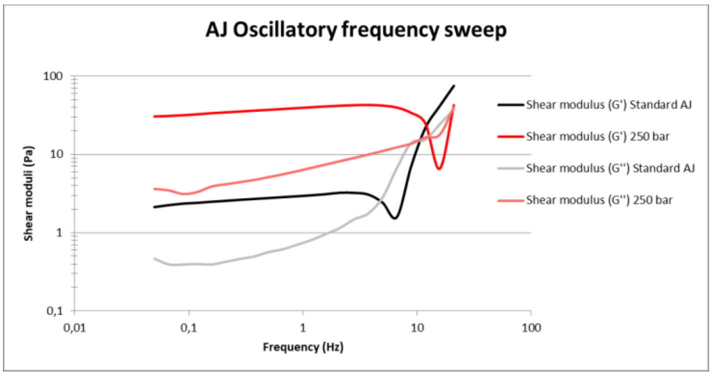


Figure 19 Typical results for the oscillatory frequency sweep performed with the standard AJ (black, grey) and the 250 bar homogenized AJ (Red, light red)

The apparent elasticity can be more directly interpreted as the strength of the network. The un-homogenized standard juice had a G' value of 1,40 Pa at a frequency 0f 0,1 Hz (see Figure 20).It increased sharply with pressure up to 31,6 Pa at 250 bar homogenization pressure.

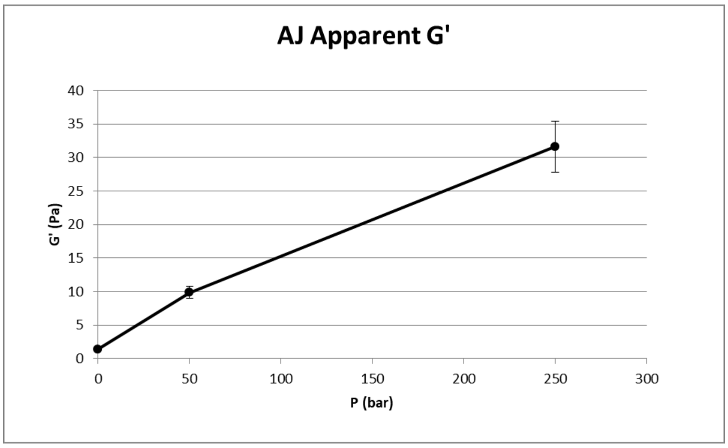


Figure 20 G' at a frequency of 0,1 Hz as a function of homogenization pressure for apricot nectar

Size distribution

The un-homogenized AJ has a surface based average diameter of 120 µm. The D(3,2) was most affected by small pressures but continued to decrease when the pressure was increased (Figure 21).

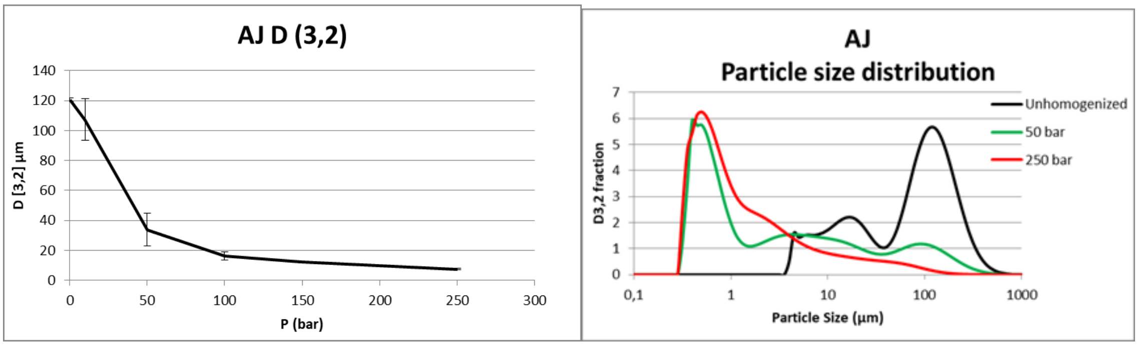


Figure 21 Surface weighted apricot nectar particle size as a function of pressure and their particle size distribution

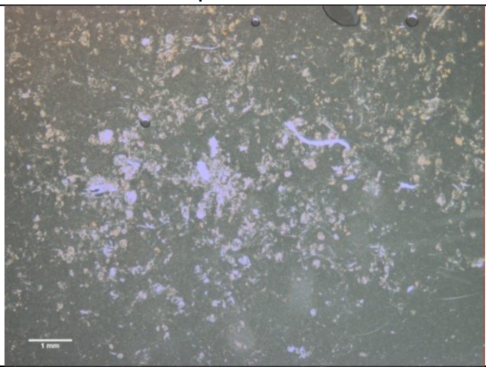
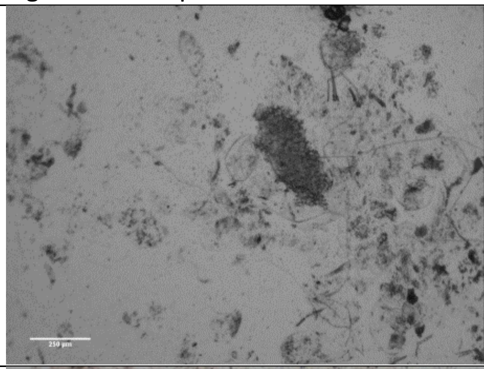
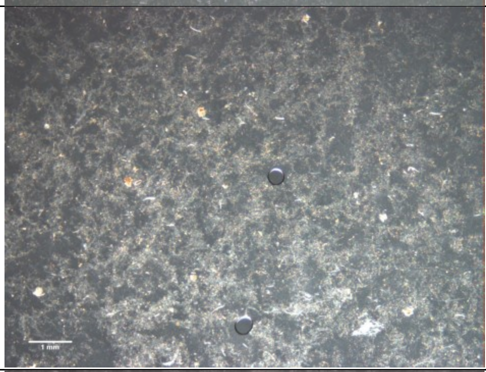
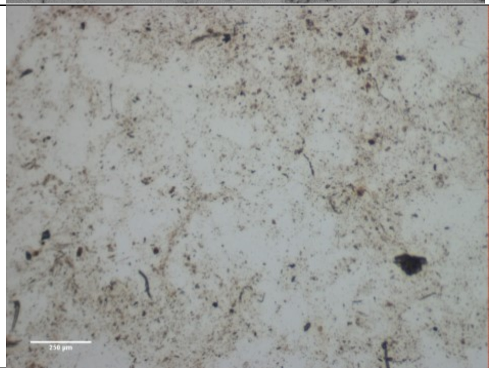
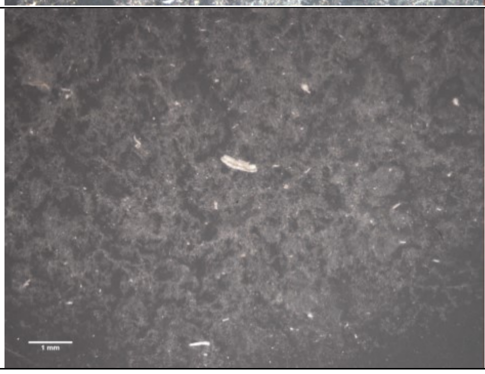
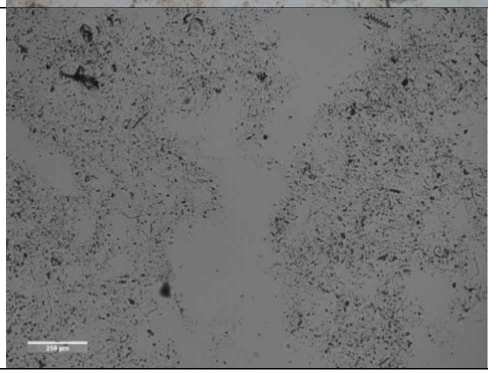
It can be clearly seen that there is a correlation between the D (3,2) results of the AJ and the rheological parameters.

The D(4,3) values for both juices can be seen in Appendix III.

4.1.3 Microstructure

It can be seen in Table that the non-homogenized AJ has clearly visual intact cells, which are distributed all over the microscope slide. The largest visible cells are approximately 0,25 mm in diameter. With rising pressure, the cells get broken and a network of particles at 250 bar is formed. Within this network clear serum channels between the aggregated fiber particles can be seen. It is noticeable that yet 50 bar homogenization pressure is enough to break up most of the apricot cells.

Table 10 Apricot nectar microstructure as a function of pressure

AJ	Stereo microscope 10x	Light microscope 50 x
Standard		
50 Bar		
250 bar		

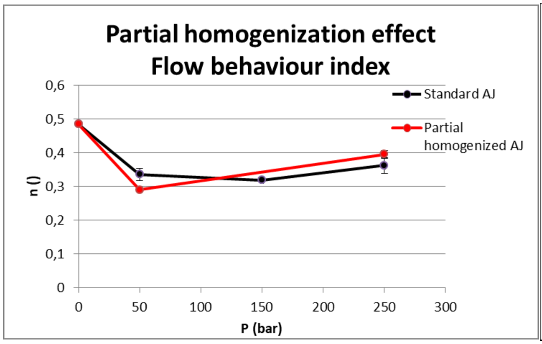
The change in structure matches with the interpretation in change of the rheological properties because the biggest change in viscosity and network strength can be seen between the un-homogenized and the samples where 50 bar homogenization pressure were applied. Consequently, the breakup of the intact cells influenced most the rheological properties of the apricot nectar. Comparing the particle size distribution with the cells and particles on the images it can be said that there is a good match for all homogenization pressure levels.

4.2 The effect of partial homogenization on apricot juice

The first goal of this thesis is to find out if there is a physical quality difference between partial homogenized juice and homogenized juice. In the following graphs, the black lines are the standard apricot nectar, meaning that the concentrate was first diluted to juice before being homogenized. The red slopes are the data from the juice samples where the pure apricot concentrate was first homogenized and afterwards diluted to apricot nectar.

4.2.1 Viscosity

Figure 22 compares the flow behavior index and the consistency factor between the standard AJ and the partial homogenized AJ. As it can be seen on the left side, the n-value for the partial homogenized AJ were not significantly different compared to the AJ at 250 bar. The slopes for the consistency factor have a similar shape but the partially homogenized juice had a significantly lower consistency for high-pressure homogenization.



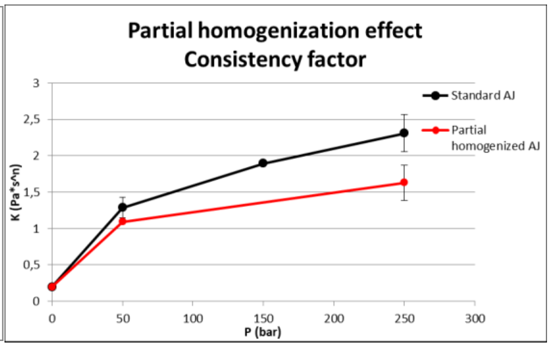


Figure 22 Flow behavior index (left) and the consistency factor (right) of apricot nectar and partial homogenized apricot nectar as a function of pressure

The average yield stress for the partial homogenized AJ was in average lower but not significantly different to the AJ.

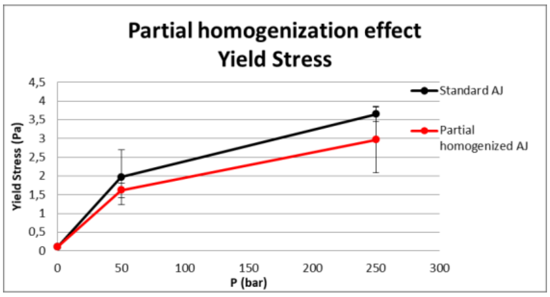


Figure 23 Comparison between the yield stress of the partial homogenized AJ and AJ

There was an increase in consistency for both the homogenized and partial homogenized juice. The difference is between the two juices becomes more significant the higher the pressure. Therefore, it depends on the desired viscosity to which extent the partial homogenization can be replaced with the standard method.

4.2.2 Elasticity

Figure 24 shows that the apparent elasticity of the partially homogenized AJ was increasing with homogenization pressure. However, the effect is less compared with the standard AJ.

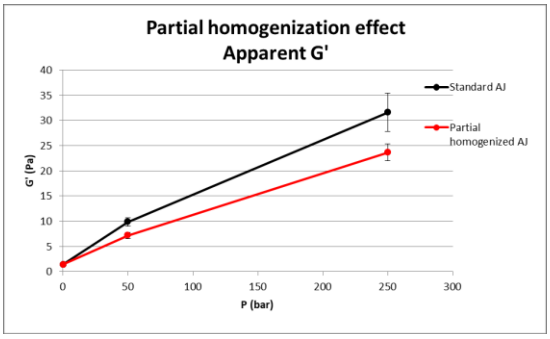


Figure 24 Apparent elastic modulus of apricot nectar and partial homogenized apricot nectar as a function of pressure

Overall the increase in consistency, yield stress and apparent G’ is slightly less when the homogenized concentration of fruit pure/paste is increased. However, it can be questioned how much influence these parameters have regarding the product quality. In addition, it is unclear to which extent shearing forces influence homogenized product in an industrial facility. In the case the juice is exposed to strong shearing after the juice homogenization, the rheological properties might not be different between the different concentrations, since it would simulate the subsequent shearing effect.

4.2.3 Size distribution

All the partially homogenized AJ samples had the same D(3,2) value compared with the standard juice except for a homogenization pressure of 50 bar where the mean area-based diameter for the partial homogenized AJ is 43 µm larger than the AJ (Figure 25). A pressure of more than 50 bar is needed to break down the cell fragments >100 µm which contributed significantly to the surface area weighted average particle size value. The D(4,3) results can be seen in Appendix III.

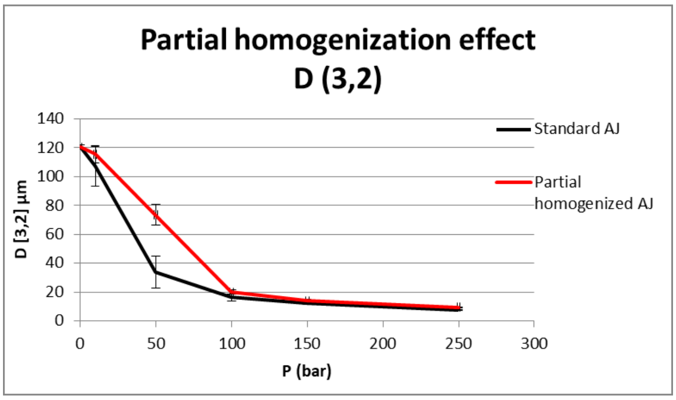
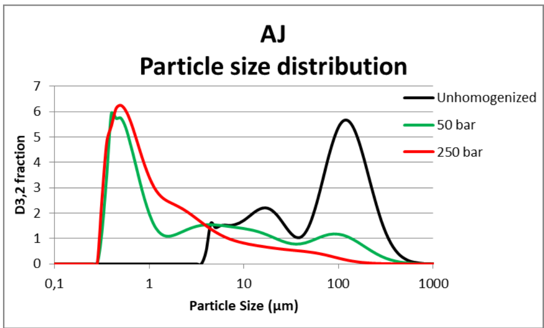


Figure 25 Influence of partial homogenized AJ on mean surface based size distribution7

Figure 25 shows the detailed size distribution of the particles.

The un-homogenized AJ had a clear largest peak of at 110 µm and the smallest size which contributed to the surface area were 3,9 µm. When 50 bar homogenization pressure was applied the peak at 110 µm was shifted to 0,45 µm. The increase in homogenization pressure to 250 bar decreased the particle fraction between 8 and 300 µm which contributed to the main peak with the mean at 0,50 µm. Comparing these results with the graph on the right side, it can be seen that a homogenization pressure of 50 bar decreases the size fraction of the largest particle group only partially and no peak of particles smaller than 1,0 µm could be seen.



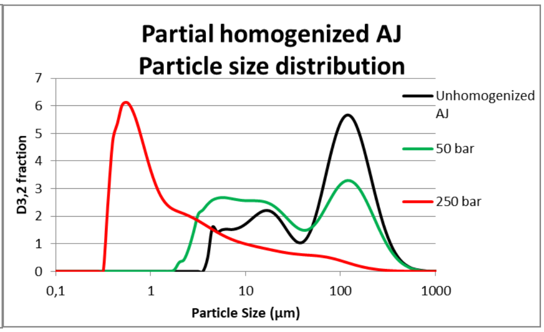


Figure 26 Comparing (left)surface area based size particle distribution of AJ and (right) surface area particle size distribution of partial AJ. Colors indicate the homogenization pressure

However, the particle size fraction is the same for both AJ and partial homogenized AJ when a homogenization pressure of 250 was used.

The effect of partial homogenization on the particle size distribution for the samples, which were homogenized with 50 bar, matches with the microscopic images. It can be assumed that the short distance between the cells enhances their resistance to the homogenization forces . However, this effect can be neglected when homogenization pressures >150 bar are used.

4.2.4 Microstructure

4.2.4.1 Visual comparison

It can be seen in Figure 27 that the cell fragments of the partial homogenized AJ were evenly distributed at 50 bar and large pieces of cell fragments are still visible. At a pressure of 250 bar the fiber particles are clearly organized, however the channel size seems to be more uneven compared with the AJ.

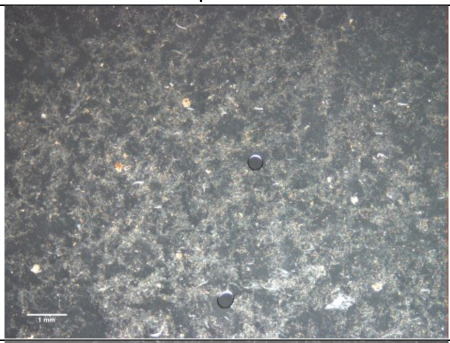
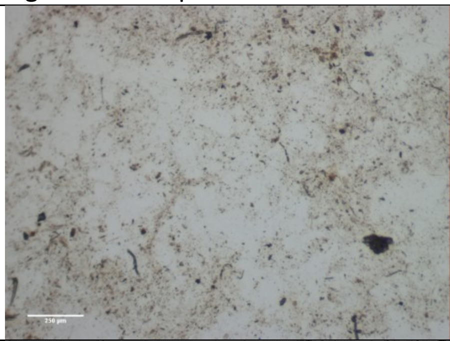
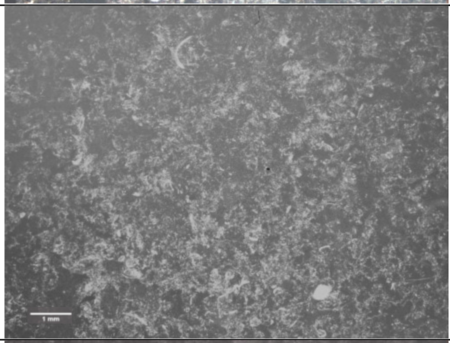
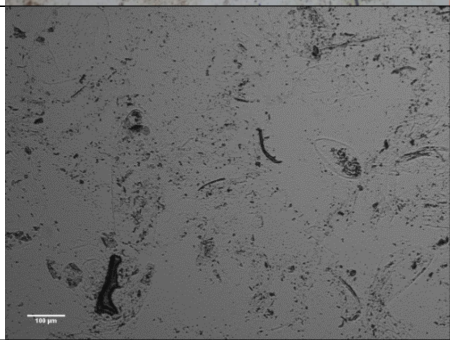
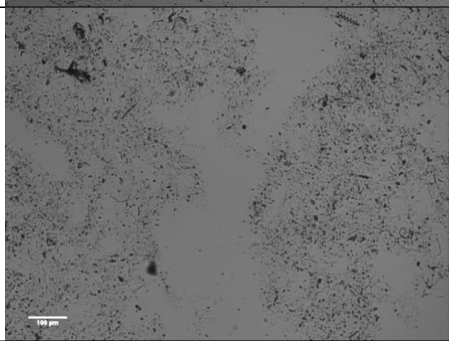
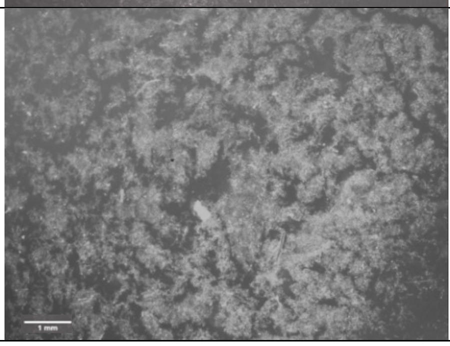
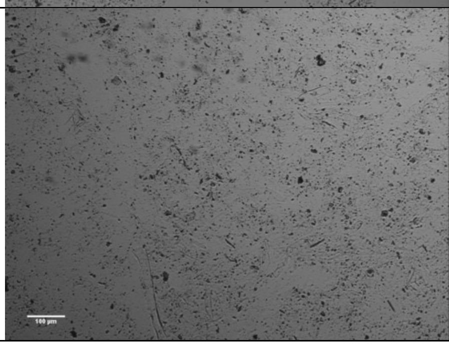
	Stereo microscope 10x	Light microscope 50 x
Standard AJ50 Bar		
Partially homogenized AJ 50 bar		
Standard AJ 50 Bar		
Partially homogenized AJ 250 bar		

Figure 27 Comparing microstructure of homogenized AJ with partially homogenized AJ for different homogenization pressure

4.2.4.2 Image analyzing

The characteristic fiber length (mean length between intersections) is slightly increasing with pressure. There is no significant difference between the AJ and the AJ concentrate (Figure 28).

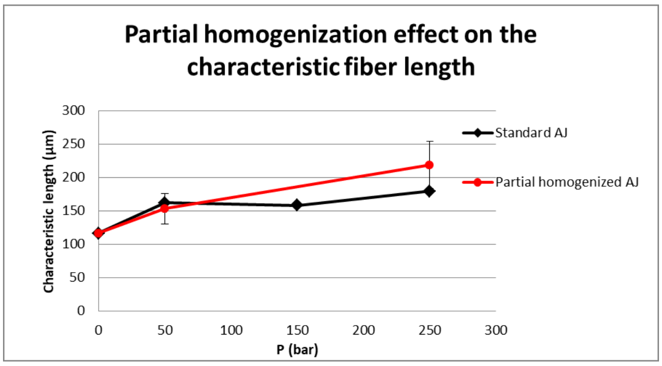


Figure 28 Characteristic fiber lengths of the 10x stereomicroscope images as a function of pressure. No duplicates could be made for the AJ (black line).

Obviously only visible fiber particles can be examined with a light and stereo microscope. Therefore, it is crucial to remember that the juices have also a large amount of soluble fibers, which are not displayed in the images.

The critical length values for the standard juice shown in Figure 28 does not contain the usual duplicates for all points because the method had to be improved during the time when the experiments were taken. It is still included in the result section to examine a trend and the possibilities of image analyzing.

4.3 Difference between the juices

The tomato juice (TJ) samples were not subsequently sheared as described in 3.4.1. Therefore, the rheological data cannot be directly compared. However, some results are still useful to fulfill the goals of this project and are therefore included.

4.3.1 Rheology

The different rheological parameters between the AJ and TJ have the same patterns. Therefor only the apparent G' moduli are shown here, and the results can be transferred to consistency factor and yield stress later.

Figure 29 shows the change in elastic modulus vs pressure for partially homogenized TJ. The black line is the homogenized tomato juice. The yellow and red slopes are the partial homogenized TJ with a homogenized TJ concentrate of 38 % and 75 %, respectively (See Methods). The black measurement point was taken from the Alex S05 homogenizer.

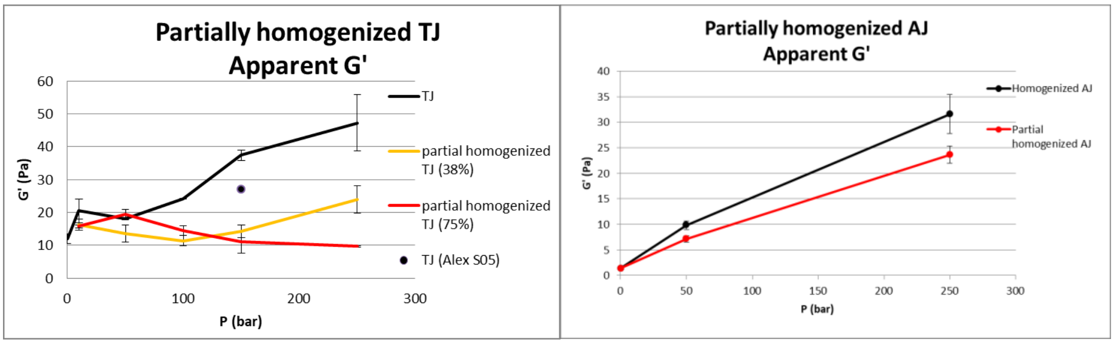


Figure 29 Comparison the change in elastic modulus between the partially homogenized TJ (left) and AJ (right) as a function of pressure.

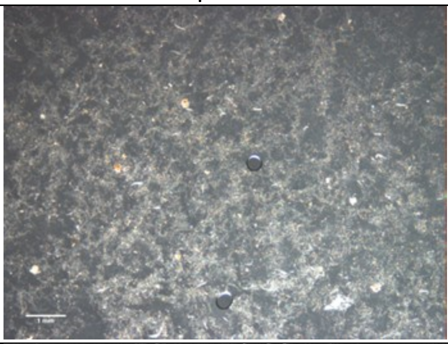
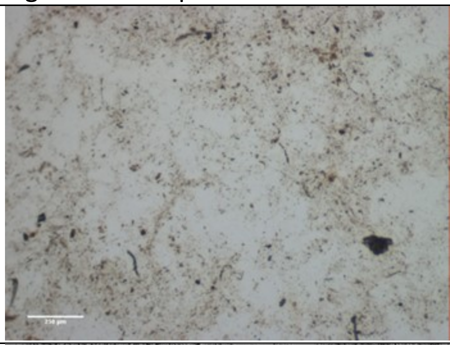
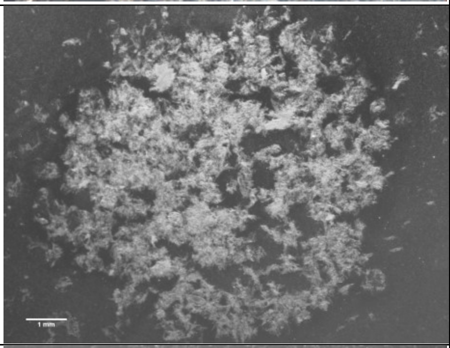
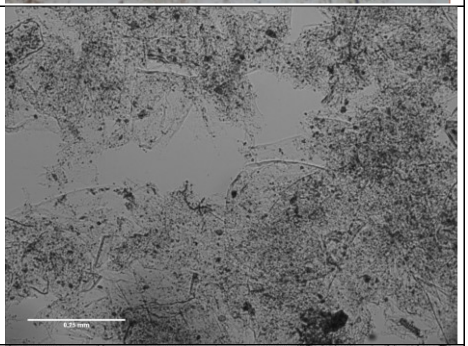
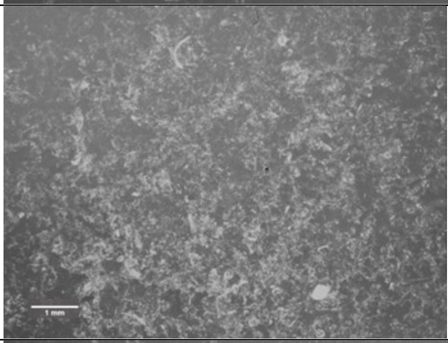
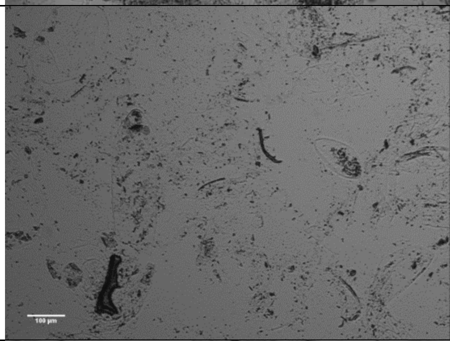
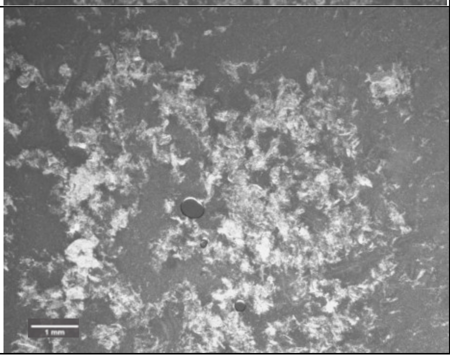
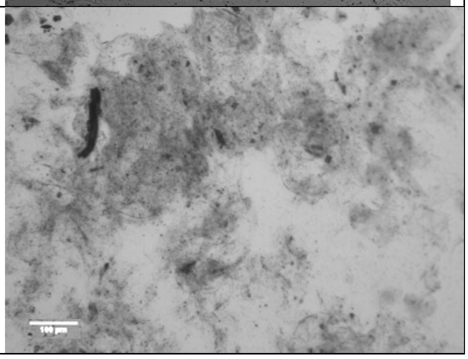
Comparing the un-homogenized juices (black lines at 0 bar pressure), the TJ has initially a higher elastic modulus. Both juices have a clear increase in the elastic modulus with an increase in pressure. The partially homogenized TJ 38 % has a stable apparent G' modulus until 150 bar and rises steadily at 250 bar to an average elastic modulus of 24,00 Pa. The slope for the partial homogenized AJ 75% has its maximum at 50 bar with a value 19,47 Pa and decreases then steadily to 9,67 Pa at 250 bar.

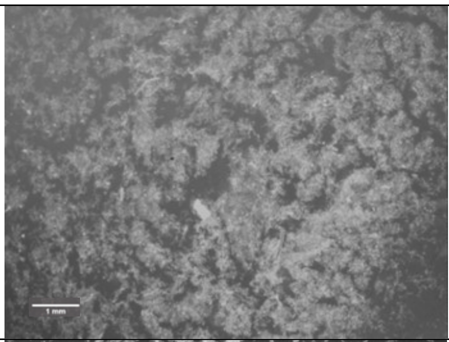
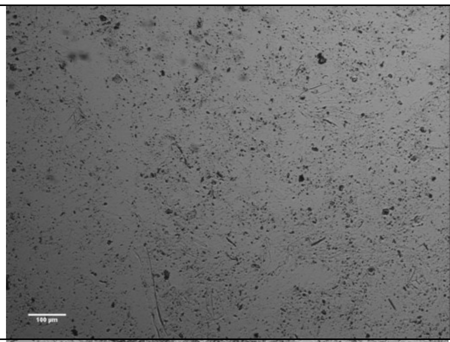
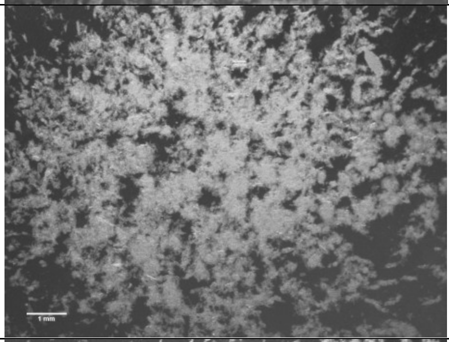
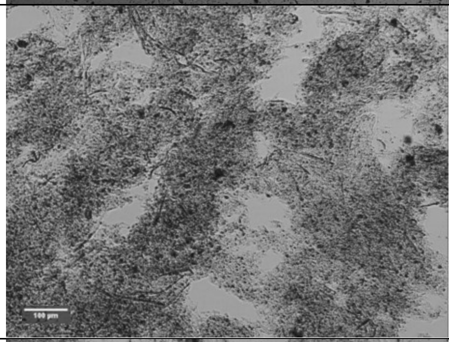
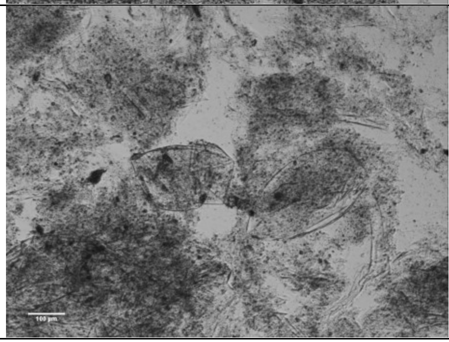
The different gradients between the partial homogenized TJ and partially homogenized AJ is probably a result of the missing subsequently sheared TJ samples. Since the apparent gel is not broken through shearing after the homogenization, the black TJ curve might be too steep and the measuring point from the Alex homogenizer might be a good indicator for corrections. On the other hand, it can be expected that the apparent G' for the partially homogenized tomato juice are slightly for high homogenization pressures, because fiber lumps would have broken up. The resulting increase in spicular, small fiber particles would have contributed to the cloud and gel formation. Therefore, comparing the juices and the data points from the Alex S05 it can be assumed that the addition of shearing leads to a similar results for both juices.

4.3.2 Comparing the microstructure of TJ and AJ

The homogenized TJ shows overall a higher tendency to form a compact fiber network compared with the AJ (Table 11). However, this network seems to be weaker when there is a combination of high homogenization pressure and a high juice concentrate concentration was homogenized.

Table 11 Comparing Microstructure of TJ with different partial homogenization concentration and AJ.

	Stereo microscope 10x	Light microscope 50 x
Standard AJ50 Bar		
Standard TJ 50 bar bar		
Partially homogenized AJ 50 bar		
Partially homogenized TJ 38 % concentrate 50 bar		

Partially Homogenized AJ 250 bar		
Partially homogenized TJ 38 % concentrate 250 bar		
Partially homogenized TJ 75 % 250 bar		

4.3.3 Size distribution

Comparing the D (3,2)-values for the two juices it can be seen that the TJ had larger particles before it was homogenized. Between the lowest applied homogenization pressure and 100 bar both juices decreased sharply their surface area based mean diameter to approximately 20 µm and reached a low of approximately 10 µm at the maximum applied pressure of 250 bar.

Furthermore, both juices followed the trend that the particle sizes of the partial homogenized juice samples are overall larger compared to the standard juices.

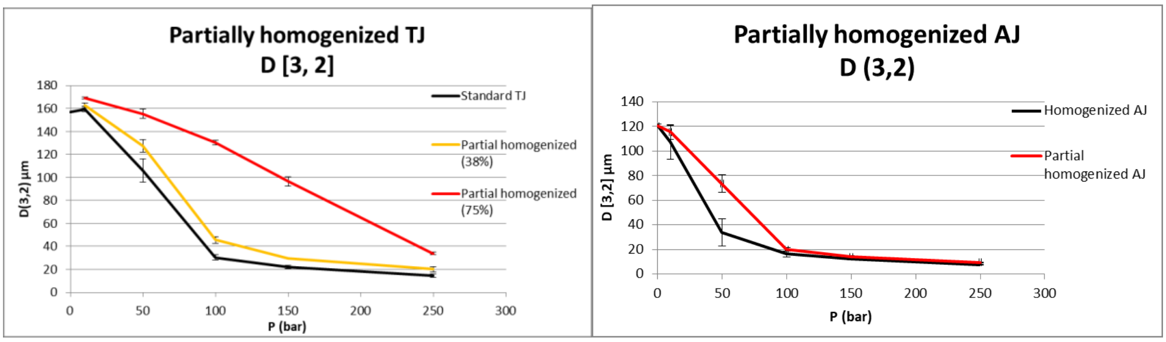


Figure 30 Comparing Area weighted mean diameter between (left) TJ and (right) AJ

The results show clearly that the whole cells are more resistance towards pressure when the juice concentrate concentration is higher.

It confirms the literature results that the cells are able to pass the homogenizer gap undamaged although the gap size is smaller than the cells' diameter because the gap does not change with higher partial concentration levels. It is more likely that the high juice concentration is lowering the turbulences after the homogenizer due to a lack of liquid. Based on these results and the literature, the turbulences just after the gap of the homogenizer seems the most important break up factor.

To determine the composition of the juice concentrate was outside the scope but it can be assumed that not the juice type but the insoluble fiber concentrations within the juice concentrate correlate to the homogenization pressure, which is needed to break up most of the large cells.

4.4 Influence of homogenization on from the consumers' perspective

4.4.1 Sensory results

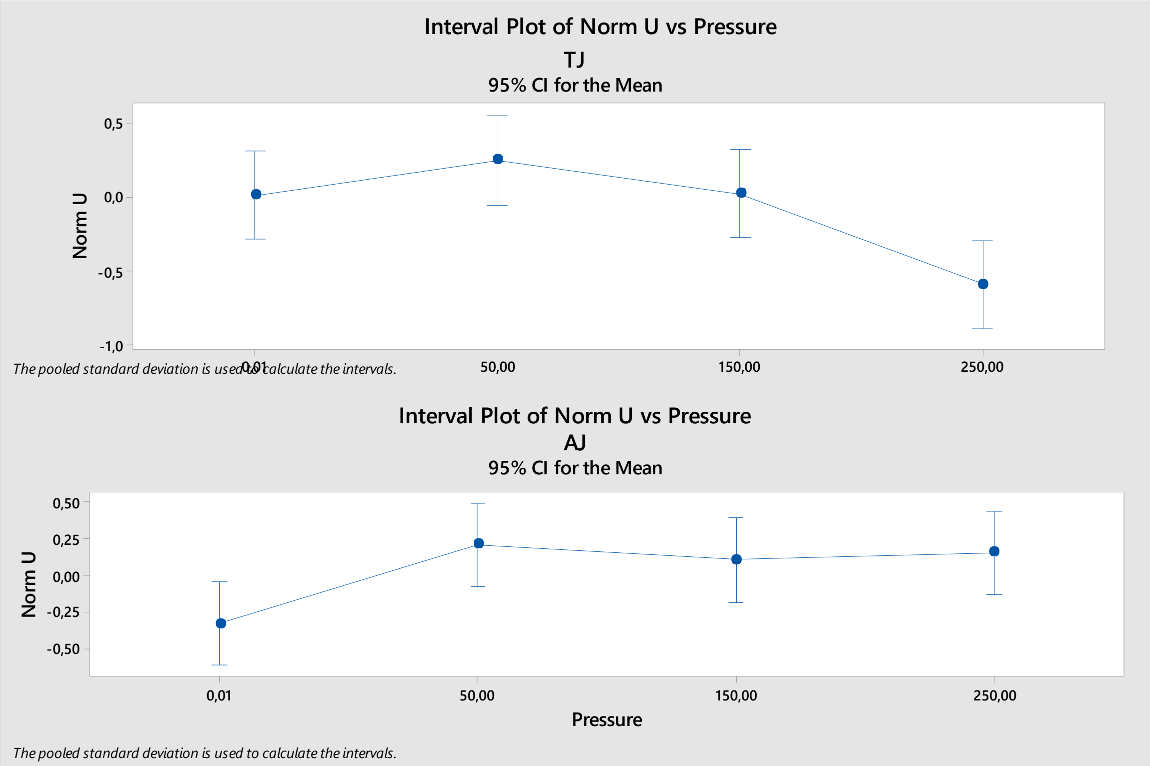
For both juices, there is no significant correlation between age, gender, concentration, and juice preference, the date of the experiment and the liking of any asked attribute. Furthermore, there is no correlation between the interaction of partial homogenization and pressure and any of the liking attributes.

Therefore, pressure is the only significant factor, which was determined for this sensory analysis (see Appendix II).

4.4.2 Uniformity

Regarding the TJ the change in pressure has no significant effect for 50 and 150 bar. The sample with 250 bar was rated significantly lower.

The AJ has a better score for the uniformity at 50 bar. The other samples do not differentiate to the un-homogenized sample.



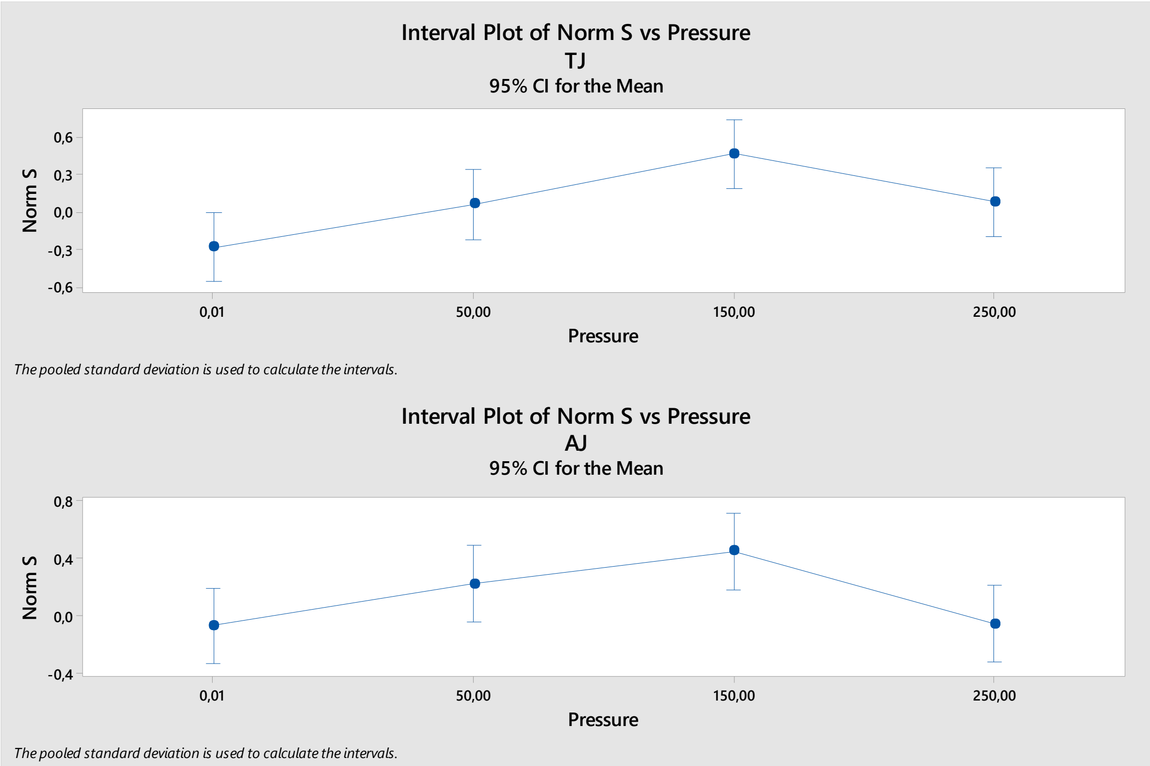
Grouping Information Using the Dunnett Method and 95% Confidence

	TJ			AJ		
Pressure	N	Mean	Grouping	N	Mean	Grouping
0,01 (control)	36	0,011	A	34	-0,333	A
50,00	36	0,248	A	34	0,210	
150,00	36	0,024	A	34	0,155	A
250,00	36	-0,591		N	0,105	A

Means not labeled with the letter A are significantly different from the control level mean.

Sweetness

The sweetness is scored best for both juices at 150 bar pressure. The pressures at 50 and 250 bar had no effect in the liking of the sweetness.



Grouping Information Using the Dunnett Method and 95% Confidence

	TJ			AJ		
Pressure	N	Mean	Grouping	N	Mean	Grouping
0,01 (control)	39	-0,286	A	40	-0,073	A
50,00	39	0,060	A	40	0,221	A
150,00	39	0,465		40	0,447	
250,00	39	0,079	A	40	-0,060	A

Means not labeled with the letter A are significantly different from the control level mean.

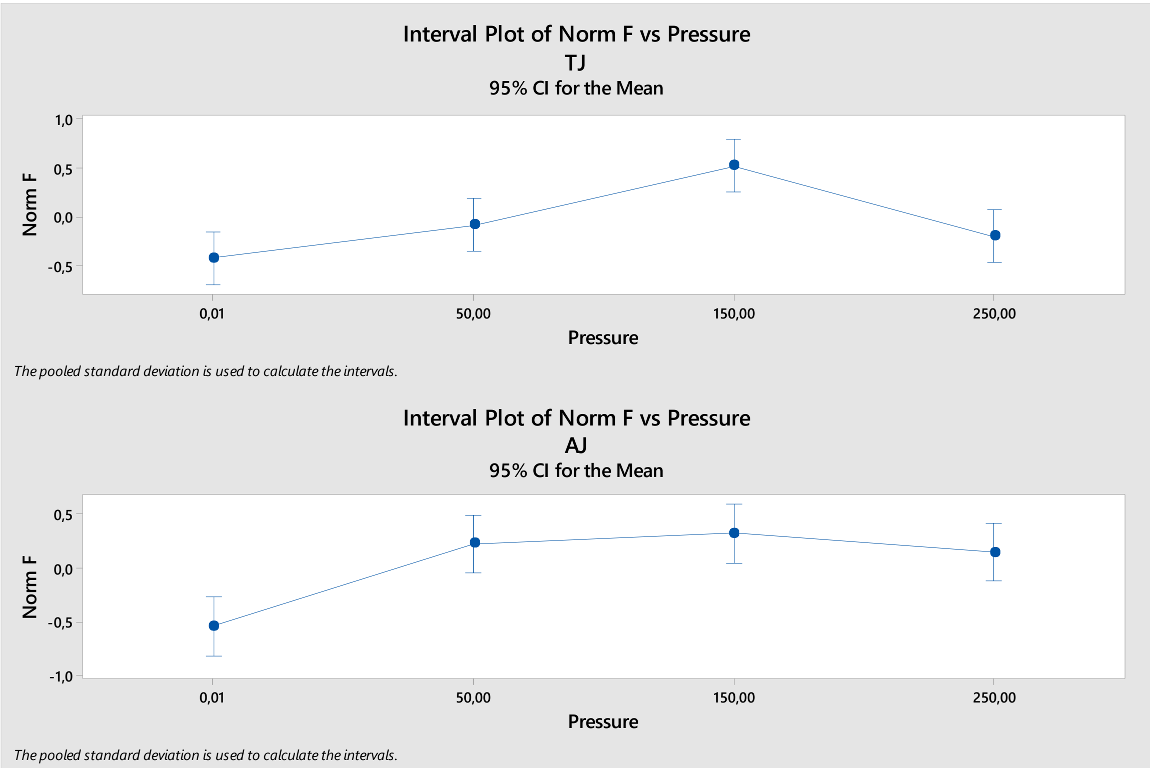
Five out of the 40 participants commented that the un-homogenized apricot juice was too sweet.

Five people commented that the CAJ with a pressure of 50 bar was sour.

Juice	Pressure	Concentrate	Too sour	Too less sweet	Not too sweet	Too sweet
AJ	0,01	50		1		5
AJ	50	50				2
AJ	150	50	1			
AJ	250	50				
CAJ	50	100	5		3	1
CAJ	250	100	2	1	1	
TJ	0,01	19		1		
TJ	50	19		1		
TJ	150	19				
TJ	250	19		2		1
CTJ	50	38		4		
CTJ	250	38		3		

Flavor

The TJ flavor had the best scoring clearly at 150 bar. The AJ flavor liking also increased when the juice was homogenized. However, all three tested homogenization pressure improved the liking in similar way.



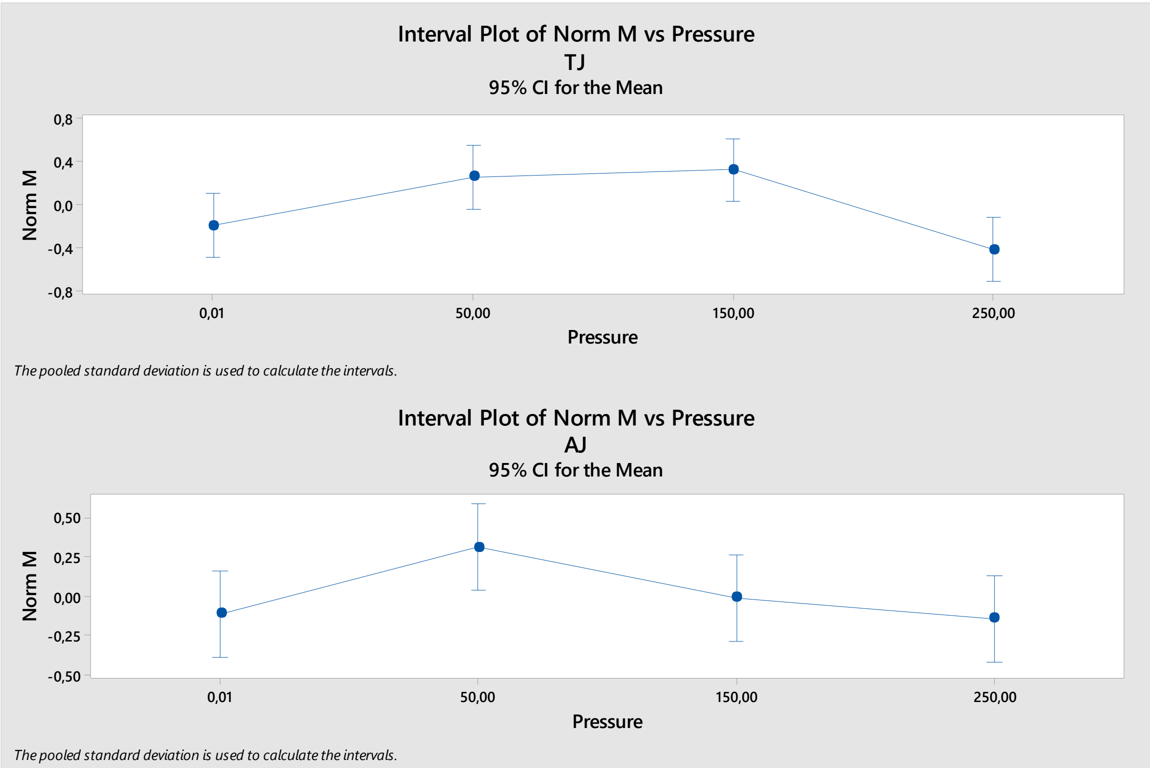
Grouping Information Using the Dunnett Method and 95% Confidence

	TJ			AJ		
Pressure	N	Mean	Grouping	N	Mean	Grouping
0,01 (control)	38	-0,428	A	39	-0,544	A
50,00	38	-0,086	A	39	0,227	
150,00	38	0,520		39	0,325	
250,00	38	-0,200	A	39	0,151	

Means not labeled with the letter A are significantly different from the control level mean.

Mouthfeel

The only significant differentiation in mouthfeel liking was for the TJ at 150 where it was liked more compared with the control sample.



Grouping Information Using the Dunnett Method and 95% Confidence

Pressure	TJ			AJ		
	N	Mean	Grouping	N	Mean	Grouping
0,01 (control)	39	-0,194	A	40	-0,113	A
50,00	39	0,256	A	40	0,312	A
150,00	39	0,320		40	-0,013	A
250,00	39	-0,422	A	40	-0,146	A

Means not labeled with the letter A are significantly different from the control level mean.

At least 7 participants commented that the AJ with a pressure greater or equal 150 bar was disliked because of a too high viscosity (thickness). In addition, 5 participants felt lumps or similar in the CAJ with 250 bar.

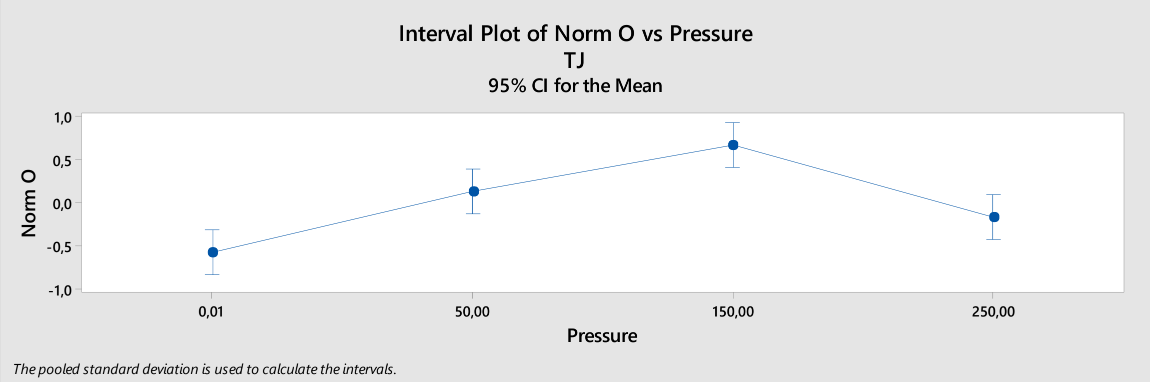
Five people noted that the not homogenized TJ as too watery, however two people commented the same sample as smooth and three other people wanted to have a thinner TJ.

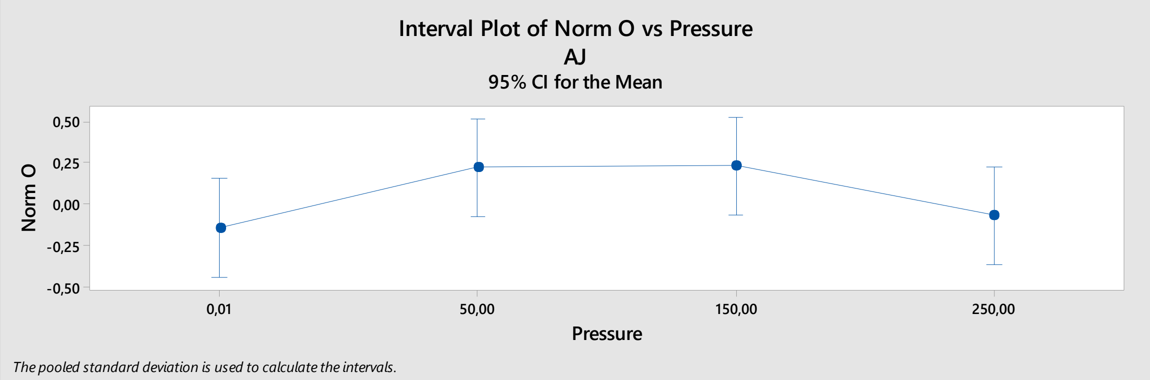
Juice	Pressure	Concentrate	Too watery	Smooth	Too thick	Lumps;pieces; brittle
AJ	0,01	50	2	4		
AJ	50	50	1	3	1	1
AJ	150	50		1	10	2
AJ	250	50		3	7	1
CAJ	50	100	2	1	1	
CAJ	250	100		4	8	5
TJ	0,01	19	5	2	3	
TJ	50	19		1	3	
TJ	150	19			6	
TJ	250	19			13	
CTJ	50	38		3	1	
CTJ	250	38			4	2

Six people felt that the TJ with 150 bar was too thick and more than 25 % of the participants commented that the TJ with 250 bar was too thick.

Overall Liking

The TJ is overall preferred with an increase in pressure up to 150 bar and was not significantly liked differently at 250 bar. The overall likeability of the AJ remained almost constant so that no significant change could be observed.





Grouping Information Using the Dunnett Method and 95% Confidence

Pressure	TJ			AJ		
	N	Mean	Grouping	N	Mean	Grouping
0,01 (control)	38	-0,583	A	40	-0,145	A
50,00	38	0,130		40	0,235	A
150,00	38	0,667		40	0,224	A
250,00	38	-0,169	A	40	-0,068	A

Means not labeled with the letter A are significantly different from the control level mean.

That the uniformity of the 250 bar homogenized TJ was disliked was probably caused by the high yield stress. As seen in the mouthfeel section, the highest homogenized TJ is also perceived as too viscous. A too viscous juice has also a negative influence on the appearance.

Lumps do not seem to play a significant role for the uniformity liking because the AJ should have been negatively influenced as well.

In contrast to the TJ, the uniformity of the homogenized AJ was perceived better compared to the un-homogenized AJ. A phase separation for the AJ could be the reason because the apparent G' was clearly lower for the AJ than for the TJ.

To keep it as simple as possible for the untrained participants and because the same questionnaire was used in a previous paper only a liking scale was given for all questions. However, the results could become ambiguous. For instance, the disliked sweetness for un-homogenized juices could mean either too less or too much sweet. Though, based on the evaluated comments , it can be assumed that the assumption is correct that the sweetness decreases with pressure and the optimal sweetness was reached at 150 bar. However, it can only be speculated why the homogenization pressure influenced the sweetness.

The most striking result in this sensory analysis was the improved flavor perception for both juices with a best score at 150 bar pressure. That might be correlated to the fact that at 150 bar the majority of the cells are destroyed. Consequently, the small aroma molecules were then released and could be easier noticed. However, when the gel network is too compact some of the components might be trapped in the gel and it is more difficult to smell or taste them.

It can be seen in the comment section on the mouthfeel that there are different opinions about the perfect viscosity of the AJ. That the consumer does not agree how thick an AJ is also indicated by the high standard deviation.

It is surprising that the mouthfeel for the TJ is clearly the best at 150 bar although 6 people commented it to be too thick. A reason might be that the acceptance of a too high viscous TJ is higher than a too low viscous TJ. Another reason could be that the improved aroma of the juice influences the participants or that the higher viscous TJ has other positive aspects like creaminess, which were not investigated in this research.

The overall likeability of the TJ is a good match with the asked attributes and therefore, the result can be considered as expected. However, the participants have different opinions about the apricot juice. The results are still valuable since they show that the aroma is improved. Since sugar is an ingredient in apricot nectar anyway it might be interesting to test the AJ with different weight concentrations of apricot concentrate at a pressure of 150 bar because raw material could be saved without affecting the taste.

5 Conclusions

Partial homogenization is in principle possible for both investigated fruit juices without any adverse effect compared with the standard homogenization method. However, it must be provided that first, the homogenization pressure is adjusted to the level of the partial homogenized juice concentrate and second, that the shearing forces after the homogenization are strong enough to solve clump which might have been formed due to the combination of high pressure and high fiber density. Therefore, it depends also on the juice production lines if a partial homogenization is cost effective because it could be possible that no extra subsequent shearing is needed.

It is clear from the sensory analysis that there is an optimum homogenization pressure of approximately 150 bar for TJ because all the asked quality attributes were scored best at this pressure level. However, each juice must be judged individually. There is no real homogenization optimum for AJ because at least the participants on this study had a diverse expectation about the AJ’s mouthfeel. Nonetheless, there is the opportunity to use less AJ concentrate when the juice is homogenized since the aroma is improved with pressure.

Summarized, there is an economical benefit in using partial homogenization, but more studies must be done to manifest these results.

Homogenization is able to influence positively the consumer’s perception not only for the mouthfeel but also for taste and flavor.

6 Recommendations

Various articles have stressed the importance of the shearing after homogenization. It would be very useful to establish a standardized method how future studies should treat samples after homogenization. Since it is mostly used for commercial processes, a useful approach would be to investigate the total average shearing forces that is carried on a specific juice volume. This force could be converted to a lab or pilot scale. These data would also show to which extent the used shearing forces so far differ from the given ones in the industry. Furthermore, it would improve the comparability among similar studies.

The sensory analysis revealed important and unexpected results. It should be analyzed if there are any cross correlations between the change in physical properties and liking as a function of homogenization pressure. Furthermore, it is interesting to know in which extent lumps influenced the participants. In a future sensory analysis samples which were treated with high homogenization pressure could be treated with different shearing forces after the homogenization, which would result in different lump sizes and density. A similar sensory analysis as it was performed here could give more insight and possibly explain why the liking for many attributes turned negatively for high pressures.

Analyzing the microscope pictures systematically could not fully realized in this study because it took too much time to develop a precise and time efficient method for the fiber network analyzing. However, the described method and tool is a good approach and the results could give a more fundamental understanding about the influence of fiber particles in the gel formation. Therefore, this method could be further developed in the future.

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APPENDIX

I) Questionnaire

Gender: Female ☐ Male ☐ Date: ______________

Age: 20 – 34 ☐ 35-55 ☐ Over 55 ☐

How often do you drink...

... apricot or tropical juices: Not at all ☐ Occasionally (≈once per months) ☐ Frequently (>Once per week) ☐

...tomato juice: Not at all ☐ Occasionally (≈once per months ☐ Frequently (>Once per week) ☐

1) What do you think of the **Uniformity**:

Sample n°: 615 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 556 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 438 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 305 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 765 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 289 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 409 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 278 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 214 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 798 Dislike ☐ ☐ ☐ ☐ ☐ Like

2) What do you think of the **Sweetness**:

Sample n°: 615 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 556 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 438 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 305 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 765 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 289 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 409 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 278 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 214 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 798 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 605 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 848 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

3) What do you think of the **Apricot/ Tomato flavour**:

Sample n°: 615 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 556 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 438 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 305 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 765 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 289 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 409 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 278 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 214 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 798 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 605 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 848 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

4) What do you think of the **Mouthfeel**:

Sample n°: 615 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 556 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 438 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 305 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 765 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 289 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 409 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 278 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 214 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 798 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 605 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 848 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

5) What do you think of the **Overall Likeability**:

Sample n°: 615 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 556 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 438 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 305 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 765 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 289 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 409 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 278 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 214 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 798 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 605 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

Sample n°: 848 Dislike ☐ ☐ ☐ ☐ ☐ Like

Comments:

II) General statistics for the sensory analysis

TJ

Influence of factors

General Linear Model: Norm U; Norm S; ... versus TJHabits; Age; ...

MANOVA Tests for TJHabits

Criterion	Test Statistic	F	DF Num	DF Denom	P
Wilks'	1,00000	0,000	5	190	1,000
Lawley-Hotelling	0,00000	0,000	5	190	1,000
Pillai's	0,00000	0,000	5	190	1,000

s = 1   m = 1,5   n = 94,0

MANOVA Tests for Age

Criterion	Test Statistic	F	DF Num	DF Denom	P
Wilks'	1,00000	0,000	10	380	1,000
Lawley-Hotelling	0,00000	0,000	10	378	1,000
Pillai's	0,00000	0,000	10	382	1,000

s = 2   m = 1,0   n = 94,0

MANOVA Tests for Gender

Criterion	Test Statistic	F	DF Num	DF Denom	P
Wilks'	1,00000	0,000	5	190	1,000
Lawley-Hotelling	0,00000	0,000	5	190	1,000
Pillai's	0,00000	0,000	5	190	1,000

s = 1   m = 1,5   n = 94,0

MANOVA Tests for Date

Criterion	Test Statistic	F	DF Num	DF Denom	P
Wilks'	1,00000	0,000	5	190	1,000
Lawley-Hotelling	0,00000	0,000	5	190	1,000
Pillai's	0,00000	0,000	5	190	1,000

s = 1   m = 1,5   n = 94,0

MANOVA Tests for Concentration

Criterion	Test Statistic	F	DF Num	Denom	P
Wilks'	0,95714	1,702	5	190	0,136
Lawley-Hotelling	0,04478	1,702	5	190	0,136
Pillai's	0,04286	1,702	5	190	0,136

s = 1 m = 1,5 n = 94,0

MANOVA Tests for Pressure

Criterion	Test Statistic	Approx F	DF Num	Denom	P
Wilks'	0,79289	3,069	15	524	0,000
Lawley-Hotelling	0,24444	3,074	15	566	0,000
Pillai's	0,22065	3,049	15	576	0,000

s = 3 m = 0,5 n = 94,0

AJ

General Linear Model: norm U; Norm S; ... versus TJHabits; Age; ...

MANOVA Tests for AJHabits

Criterion	Test Statistic	F	DF Num	Denom	P
Wilks'	1,000	0,000	10	394	1,00
Lawley-Hotelling	0,000	0,000	10	392	1,00
Pillai's	0,000	0,000	10	396	1,00
Roy's	0,000				

s = 2 m = 1,0 n = 97,5

MANOVA Tests for Age

Criterion	Test Statistic	F	DF Num	Denom	P
Wilks'	0,99999	0,000	10	368	1,000
Lawley-Hotelling	0,00001	0,000	10	366	1,000
Pillai's	0,00001	0,000	10	370	1,000

s = 2 m = 1,0 n = 91,0

MANOVA Tests for Gender

Criterion	Test Statistic	F	DF Num	Denom	P

Wilks'	0,99992	0,003	5	184	1,000
Lawley-Hotelling	0,00008	0,003	5	184	1,000
Pillai's	0,00008	0,003	5	184	1,000

s = 1   m = 1,5   n = 91,0

MANOVA Tests for Date

	Test		DF		
Criterion	Statistic	F	Num	Denom	P
Wilks'	0,99985	0,006	5	184	1,000
Lawley-Hotelling	0,00015	0,006	5	184	1,000
Pillai's	0,00015	0,006	5	184	1,000

s = 1   m = 1,5   n = 91,0

MANOVA Tests for Concentration

	Test		DF		
Criterion	Statistic	F	Num	Denom	P
Wilks'	0,94560	2,117	5	184	0,065
Lawley-Hotelling	0,05753	2,117	5	184	0,065
Pillai's	0,05440	2,117	5	184	0,065

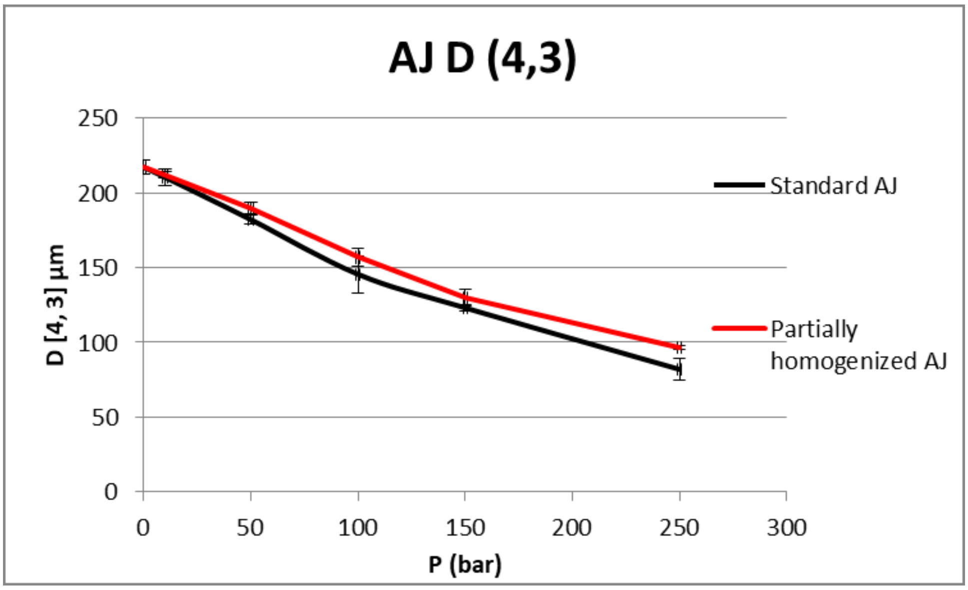
s = 1   m = 1,5   n = 91,0

MANOVA Tests for Pressure

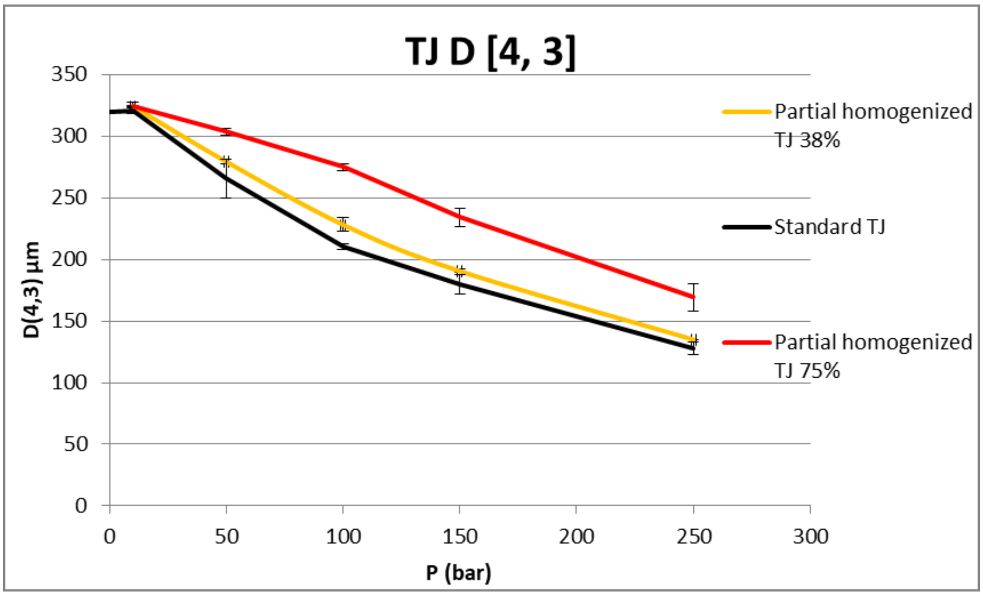
	Test		DF		
Criterion	Statistic	Approx F	Num	Denom	P
Wilks'	0,72996	4,093	15	508	0,000
Lawley-Hotelling	0,34206	4,165	15	548	0,000
Pillai's	0,29045	3,988	15	558	0,000

s = 3   m = 0,5   n = 91,0

III) Volume based particle sizes



D(4,3) for AJ with different partial homogenization pressure and homogenizer



D(4,3) for TJ with different partial homogenization pressure and homogenizer