Extrusion Processing of Starch Film

Bing Su, South China University of Technology
Fengwei Xie, South China University of Technology
Ming Li, South China University of Technology
Penny A. Corrigan, CSIRO
Long Yu, CSIRO; South China University of Technology
Xiaoxi Li, South China University of Technology
Ling Chen, South China University of Technology

Recommended Citation:
Su, Bing; Xie, Fengwei; Li, Ming; Corrigan, Penny A.; Yu, Long; Li, Xiaoxi; and Chen, Ling (2009) "Extrusion Processing of Starch Film," International Journal of Food Engineering: Vol. 5: Iss. 1, Article 7.
DOI: 10.2202/1556-3758.1617
Extrusion Processing of Starch Film

Bing Su, Fengwei Xie, Ming Li, Penny A. Corrigan, Long Yu, Xiaoxi Li, and Ling Chen

Abstract

Processing behaviors of starch film using a twin screw extruder were studied; in particular the effect of processing conditions, such as temperature, screw speed, feeding speed, and water content, on the extrusion torque and die pressure were systematically investigated. A specific focus of this work was to investigate the effect of amylose/amylopectin ratio containing in cornstarch on the film processing and performances. It was found that the processibility was decreased as the amylose content increased. Pre-mixing and equilibration improve the processibility of starch films, especially for the high amylose starches. The high amylose starches need higher moisture content and temperature for film extrusion.

KEYWORDS: starch, amylose/amylopectin, extrusion, film

Author Notes: The authors from SCUT, China, would like to acknowledge the research funds NRDPHT (863)(2007AA10Z312, 2007AA100407), GECXYF (2006D90404004) and ETRFNK (2006C40038).
1. INTRODUCTION

The application of edible films has been constantly increasing in the food industry (Arvanitoyannis, Psomiadou et al. 1997; Arvanitoyannis, Nakayama et al. 1998; Chambi and Grosso 2006; Cho, Park et al. 2007; Beverlya, Janes et al. 2008; Carvalho, Sobral et al. 2008). Starch-based films act as a key role in this kind of film. The advantages of starch based films are more in the area of decreasing gas exchange rather than retardation of water loss due to their hydrophilic nature (Rindlav-Westling, Stading et al. 1998; Sobral, Menegalli et al. 2001; Parra, Tadini et al. 2004; Petersson and Stading 2005; Bertuzzi, Vidaurre et al. 2007). The functional, organoleptic, nutritional and mechanical properties of an edible film can be modified by the addition of various chemicals in minor amounts. Extrusion has been developed in processing starch films for many years, but there are still no commercial products in the market so far mainly due to its poor processibility. Film extrusion of starch is much more complex than that of conventional polymers since multi-phase transitions have been involved during processing (Ilo, Liu et al. 1999; Fishman, Coffin et al. 2000; Chen, Yu et al. 2007; Dean, Yu et al. 2007; Xue, Yu et al. 2008).

A simple and common technique of producing sheet or film by extrusion is using a twin-screw extruder with a slit or flat film die followed by a take-off device for orientation and collection (van Soest and Knooren 1997; Fishman, Coffin et al. 2000; Walenta, Fink et al. 2001; Walenta, Fink et al. 2001; Yu and Christie 2004; Dean, Yu et al. 2007). During film or sheet extrusion, the viscoelastic starch-based materials are forced through the die to form sheet or film products (Chiang and Johnson 1977). Another technique of two-stage sheet or film extrusion processing was also used by some researchers (Myllymäki, Myllärinen et al. 1998; Fishman, Coffin et al. 2000; Matzinos, Tserki et al. 2002; Matzinos, Tserki et al. 2002). Fishman et al. (2000)’s work presented a typical example of the two-stage sheet/film extrusion. Blends of pectin with starch (high amylose and normal), poly(vinyl alcohol) (PVOH), and glycerol were compounded in a twin screw extruder to form ribbons. The compounded blends were dried and ground into a powder, pelletized, and then extruded both as flat sheet and as blown film using a single screw extruder.

In this work, the processibility of cornstarch with different amylose/amyllopectin ratio was evaluated by a twin-screw extruder with a slit die. Effect of processing conditions, such as temperature, screw speed, feeding speed, and formulations, on the processing were systematically investigated. The extrusion torque and the die pressure were used to evaluate the processibility.
2. EXPERIMENTAL WORK

2.1 MATERIALS

Cornstarches with different amylose/amylopectin contents were used in the experimental work. Details of the starches are listed in Table 1. An infra-red heating balance (Model DHS-20) was used to measure moisture content through heating samples to 110 °C for 20 min.

<table>
<thead>
<tr>
<th>Starch</th>
<th>Amylose content (%)</th>
<th>Moisture content (%)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waxy</td>
<td>0</td>
<td>15.17</td>
<td>Jinli Industry Group, China</td>
</tr>
<tr>
<td>Maize</td>
<td>23</td>
<td>15.45</td>
<td>Honglong Food, China</td>
</tr>
<tr>
<td>G50</td>
<td>50</td>
<td>14.97</td>
<td>Penford, Australia</td>
</tr>
<tr>
<td>G80</td>
<td>80</td>
<td>14.86</td>
<td>Penford, Australia</td>
</tr>
</tbody>
</table>

In order to evaluate the effect of amylose/amylopectin ratio on the processibility and performances, water was the only plasticizer used in this experiment. There are two ways to add water into starch for extrusion. One method is to add water by a liquid feeding system connected to the extruder. The starches contain different initial moisture content (Table 1) was fed into a Haake twin-screw extruder by a powder feeder (GBL SS ST) with carefully controlled feeding rate. The water was injected into the extruder through a liquid entrance on zone 2. The feeding rate was precisely controlled based on the starch feeding rate in order to obtain specific water content (20–46%).

Another method involves premixing starch with water in a high-speed mixer (SRL-Z) at 7500 rpm for 5 min. The premixed starch was stored in a sealed plastic bag at room temperature to equilibrate for 24 hrs before extrusion. The total moisture content of specimen was taken as the sum of the original moisture content and the added water. The effect of premixing starch with water on extrusion processing will be discussed later.

2.2 FILM EXTRUSION

Starches with a certain moisture content were extruded by a Haake twin-screw extruder (Rheomex PTW 24/40p, Ø30, screw diameter D = 24 mm and screw length 28D) with a slit die (slit width 150 mm). The extruder has eight individually controlled temperature zones and the temperature of the slit die can also be controlled separately. The film coming out at the end of the die was towed and collected by a take-off device.

Each of the four starches with different amylose content has its own optimized processing conditions. As the focus of this paper is to study the effect
of amylose/amylopectin ratio containing in cornstarch on the processing behaviors, the starches were extruded at the same conditions to collect films for comparison. The following processing parameters were settled after a series of preliminary experiments. The extrusion temperature profile was 60, 90, 120, 145, 145, 140, 120, 110, and 100 °C for zones from the feeding position to the die; the moisture content is 36.5% for all the starches; the starch feeding speed was 1.8 kg/h; the screw speed was 90 rpm; and the speed of the take-off device was 70 rpm. After extrusion, the collected films were stored at the same condition to achieve the equilibrium moisture content. The moisture content of these films were detected by an vacuum oven heating samples to 120 °C for 24 hours. Table 2 lists the details of the films obtained from extrusion.

<table>
<thead>
<tr>
<th>Starch film</th>
<th>Thickness (mm)</th>
<th>Moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waxy</td>
<td>0.23±0.02</td>
<td>17.11</td>
</tr>
<tr>
<td>Maize</td>
<td>0.23±0.02</td>
<td>17.05</td>
</tr>
<tr>
<td>G50</td>
<td>0.23±0.04</td>
<td>16.97</td>
</tr>
<tr>
<td>G80</td>
<td>0.23±0.04</td>
<td>17.06</td>
</tr>
</tbody>
</table>

2.3 POLARIZATION MICROSCOPE

A polarization microscope (Axioskop 40 Pol/40 A Pol, Zeiss) with both normal and polarized light was used to investigate the surface structure and the disappearance of birefringence of films. Starch films were cut into small squares and each sample was clipped between two microscope glass slides, and the films were observed under both visual and polarized light at a magnification of 500 (50×10). An observation of the original starches at the same condition was also done for comparison.

3. RESULTS AND DISCUSSION

3.1 EFFECT OF PREMIXING ON PROCESSING

Premixing and equilibration were used to enhance the diffusion of water into starch granules, which could make extrusion more stable and smoothly. The stability and quality of extrusion were mainly detected by the measurements of the motor torque and the die pressure. Table 3 lists the torque and die pressure with and without premixing. It can be seen that starches with premixing had lower average torque and fluctuation extent than those without premixing. The die pressure for the samples with premixing was lower than those without premixing. The effect of premixing on higher amylose starches (G50 and G80) is stronger.
that that on lower amylose starch (waxy and maize). This indicates the premixing is necessary for processing films from G50 and G80.

Table 3 Effect of premixing on torque and die pressure.

<table>
<thead>
<tr>
<th>Starch</th>
<th>Torque without premixing (%)</th>
<th>Torque with premixing (%)</th>
<th>Die pressure without premixing (bar)</th>
<th>Die pressure with premixing(bar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waxy</td>
<td>20.3±1.0</td>
<td>20.1±1.0</td>
<td>30.0±2.0</td>
<td>30.4±2.0</td>
</tr>
<tr>
<td>Maize</td>
<td>23.0±1.5</td>
<td>22.7±1.5</td>
<td>41.2±2.6</td>
<td>40.7±2.5</td>
</tr>
<tr>
<td>G50</td>
<td>27.6±3.0</td>
<td>26.5±2.5</td>
<td>47.3±5.0</td>
<td>45.2±5.0</td>
</tr>
<tr>
<td>G80</td>
<td>31.6±4.1</td>
<td>28.7±2.9</td>
<td>54.9±9.0</td>
<td>51.4±7.0</td>
</tr>
</tbody>
</table>

3.2 Effect of moisture content on processing

Water was an effective plasticizer for starch, and was the only plasticizer used in this experiment. It is seen from Fig. 1 and Fig. 2 that, with increasing the moisture contents, both extrusion torque and die pressure decreased. The effect of moisture content became weaker when the water content was higher than 40%. The observation from extrusion showed that more homogeneous and thinner film can be produced with higher moisture content. However, when moisture content was higher than 40%, there is some foaming appeared on the film. Furthermore, the high-moisture starch film would become sticky due to high moisture content, which was unfavourable for rolling and storage, especially for lower amylose starches (waxy and maize).

Fig. 1 and Fig. 2 also show that the extrusion torque and the die pressure were increased with increasing amylose content under same conditions, which also indicates that the difficulty of processing was increased with increasing amylose content in starch. For example, with the moisture content of about 36.5%, the torque value percentages (the percentage of the measured torque value accounted for the maximum safely allowed torque value of the extruder) are 21–23.5%, 24–27%, 28–36%, and 29–40% for waxy, maize, G50, and G80, respectively. The higher and fluctuating torque value for high amylose starch was accompanied by the unstable flow of the extrudate and the clogging of the die. This phenomenon can be reduced or eliminated by increasing moisture content. The similar results have been reported by previous researchers (Thuwall, Boldizar et al. 2006).
3.3 EFFECT OF TEMPERATURE (BARREL ZONES AND DIE) ON PROCESSING

Processing temperature is one of the most important factors during extrusion; it involves the barrel temperature and the die temperature. When the other conditions were fixed, the processing torque was decreased with increasing barrel temperature. However, the torque remained stable when the temperature was higher than 170 °C. The film could start foaming if the temperature continuously increased. The barrel temperature affects the whole extrusion processing; and each set of temperature profile suits for a certain formulation. If the barrel temperature was too low for a starch, the starch would not be completely gelatinized. In this case, the extrusion would be unstable; higher and fluctuating torque and higher die pressure would be observed, and the extruded film would have an uneven thickness. The similar phenomenon has been reported previously (Guha, Ali et al. 1997; Henrist and Remon 1999). On the other hand, the die
temperature mainly controlled the foaming, which could happen when the die temperature was too high. Foaming could make the film lose much moisture and have a rough surface; as a result, high die temperature should be avoided. However, if the die temperature was too low, the viscosity of materials would be very high, which resulted in the blocking of the die.

Fig. 3 shows the effect of processing temperature on the extrusion torque, where the dots represent the highest temperature on the extruder during extrusion. It can be seen that the processing torque of G50 and G80 decreased significantly as the temperature was increased from 120 °C to 150 °C; but no further decreasing was observed when the temperature was increased from 150 °C to 180 °C. Fig. 3 also showed that the effect of temperature on waxy and maize starch was much less in the temperature range of 125 °C and 180 °C. Waxy and maize starch started foaming when the temperature was above 145 °C. Under the same extrusion temperature, the torque increased with increasing amylose content, and the torque value of G80 and G50 was much higher than that of waxy and maize starches.

![Fig. 3. Effect of extrusion temperature on torque for different starches.](image)

3.4 Effect of RPM on Processing

Generally, the torque was decreased as the screw speed (RPM) increased due to the decrease in the filled length in the extruder and the increase in the shear rate. The apparent viscosity of the starch was decreased as increasing the shear rate due to the shear thinning behavior of the pseudoplastic material (Guha, Ali et al. 1997). Seker (Seker 2005) reported the similar results. Fig. 4 shows that the processing torque decreased significantly as the screw speed increased from 60 to 100 rpm, but the torque remained stable as the screw speed further increased from 100 to 140 rpm. When screw speed reached 120 rpm, the torque value became
more fluctuating and the extrudate flow at the die showed to be unstable. Fig. 4 also showed that G80 and G50 had much higher torque than that of maize and waxy starch at the same screw speed, which indicates again that increasing amylose content can increase the processing torque.

![Fig. 4. Effect of extrusion screw speed on torque for different starches.](image)

3.5 **Effect of Feeding Speed on Processing**

The effect of feeding speed had a connection with screw speed. Similar as lower screw speed, higher feeding speed increased filled length, which resulted in higher torque. Fig. 5 shows the effect of feeding speed on the starch extrusion. It can be seen that the processing torque increased significantly as the feeding speed was increased. The increasing rate of the torque increased with increasing the amylose content.

![Fig. 5. Effect of feeding speed on extrusion torque for different starches.](image)
3.6 MICROSTRUCTURE OF FILMS

Fig. 6 shows the starches observed under polarization microscope before extrusion. The microscopy images were taken under normal and polarized light, respectively. It can be seen that waxy maize starch, normal maize starch, G50 and G80 had granule structure under normal light. The images taken under polarized light show that all the starches had clear birefringence, which represent crystalline structure. Fig. 6 also shows the images of starch films taken under normal and polarized light, respectively, under the same extrusion conditions. The images under normal light show that granule structures were completely destroyed during extrusion for waxy maize starch and normal maize starch. But the images of G50 and G80 under normal light still show some granule structure still existing, which indicates that the granule structure has been partly remained after extrusion. This phenomenon suggests the processing conditions for different starches should be different. Waxy maize starch and normal maize starch were completely destroyed under these particular conditions, but G50 and G80 needed a higher temperature or screw speed to produce homogeneously film. All the films observed under polarized light shows that the birefringence has disappeared, which indicates that their crystalline structure was destroyed during extrusion.

---

**Fig. 6. Starch granules and film observed under microscope.**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Normal light</th>
<th>Polarized light</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Granule</td>
<td>Film</td>
</tr>
<tr>
<td>Waxy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G80</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

DOI: 10.2202/1556-3758.1617
4. CONCLUSION

The extrusion of starch film showed that the processing parameters had different effects on the starches with different amylose content. Premixing had less influence on the extrusion of lower amylose starches (waxy and normal maize starch), but it had stronger effect on that of higher amylose starches (G50 and G80). Premixing improved the extrusion stability and decreased the torque and the die pressure. The difficulty of processing generally increased as the amylose content increased, which was indicated by the higher torque and die pressure and the unstable flow. Increasing moisture content for G50 and G80 during extrusion was necessary to improve the stable extrusion. Waxy and normal maize starch could be extruded smoothly at the temperature of about 130 °C, while G50 and G80 needed a higher temperature of about 150 °C to maintain the stable extrusion. The torque value decreased as the screw speed increased, but the residence time decreased in the meantime, which could result in the incompletion of starch gelatinization. Increasing the feeding speed increased the extrudate flow rate and the torque value. The feeding speed had a direct relationship with screw speed, so the two issues need to be optimized at same time. Based on the above results, the processing difficulty of the starches was generally in the following order: G80 > G50 > Maize > Waxy.

REFERENCES


