



รายงานผลการวิจัยฉบับสมบูรณ์ (ฉบับร่าง)
ทุนอุดหนุนวิจัย มก.ปีงบประมาณ 2552

รหัสโครงการวิจัย ว-ท(ด)115.51
การวิเคราะห์ผลของไฮโดรคอลลอยด์ต่อการลดปริมาณน้ำมันในผลิตภัณฑ์ทอด
Analysis of the influence of hydrocolloids on oil uptake reduction in fried products

หัวหน้าโครงการ ศศ.รุ่งนภา พงศ์สวัสดิ์มานิต
หน่วยงานต้นสังกัด ภาควิชาพัฒนาผลิตภัณฑ์ คณะอุตสาหกรรมเกษตร บางเขน
หน่วยงานหลัก ภาควิชาพัฒนาผลิตภัณฑ์ คณะอุตสาหกรรมเกษตร บางเขน

แหล่งทุน : ทุนอุดหนุนวิจัย มก.

สถาบันวิจัยและพัฒนาแห่งมหาวิทยาลัยเกษตรศาสตร์
ระยะเวลาวิจัย 2 ปี (ตั้งแต่ปีงบประมาณ 2551 ถึงปีงบประมาณ 2552)

รายงานผลการวิจัยฉบับสมบูรณ์

โครงการวิจัย (Project)

โครงการวิจัยทุนอุดหนุนวิจัย มก. ปีงบประมาณ 2551-2552

ส่วนที่ 1 สรุปผลการดำเนินงานโครงการวิจัย (Project)

1.1 รหัส ว-ท(ด) 115.51 ชื่อโครงการ การวิเคราะห์ผลของไฮโดรคอลลอยด์ต่อการลดปริมาณน้ำมันในผลิตภัณฑ์ทอด

1.2 ลักษณะโครงการ ☒ เป็นโครงการวิจัยเดี่ยว☐ เป็นโครงการย่อยในชุดโครงการวิจัย (ระบุชื่อชุดโครงการวิจัย)

1.3 ชื่อหัวหน้าโครงการ รศ.ดร.รุ่งนภา พงศ์สวัสดิ์มานิต

1.4 หน่วยงานหลักรับผิดชอบ ภาควิชาพัฒนาผลิตภัณฑ์ คณะอุตสาหกรรมเกษตร

1.5 ประเภทโครงการ ☒ โครงการวิจัย 3 สาขา; ☐ เกษตรศาสตร์ ☒ วิทยาศาสตร์และเทคโนโลยี ☐ สังคมศาสตร์☐ โครงการวิจัยเพื่อพัฒนาคุณภาพสถาบัน☐ โครงการวิจัยเพื่อพัฒนาหน่วยปฏิบัติการวิจัยเชี่ยวชาญเฉพาะ (SRU)☐ โครงการวิจัยและถ่ายทอดงานวิจัยสู่ประชาชน☐ โครงการงบประมาณเฉพาะกิจ (เดิม)☐ โครงการเสริมสร้างความเข้มแข็งด้านการวิจัย มก.☐ โครงการวิจัยและพัฒนาเพื่อเพิ่มศักยภาพเชิงบูรณาการเพื่อการแข่งขัน

1.6 ระยะเวลาดำเนินงานวิจัยตลอดโครงการ 2 ปี ตั้งแต่ปีงบประมาณ 2551 ถึงปีงบประมาณ 2552

1.7 สถานที่ดำเนินงานวิจัย/เก็บข้อมูล ภาควิชาพัฒนาผลิตภัณฑ์ คณะอุตสาหกรรมเกษตร

1.8 งบประมาณรวมตลอดโครงการ 630,000 บาท ประกอบด้วย

ปีงบประมาณ 2551 ได้รับ 310,000 บาท ปีงบประมาณ 2552 ได้รับ 320,000 บาท

1.9 วัตถุประสงค์โครงการวิจัย (2 ปี)

1. เพื่อให้เข้าใจผลของไฮโดรคอลลอยด์ต่อคุณภาพของผลิตภัณฑ์ทอดประเภทซุบแบ่งทอดโดยเฉพาะการลดปริมาณน้ำมัน
2. เพื่อให้เข้าใจผลของไฮโดรคอลลอยด์ในสูตรของเบทเทอร์ (batter) ต่อสมบัติรีโอโลยีซึ่งมีผลต่อปริมาณแบ่งซุบในผลิตภัณฑ์
3. เพื่อให้สามารถผลิตนักวิจัยรุ่นใหม่ในลักษณะของนิสิตระดับบัณฑิตศึกษาให้มีความสามารถในการวิจัยต่อไปในอนาคต
4. เพื่อตีพิมพ์ผลงานวิจัยในวารสารระดับนานาชาติ หรือเพื่อนำไปสู่การจดอนุสิทธิบัตรหรือสิทธิบัตร และมีการถ่ายทอดเทคโนโลยีสู่กลุ่มเป้าหมาย

1.10 เป้าหมายผลงานวิจัยตลอดโครงการ

ปีที่	เดือนที่	ผลงานวิจัยที่คาดว่าจะได้
1	1-6	1. ได้สูตรเบทเทอร์ที่เหมาะสม 2. ทราบผลของไฮโดรคอลลอยด์ต่อสมบัติทางรีโอโลยีของเบทเทอร์ซึ่งมีผลต่อปริมาณแป้งชูบในผลิตภัณฑ์
	7-12	3. ผลของไฮโดรคอลลอยด์ในสูตรของเบทเทอร์ต่อสมบัติทางด้านความร้อน ซึ่งมีผลต่อปริมาณแป้งชูบในผลิตภัณฑ์ 4. นำเสนอผลงานในที่ประชุมระดับชาติ 1 เรื่อง
2	1-6	5. ทราบผลของไฮโดรคอลลอยด์ต่อคุณภาพของผลิตภัณฑ์ชูบแป้งทอดในการลดปริมาณน้ำมัน
	7-12	6. ได้ผลงานตีพิมพ์ในวารสารที่เป็นที่ยอมรับอย่างน้อย 1 เรื่อง

1.11 สรุปการดำเนินงานวิจัยตลอดโครงการ (2 ปี)

วัตถุประสงค์ / กิจกรรม (ตามแผน)	เป้าหมาย / ผลที่คาด (ตามแผน)	ผลการดำเนินงาน (ปฏิบัติได้จริง)
1. การศึกษาผลของไฮโดรคอลลอยด์ต่อคุณภาพของผลิตภัณฑ์ทอดประเภทชูบแป้งทอดโดยเฉพาะการลดปริมาณน้ำมัน	1. ได้สูตรเบทเทอร์ที่เหมาะสม 2. ทราบผลของไฮโดรคอลลอยด์ต่อสมบัติทางรีโอโลยีของเบทเทอร์ซึ่งมีผลต่อปริมาณแป้งชูบในผลิตภัณฑ์	1. ทราบผลของการใช้แป้งมันสำปะหลังต่อสมบัติเบทเทอร์และปริมาณน้ำมันในผลิตภัณฑ์ปึกไก่ชูบแป้งทอด 2. ได้ส่งผลงานเพื่อการนำเสนอในที่ประชุมระดับนานาชาติ 2 เรื่อง 3. มีนิสิตปริญญาโทสำเร็จการศึกษา 1 คน
2. เพื่อให้เข้าใจผลของไฮโดรคอลลอยด์ในสูตรของเบทเทอร์ (batter) ต่อสมบัติรีโอโลยีซึ่งมีผลต่อปริมาณแป้งชูบในผลิตภัณฑ์	3. ทราบผลของไฮโดรคอลลอยด์ต่อคุณภาพของผลิตภัณฑ์ชูบแป้งทอดในการลดปริมาณน้ำมัน	4. ทราบสมบัติทางรีโอโลยีของเบทเทอร์จากแป้งสาลีที่ผสมแป้งมันสำปะหลัง 5. นำเสนอผลงานในที่ประชุมระดับนานาชาติ 2 เรื่อง ทั้งในประเทศและต่างประเทศ เพื่อเปิดโอกาสให้บุคลากรทั้งในมหาวิทยาลัย หน่วยงานวิจัย หรือภาคอุตสาหกรรมทราบผลการวิจัย แทนการฝึกอบรมเพื่อให้เผยแพร่องค์ความรู้ได้มากขึ้น 6. ได้ตีพิมพ์ใน KU Journal 1 เรื่อง 7. อยู่ระหว่างการเตรียมต้นฉบับเพื่อตีพิมพ์ในวารสารเพิ่มเติมอีก 2 เรื่อง

1.12 สรุปผลการดำเนินงานตามวัตถุประสงค์

- ☒ บรรลุ.....
- ☐ บรรลุบางส่วน (ร้อยละ.....) เหตุผล.....
- ☐ ไม่บรรลุ เหตุผล.....

1.13 ผลผลิต/ สิ่งที่ได้จากการวิจัย (Outputs) (โปรดระบุรายละเอียด)

☒ องค์ความรู้/ข้อมูลพื้นฐาน สมบัติของแป้งและไฮโดรคอลลอยด์ต่อคุณภาพเบทเทอร์และปริมาณน้ำมันในผลิตภัณฑ์ซูปทอด

☐ สายพันธุ์พืช/สัตว์/จุลินทรีย์

☐ ผลิตภัณฑ์

☐ สิ่งประดิษฐ์

☒ เทคโนโลยี/นวัตกรรม ผลิตภัณฑ์ซูปทอดที่สามารถปรับความหนาของปริมาณแป้งและลดปริมาณน้ำมันในผลิตภัณฑ์สุดท้ายได้

☐ ฐานข้อมูล/ซอฟต์แวร์

☐ คู่มือ

☐ วิดีทัศน์

☒ การสร้างนักวิจัย/สนับสนุนนิสิตปริญญาตรี 1.. คน ปริญญาโท 1.. คน ปริญญาเอก 1.. คน

☐ สนับสนุนการศึกษาปัญหาพิเศษ เรื่อง (ระบุ) วิทยานิพนธ์ 2 เรื่อง (ระบุ)

..... ผลของแป้งมันสำปะหลังและเมทิลเซลลูโลสต่อการดูดซับน้ำมันของปึกไก่บนซูปทอด (IS ปริญญาโท)

..... คุณภาพของผลิตภัณฑ์ซูปทอดและสมบัติของเบทเทอร์ที่เตรียมจากแป้งผสมของแป้งสาลีและแป้งมันที่มีและไม่มีไฮโดรคอลลอยด์ (ปริญญาเอก)

☒ อื่นๆ (ระบุ)

(1) ผลงานที่ได้ บริษัทอุตสาหกรรมอาหารที่เกี่ยวข้องกับการซูปทอดสามารถนำไปประยุกต์ได้

(2) สามารถนำความรู้ไปใช้ประโยชน์ได้อย่างแพร่หลาย เนื่องจากมีการนำเสนอผลงานในที่ประชุมต่างๆ ทำให้องค์ความรู้ที่ได้มีการนำไปใช้ได้

(3) อุตสาหกรรมสามารถนำไปใช้พัฒนาผลิตภัณฑ์ใหม่ รวมทั้งเพิ่มมูลค่า

1.14 ผลลัพธ์/ผลสำเร็จที่ได้/หรือคาดว่าจะได้จากการนำผลการวิจัยไปใช้ประโยชน์ (Outcomes)

(1) เป้าหมายการนำไปใช้ประโยชน์ (ระบุกลุ่มเป้าหมายของงานวิจัยเชิงปริมาณ/คุณภาพ)

☒ ด้านการศึกษา/เสริมการเรียนรู้ การสอนของระดับปริญญาตรี โท และเอก

☐ ด้านการเกษตร

☒ ด้านอุตสาหกรรม นำองค์ความรู้ไปพัฒนาผลิตภัณฑ์

☐ ด้านทรัพยากรธรรมชาติ/สิ่งแวดล้อม

☐ ด้านคุณภาพชีวิต สุขภาพอนามัย

☐ ด้านเศรษฐกิจ

☐ ด้านสังคม

☐ ด้านการทำนุบำรุงศิลป ศาสนา วัฒนธรรม

☒ ด้านการถ่ายทอดเทคโนโลยี/ฝึกอบรม แก่กลุ่มเป้าหมาย มีการนำเสนอผลงานในที่ประชุม

☐ เสนอภาครัฐ เพื่อใช้กำหนดแผน/นโยบาย ฯลฯ

☐ นำความรู้ไปวิจัย/พัฒนาขั้นต่อไป

☐ ก่อให้เกิดความร่วมมือระหว่างหน่วยงาน/การสร้างเครือข่าย

☐ อื่นๆ (ระบุ)

- (2) สรุปผลการนำผลการวิจัยไปเผยแพร่ / ถ่ายทอด ตั้งแต่เริ่มต้นจนสิ้นสุดโครงการ (ระบุรายละเอียด อยู่ระหว่างดำเนินการส่งตีพิมพ์/ตีพิมพ์แล้วในรูปแบบเอกสารอ้างอิงและแนบสำเนาเป็นภาคผนวกของรายงาน)

☐ ตีพิมพ์ในวารสารวิชาการต่างประเทศ.....เรื่อง (อยู่ระหว่างการเตรียมต้นฉบับ)

☒ ตีพิมพ์ในวารสารวิชาการในประเทศระดับนานาชาติ 1.....เรื่อง (ระบุ)

Ketjarut, S., T. Suwonsichon and R. Pongsawatmanit. (2010). Rheological properties of wheat flour-based batter containing tapioca starch. *Kasetsart Journal (Nat. Sci.)*, 44 (1), 116-122.....

☒ นำเสนอในการประชุม/สัมมนา ต่างประเทศ.....2.....เรื่อง (ระบุ)

1. Ketjarut, S., N. Kumpai and R. Pongsawatmanit. 2008. Influence of tapioca starch on properties of wheat flour-based batter and oil uptake in fried product. The 14th World Congress of Food Science and Technology, Shanghai, China, October 19-23. 2008.

2. Pongsawatmanit, R. and S. Ketjarut. 2009. Rheological properties of wheat flour-based batters containing tapioca starch on the quality of fried chicken wingsticks. Academic Plaza in FOOMA JAPAN, 2009, Tokyo Big Sight Ariake, Koto-Ku, Tokyo, June 9-12, 2009 (Academic Plaza (AP) Special Prize from The Japan Food Machinery Manufacturers' Association (JFMA))

☐ นำเสนอในการประชุม/สัมมนา ในประเทศ.....เรื่อง (ระบุ)

☐ นำเสนอทางวิทยุ/โทรทัศน์/Website.....เรื่อง/ครั้ง (ระบุ).....

☐ นำเสนอทางนิทรรศการ.....เรื่อง/ครั้ง (ระบุ).....

☐ บทความ/เอกสารสิ่งพิมพ์/วิทยุทัศน์.....เรื่อง/ครั้ง (ระบุ).....

☐ ถ่ายทอด/ฝึกอบรมแก่เกษตรกร/ผู้สนใจ.....เรื่อง/ครั้ง (ระบุ).....

☐ ถ่ายทอดสู่ภาคเอกชน/อุตสาหกรรม/ผู้ประกอบการ (ประโยชน์เชิงพาณิชย์).....ครั้ง(ระบุ) ปีที่.....

☐ ภาครัฐนำไปใช้กำหนดแผน/นโยบาย ฯลฯ (ระบุ).....

☐ มีผู้นำผลงานวิจัยไปอ้างอิง (ระบุ).....

☐ อื่นๆ (ระบุ).....

1.15 การยื่นจด ☐ สิทธิบัตร ☐ อนุสิทธิบัตร ☐ ลิขสิทธิ์

☐ มีศักยภาพที่จะยื่นจด (ระบุ)

.....☐ ยื่นจดแล้ว เมื่อ.....

1.16 ผลกระทบ (Impact) ที่เกิดจากการนำผลการวิจัยไปใช้ (ระบุว่าก่อให้เกิดผลกระทบอย่างไร)

- ☐ ด้านความมั่นคง อาทิ การเมืองการปกครอง กฎหมาย การต่างประเทศ โครงสร้างพื้นฐาน และบริการ โทรคมนาคม ฯลฯ (ระบุ).....
- ☒ ด้านการเศรษฐกิจ อาทิ การพาณิชย์กรรม การเกษตรกรรม การอุตสาหกรรม การท่องเที่ยว วิทยาศาสตร์ และเทคโนโลยี พลังงาน ฯลฯ (ระบุ) เป็นองค์ความรู้พื้นฐานเพื่อการพัฒนาผลิตภัณฑ์ให้มีปริมาณน้ำมัน ลดลงซึ่งเป็นอาหารที่มีผลดีต่อสุขภาพผู้บริโภค ทำให้มีความสามารถในการแข่งขันมากขึ้น.....
- ☐ ด้านคุณภาพชีวิตและสังคม ศักยภาพของคนและการศึกษา การแพทย์และสาธารณสุข หลักประกันความ มั่นคง สวัสดิการสังคม วัฒนธรรม จริยธรรมและค่านิยม ฯลฯ (ระบุ).....
- ☐ ด้านทรัพยากรธรรมชาติและสิ่งแวดล้อม การบริการจัดการการใช้ทรัพยากรให้เกิดประโยชน์ การป้องกัน การทำลาย ลดการสูญเสีย การฟื้นฟูทรัพยากรและสิ่งแวดล้อม ฯลฯ
- ☐ อื่นๆ (ระบุ).....

1.17 ผลการดำเนินงานวิจัยสอดคล้องกับยุทธศาสตร์ชาติ ในด้าน

- ☐ ยุทธศาสตร์ความมั่นคงของชาติ การต่างประเทศและการอำนวยความสะดวก
- ☒ ยุทธศาสตร์เพื่อเพิ่มศักยภาพในการแข่งขันของประเทศ
- ☐ ยุทธศาสตร์การพัฒนาสังคม การแก้ไขปัญหาความยากจนและยกระดับคุณภาพชีวิต
- ☐ ยุทธศาสตร์การเสริมสร้างการพัฒนาที่ยั่งยืนของประเทศ
- ☐ ยุทธศาสตร์การบริหารจัดการประเทศ

1.18 ปัญหา อุปสรรค ในการดำเนินงานวิจัยและแนวทางแก้ไข ไม่มี.....

1.19 งานที่จะทำต่อไป/คำชี้แจงเพิ่มเติม -.....

1.20 ได้แนบ “รายงานผลการวิจัยฉบับสมบูรณ์ของโครงการ (Project)” ตามหัวข้อ ในส่วนที่ 2 (หน้าถัดไป) มาด้วยแล้ว

ลงชื่อ.....หัวหน้าโครงการ

(รศ.ดร.รุ่งนภา พงศ์สวัสดิ์มานิต)

..... 31 / พค / 2554 วัน/เดือน/ปี ที่รายงาน

ส่วนที่ 2

รายงานผลการวิจัยฉบับสมบูรณ์

โครงการวิจัยทุนอุดหนุนวิจัย มก. ปีงบประมาณ 2551-2552

โครงการวิจัยรหัส ว-ท(ด) 115.51....

(ชื่อโครงการ การวิเคราะห์ผลของไฮโดรคอลลอยด์ต่อการลดปริมาณน้ำมันในผลิตภัณฑ์ทอด
(Analysis of the influence of hydrocolloids on oil uptake reduction in fried products))

รุ่งนภา พงศ์สวัสดิ์มานิต¹
Rungnaphar Pongsawatmanit¹

บทคัดย่อ

สมบัติของแบดเทอร์มีความสำคัญต่อการพัฒนาผลิตภัณฑ์ชุบทอด ในการศึกษาครั้งนี้ จึงได้ศึกษาผลของแป้งมันสำปะหลัง (TS) และอุณหภูมิต่อความหนืดของแบดเทอร์จากแป้งสาลี (WF) ด้วยการเตรียมส่วนผสมแห้งจากแป้งผสม (91.4%) ที่ประกอบด้วยแป้งสาลีเอนกประสงค์และแป้งมันสำปะหลัง 3 อัตราส่วนผสมที่แตกต่างกัน (WF: TS = 100:0, 75:25 และ 50:50) ผงฟู (3.1%) และเกลือ (5.5%) จากนั้น นำส่วนผสมแห้งไปเติมน้ำเย็น (15°C) ในอัตราส่วน 1:1.3 ผสมให้เข้ากันจนได้แบดเทอร์ และเก็บไว้ที่อุณหภูมิ 10°C เป็นเวลา 1 ชั่วโมง ก่อนนำไปวิเคราะห์สมบัติทางวิทยากระแสด้วยเครื่องวัดความหนืดแบบโรตารี (rotational) ที่อุณหภูมิ 10, 15, 20 และ 25°C พบว่า รีโอแกรมของแบดเทอร์ทุกอัตราส่วนผสมของแป้งแสดงพฤติกรรม shear-thinning ทุกอุณหภูมิที่ศึกษา เมื่อปริมาณแป้งมันสำปะหลังที่แทนที่ในแบดเทอร์เพิ่มขึ้นและวิเคราะห์ที่อุณหภูมิสูงขึ้น มีผลให้ความหนืดปรากฏของแบดเทอร์จากแป้งสาลิลดลง โดยสามารถใช้สมการ power law แสดงพฤติกรรมการไหลของแบดเทอร์ทุกอัตราส่วนผสมของ WF และ TS ($r^2 = 0.989 - 1.000$) การใช้แป้งมันสำปะหลังแทนที่แป้งสาลีทำให้แบดเทอร์มีค่า consistency coefficient (K) ลดลง แต่ค่า flow behavior index (n) เพิ่มขึ้น พลังงานกระตุ้นจากสมการอาร์เรเนียสของแบดเทอร์ทั้งที่มีและไม่มีแป้งมันสำปะหลังมีค่าประมาณ 23 – 26 kJ/mol และไม่พบความแตกต่างอย่างมีนัยสำคัญ ($p > 0.05$) แสดงให้เห็นว่า การเติมแป้งมันสำปะหลังไม่มีผลต่อความคงตัวด้านความร้อนของแบดเทอร์จากแป้งสาลี

สมบัติของแบดเทอร์มีความสำคัญต่อการพัฒนาคุณภาพของผลิตภัณฑ์ชุบทอด จึงศึกษาผลของการเติม TS ต่อสมบัติเพสติงและความร้อนของเบทเทอร์ที่มีแป้งสาลีที่เตรียมจาก WF และ TS (สัดส่วนการผสม = 100:0, 75:25 และ 50:50) และปริมาณน้ำมันในปิกโก้นชุบทอด สมบัติเพสติงของแบดเทอร์แต่ละอัตราส่วนเจือจางด้วยน้ำ (1:2) เพื่อให้ได้ความเข้มข้นของแป้งทั้งหมดเป็น 13.2 % ความหนืดที่ให้ความร้อนใน RVA ที่ 95°C เป็นเวลา 5 นาทีและความหนืดสุดท้ายมีค่าลดลงเมื่อสัดส่วนของ TS ที่แทน WF เพิ่มขึ้น สำหรับการวัดด้วย DSC ค่า T_g ของแบดเทอร์ทั้งหมดที่เตรียมจากแป้งผสมของ WF และ TS (100:0, 75:25 และ 50:50) ประมาณ 65°C ค่า batter pickup บนปิกโก้นมีค่าลดลงเพื่อสัดส่วน TS แทนที่ WF เพิ่มขึ้น หลังการทอดปิกโก้นชุบทอดที่ 167°C เป็นเวลา 3 นาที การใช้ TS ทดแทนเพิ่มขึ้น ทำให้ cooking loss เพิ่มขึ้นในขณะที่ปริมาณน้ำมันใน pre-fried battered products ลดลง คะแนนความชอบโดยรวมของปิกโก้นทอดสุดท้ายที่มีการใช้แป้ง TS มีค่าสูงกว่าของตัวอย่างที่ไม่มีการใช้ TS

1. (ภาษาไทย) ภาควิชาพัฒนาผลิตภัณฑ์ คณะอุตสาหกรรมเกษตร มหาวิทยาลัยเกษตรศาสตร์
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ผลของการเติมคาร์บอกซีเมธิลเซลลูโลส (CMC) ต่อสมบัติทางความร้อนและปริมาณเกาะติดของแบตเทอร์ที่เตรียมจากแป้งผสมของแป้งสาลี (WF) และแป้งมันสำปะหลัง (TS) (อัตราส่วน = 1:1) โดยใช้ WF (45.2 - 45.7%) TS (45.2 - 45.7%) และ CMC (0 - 1%) ผสมให้เข้ากัน ของผสมได้จากแป้งผสมที่มีและไม่มี CMC ผงฟู และเกลือ เติมน้ำเย็นลงในของผสมแห่งอัตราส่วน 1:1.3 เก็บที่ 10°C เป็นเวลา 1 ชั่วโมง ก่อนวัดความหนืด, RVA, DSC และปริมาณเกาะติดของแบตเทอร์ ผลที่ได้แสดงให้เห็นว่า รีโอแกรมของแบตเทอร์ที่มี CMC ความเข้มข้นต่างๆ กันมีพฤติกรรมเป็นแบบ shear-thinning ค่าความหนืดปรากฏและดัชนีความคงตัว (K) ของแบตเทอร์เพิ่มขึ้นเมื่อความเข้มข้นของ CMC เพิ่มขึ้น RVA pasting temperatures และความหนืดสุดท้ายของแบตเทอร์ทั้งหมดที่เติม CMC (0-1%) ซึ่งเจือจางด้วยน้ำ (1:2) ไม่มีความแตกต่างอย่างมีนัยสำคัญ ($p > 0.05$) การเติม CMC ไม่มีผลต่อการเปลี่ยนแปลง endothermic peaks ของแป้งผสม WF และ TS (1:1) เมื่อปิ้งไก่บนจุ่มลงในแบตเทอร์และทอดที่อุณหภูมิ 180°C เป็นเวลา 4 นาที จากนั้นให้ความร้อนต่อในเตาอบที่อุณหภูมิ 200°C เป็นเวลา 4 นาที ปริมาณน้ำมันใน fried batter crust ลดลงเมื่อปริมาณ CMC เพิ่มขึ้น คะแนนความชอบโดยรวมของปิ้งไก่ชุบทอดสุดท้ายที่มี CMC (0 และ 0.5%) มีค่าสูงกว่าของตัวอย่างที่เติม CMC 1% ผลที่ได้ชี้ให้เห็นว่า CMC ความเข้มข้นสูงถึง 0.5% สามารถใช้เพิ่มปริมาณการเกาะติดของแบตเทอร์และลดปริมาณน้ำมันในผลิตภัณฑ์ปิ้งไก่บนชุบทอด

คำสำคัญ: แบตเทอร์, แป้งมันสำปะหลัง, สมบัติเพสติง, ความหนืดปรากฏ, สมการอาร์เรเนียส, ไฮโดรคอลลอยด์, CMC

ABSTRACT

Batter properties are important for developing fried battered products. In this study the effects of tapioca starch (TS) and temperature on viscosity of wheat flour based batters were investigated. Flour blend (91.4%) from commercial all-purpose wheat flour (WF) and TS at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50), leavening powder (3.1%) and salt (5.5%) were mixed to obtain dry-mix. The batter was prepared by mixing the dry-mixes with water (15°C) in the proportion of 1:1.3 (w/w) and kept for 1 h at 10°C before rheological property evaluation using rotational viscometer at 10, 15, 20 and 25°C. The rheograms of all batters with different mixing ratios of flour exhibited shear-thinning behavior at all studied temperatures. Apparent viscosity of wheat flour based batter systems decreased with increasing the substitution of TS and temperature. The power law equation was found to fit all batter formulations with different mixing ratios of WF and TS ($r^2 = 0.989 - 1.000$). Replacement of TS in batters decreased consistency coefficient (K) but increased flow behavior index (n) of the batter systems. The activation energy values from Arrhenius equation of the batters with and without TS were about 23 – 26 kJ/mol and not significantly different ($p > 0.05$) suggesting that TS addition did not alter thermal stability of the wheat flour based batters.

Batter properties are important for developing better qualities of fried products. The effect of tapioca starch addition on pasting and thermal properties of batters prepared from WF and TS (mixing ratio = 100:0, 75:25 and 50:50) and oil content in fried battered chicken wingsticks was investigated. For RVA measurement, each batter was diluted with water (1:2) to obtain 13.2% total flour concentration. The viscosity at holding time for 5 min of 95°C and final viscosity decreased with increased TS substitution. For DSC measurement, onset temperature (T_o) of all batters with different mixing ratios of WF and TS (100:0, 75:25 and 50:50) were about 65°C. The percentage of batter pickup on chicken wingsticks decreased with increasing TS substitution in WF-based batter. After frying battered wingsticks at 167°C for 3 min, the substitution of TS increased cooking loss whereas decreased oil contents in the pre-fried battered products. Fat contents in fried products revealed the lower values with further oven heating and higher TS substitutions. The overall liking scores of final fried wingsticks containing TS were higher than that without TS substitution.

Effect of carboxymethylcellulose (CMC) on the thermal properties and batter pickup of batters prepared from wheat flour (WF) and tapioca starch (TS) (mixing ratio = 1:1) was investigated. WF (45.2 to 45.7%), TS (45.2 to 45.7%) and CMC (0 to 1%) were mixed. The dry-mixes of flour blend with and without CMC, baking powder and salt were mixed with cool water in the proportion of 1:1.3 and kept at 10°C for 1 h before steady shear viscosity, RVA, DSC and batter pickup measurements. The results showed that the rheograms of all batters with different CMC concentrations exhibited shear thinning behavior. Apparent viscosity and consistency index (K) of batters increased with increasing CMC concentrations. RVA pasting temperatures and final viscosities of all batters containing CMC (0-1%) and diluted with water (1:2) were not significant different ($p < 0.05$). CMC addition (up to 1%) did not alter the double endothermic peaks of WF-TS (1:1). Chicken wingsticks were battered and fried at 180°C for 4 min and further heated in oven at 200°C for 4 min. The fat content of fried crust was determined. Batter pickup increased with CMC concentration indicating the values increased with increasing viscosity. Fat contents of fried crust of fried chicken wingsticks were lower with increasing CMC content. The overall liking scores of final fried wingsticks containing CMC (0, and 0.5%) were higher than that containing 1% CMC. The results suggest that CMC can be used to increase batter pickup and to reduce oil content of fried battered chicken wingsitcks up to 0.5%.

Keywords: Batter; tapioca starch; pasting properties; apparent viscosity, Arrhenius equation, hydrocolloids, CMC.

1. Introduction

Food products are dipped into the batter prior to deep-fat frying aimed at sealing the food in order to retain all flavors and juiciness under a crisp crust (Rosana et al., 1999; Fiszman and Salvador, 2003). Batter application prior to deep-fat frying is a widely used method for food preparation. The batter forming a continuous and uniform layer over food surface enhances the desired texture, flavor and appearance of foods after frying. Usually, the batter is a liquid mixture comprised of water, flour, starch, and seasonings. The consistency of batter plays an important role in determining its performance related to process of pickup and frying leading to the final quality of fried product especially the oil uptake in fried batters (Hsia et al., 1992; Shih and Daigle, 1999; Dogan et al., 2005). Since the increase in health awareness of the consumer related to the fat content in food, the oil uptake in these fried batters increases the consumption of oil known to cause obesity and other health problems, the concern to develop fried product with less oil content in the fried products is the driving force for product development stage in food industry and leads to many extensive researches to reduce the oil uptake (Salvador, Sanz, and Fiszman, 2008).

Application of batter containing different flours provides unique flavors and textures in fried products. The batter ingredients and their interactions during frying play an important role in determining the batter oil uptake (Shih and Daigle, 1999). Wheat flour-based batters are widely used in fried products. Starch granules in batter, when heated in the presence of water, undergo gelatinization. The gelatinization involves swelling of the starch granules due to the water absorbed into portions of their structure (Davis, 1983). Then, after dipping the food into the batter, the swollen starch granules in the batter release starch molecules and provide a film barrier to inhibit both moisture loss from the food pieces and oil penetration into the food during frying process (Meyers, 1990; Xue and Ngadi, 2006) providing crispness and texture to the finish fried product. In fact, the structure of final fried batter is obtained from the gelatinized starch along with wheat flour protein. Wheat flour is the most common flour used in batter systems. Wheat flour is widely used as a functional ingredient in frying batter (Loewe, 1993) which determines its unique characteristics due to gluten can expand during frying, providing a

desirable, spongy coating and facilitating the passage of water and oil (Mukprasirt, Herrald, Boyle, and Boyle, 2001). Protein content and its quantity of amylase and amylopectin have been well correlated with the texture characteristics, oil uptake, good appearance and overall acceptability (Fizman and Salvador, 2003). Increase in water or amylopectin contents, and excess protein produced an increase of oil absorption and a decrease of crispness of the fried batter (Fizman and Salvador, 2003). Application of batter containing different flours provides unique flavors and textures in fried products. Replacing part of wheat flour with other flours has been studied recently. For example, part of rice flour changes the rheological properties of the batter which depend on the temperature and the ratio of replacement (Mukprasirt et al., 2000). Mohamed et al. (1998) reported that addition of pregelatinized rice flour resulted in an increase in oil absorption of fried product due to the porous structure. Since rice flour exhibits poor thickening agent compared with wheat flour, a higher proportion of solid or the addition of hydrocolloids to maintain required viscosity of batter is needed. For corn starch, the solid tends to sediment and leads to change in viscosity of the batter, resulting in inconsistency of batter pickup (Suderman, 1993). Modified starches with a high amylose content exhibiting a higher gelatinization temperature give good film forming properties, which alone or in combination with other ingredients such rice flour, help to reduce oil absorption by creating an effective barrier against oil entry into the food pieces during frying (Higgins, Qian, and Williams, 1999). Other types of flour were also studied in batter systems such as rice flour (Shih and Daigle, 1999), wheat - corn and corn - rice (Xue and Ngadi, 2007) to lower oil uptake. The replacement of wheat flour by corn flour in the formulation decreases significantly the oil content of the battered squids (Llorca et al., 2003).

Since the consistency of batter also plays an important role in its performance during frying (Shih and Daigle, 1999) which affects batter pickup and the quality of fried products (Dogan, Sahin, and Sumnu, 2005; Hsia, Smith, and Steffe, 1992), hydrocolloids are important ingredients adding into the batter to control the viscosity and final texture of fried products by improving the adhesion and an increase in the degree of coating to the food pieces. The gelling ability of hydrocolloids with the hydrophilic properties makes them suitable for reducing oil uptake during frying battered food (Annapure, Singhal, and Kulkarni, 1999). Therefore, the water binding capacity of hydrocolloids is an important property for fried products containing less oil since there is a strong relation between oil uptake and moisture loss during frying process (Altunakar, Sahin, and Sumnu, 2004; Dogan et al., 2005). Certain hydrocolloids have been incorporated into batter formulations and have found to be effective in oil absorption barriers (Annapure, Singhal, and Kulkarni, 1999; Hsia, Smith, and Steffe, 1992; Sanz, Salvador, and Fizman, 2004). The addition of methylcellulose (MC) and hydroxypropyl methylcellulose (HPMC) in batter systems has been used as oil barriers to reduce oil uptake in fried battered products (Meyers and Conklin, 1990; Balasubramaniam et al., 1997) such as chicken pieces, fish, vegetables, cheese, and cereal products (Albert and Mittal, 2002; Fizman and Salvador, 2003; Meyers, 1990) due to their film-forming properties and unique thermal gelation properties. A film-forming MC was found to reduce fat on fried products more than gellan gum and HPMC (Williams and Mittal, 1999). Methyl cellulose (MC) is cellulose derivative which form gel with heating but return to its original viscosities when it is cook (Dziezak, 1991). Thermal gelation and film forming properties of MC make them suitable to reduce oil absorption, (Mohamed, Hamid, and Hamid, 1998). MC also performed effectively to reduce the amount of fat absorbed during frying in a wide variety of battered food items (marrow, pork meat, cheese and squid) (Salvador et al., 2008).

Since the quality and acceptability of fried battered product depend on the batter uniformity and coating thickness on food surface determined by viscosity and temperature of the batter during dipping (Moreira et al., 1999). Rheological property measurements are used for determining and monitoring changes in the properties during batter coating and frying (Chang et al., 1996). The factors that affect the rheological properties of batters and oil uptake in fried battered products are the composition and proportion of the ingredients, the solids-water

relationship and temperature (Fizman and Salvador, 2003). Oil uptake also increased with increased removal of water from the sample during frying process.

Starch and non-starch polysaccharides were investigated in this study. Tapioca starch (TS) produced from cassava roots, sometimes called cassava starch, is a favorable thickener used in food industries due to its high viscosity, clear appearance, and low production cost, compared to other starches, especially in Thailand (Pongsawatmanit et al., 2006). The viscosity of TS is found to have a high viscosity level compared with most other tuber starches and cereal starches (Moorthy et al., 2004). Although many studies reported the effect of other flour types on the quality of batter and fried products, few studies are available in literature about the replacing starch with TS on fried product quality. Then, TS was selected for partial substitution of WF-based batter system.

Therefore, the objectives of this study were to determine the effect of TS substitution on the viscosity of WF-based batters at different temperatures to gain more understanding of the rheological properties for further application in fried battered products. The thermal properties of the batters and oil uptake of final fried products were also investigated for examining the gelatinization of starches during heating process and oil uptake of chicken wingsticks. Finally, quality of fried battered chicken wingstick prepared from wheat flour – tapioca starch blend with and without carboxymethylcellulose (CMC) was determined.

2. Materials and methods

2.1 Materials

Commercial all-purpose wheat flour (WF), tapioca starch (TS) (Chorchaiwat Industry Co., Ltd, Thailand), leavening agent ($\text{Na}_2\text{H}_2\text{P}_2\text{O}_7/\text{NaHCO}_3$), sodium carboxymethylcellulose (CMC) (Blanose 7HF, Aqualon) and commercial refined salt were used for batter preparation. Moisture contents of WF and TS determined according to the AOAC methods (1995) were 12.65% and 11.52%, respectively. Protein content of wheat flour according to the manufacturer was 10.35% whereas that of TS was 0.14% (AOAC, 1995). Starch content in WF was determined according to the starch-glucoamylase method 76-11 (AACC, 1990) was 74.42%. Chilled chicken wingsitcks were purchased from local supermarket. The refined palm olein was used for frying the sample and changed after frying for 5 h. The sodium tripolyphosphate (STPP) (Union chemical, Thailand) was used marinated chicken wingstick for the experiment related to CMC addition into the batter.

2.2 Rheological properties of wheat flour-based batter containing TS

2.2.1 Batter preparation

WF and TS were premixed at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50). The dry-mix prepared from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) as shown in Table 2.1 was mixed with water (15°C) with the proportion of dry-mix to water as 1:1.3 (w/w) using mixer to obtain homogeneous batter and kept at 10°C for at least 1 h before the measurement of rheological properties.

Table 2.1 Dry-mix formulations for batter preparation with different mixing ratios of WF and TS

Ingredient	Ingredients for each mixing ratio of WF and TS (%)		
	100:0	75:25	50:50
Wheat flour (WF)	91.4	68.55	45.7
Tapioca starch (TS)	0.0	22.85	45.7
Leavening powder	3.1	3.1	3.1
Salt	5.5	5.5	5.5

2.2.2 Rheological property measurement

Apparent viscosity of prepared batters was measured as a function of shear rate ranged from 2.5 to 62.5 s⁻¹ at 10, 15, 20 and 25°C using rotational viscometer (DV-III, Brookfield-RVT) with small sample adapter's coaxial cylinder geometry and SC4-29 spindle. Sample temperature was kept constant at least 5 min before starting measurement. Flow characteristics of the batters were evaluated using power law model. The effect of temperature on rheological properties was determined using Arrhenius equation.

2.3 Effect of TS on thermal properties of batters and quality of fried battered chicken wingstick

2.3.1 Batter preparation

WF and TS were premixed at three different mixing ratios (WF:TS = 100:0, 75:25, 50:50). The dry-mix prepared from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) was mixed with water (15°C) with the proportion of dry mix to water = 1:1.3 (w/w) at low speed of a mixer for 1 min to obtain homogeneous batter. The batters were kept at 10°C for at least 1 h before further step of battering. The thermal properties and batter pickup were evaluated using RVA, DSC and batter pickup determination. Batter pickup refers to the quantity of the batter adhering to the food surface before frying. Each wingstick was dipped into the batter (controlled temperature at 15°C). Three pieces per batch were used. The batter pickup was calculated as a percentage of the batter weight compared to the initial weight of wingsticks (non battered).

2.3.2 Battering and frying of chicken wingsticks

The chilled chicken wingsticks (in the range of 40-45g/piece) were washed, and drained for 30 min a refrigerator (4°C). Three pieces of wingsticks (a batch of frying were manually predested with 3 g of WF for 10 s in a plastic bag before battering. Each wingstick was dipped into the batter suspensions maintaining at 15±1°C in an ice-water bath to control the viscosity of the batter and any excess batter was allowed to drip off for 10 s. Three chicken wingsticks were deep-fried at 167°C in a laboratory scale fryer with the oil volume of 3 l (FRI-1355 compact, Fritel, Belgium) of refined palm olein oil for 3 min o obtain the internal temperature about 71-75 °C measured with a thermocouple at the thickest part of the wingsticks about 3 min. Some batches of wingsticks were further heated in the oven controlled at 190°C for 8 min. Then wingsticks were cooled to room temperature for 10-15 min prior to moisture and fat content evaluation (modified from Mukprasirt et al., 2001). Cooking loss with and without further oven heating was determined. The fried crust was peeled out for moisture and fat content determination. The pre-fried battered chicken wingsticks for sensory evaluation were placed in polyethylene bag (10 pieces/bag) and kept at -18°C.

2.3.3 Thermal properties of batters prepared from flour blends with different mixing ratios of WF and TS

RVA pasting measurement: The pasting properties of prepared batter mixtures were evaluated using a Rapid visco-analyzer (RVA-4, Newport Scientific, Narrabeen, Australia), with dilution ratio of 1:2 with distilled water to obtain the total flour concentrations at 13.2% w/w. The total run time was 23 min with the temperature profile and agitation speed of the paddle according to the method of Pongsawatmanit et al. (2006) as following: equilibrating the starch slurry at 50°C for 1 min, increasing the temperature to 95°C at a heating rate of 6°C/min, holding the temperature at 95°C for 5 min, decreasing the temperature to 50°C at 6°C/min, and holding at 50°C for the remainder of the run. Pasting parameters were recorded.

Differential scanning calorimetry (DSC) measurement: Gelatinization of batters with different TS substitution were evaluated using a differential scanning calorimeter (DSC822e, Mettler-Toledo GmbH, Switzerland). The prepared batters were kept constant at room temperature for 1 h before DSC measurement. About fifteen mg of dispersions were weighed

directly into a 40- μ l aluminum DSC pan and the pans were hermetically sealed. The gelatinization behaviors of each batter containing different mixing ratios of WF and TS were investigated by heating the pans from 25°C to 110°C at the rate of 5°C/min. Sealed empty pan was used as a reference. Onset temperature (T_o) peak temperature (T_p) and conclusion temperature (T_c) were determined based on heating DSC thermograms. Gelatinized enthalpy expressed as J/g dry starch was evaluated based on the area of the main endothermic peak. The sample pan was weighed before and after measurements to ensure that no weight was lost during the measurement. Three freshly prepared samples were measured and each average value was reported.

2.3.4 Determination of fried product quality

Cooking loss: Chicken wingsticks were dipped into the batters, and excess batter was allowed to drip off for 10 s before frying at 167°C for 3 min. The weight of wingsticks was determined before and after battering. Fried samples were drained and again individually weighed. Some batches of wingsticks were further heated in the oven controlled at 190°C for 8 min. Cooking loss was calculated as a percentage of the difference between weights of battered and fried samples at the specified stages (after frying with and without further oven heating) compared to the initial weight of wingsticks (non battered) (Mukprasirt et al., 2001).

Moisture and fat contents: Moisture and fat contents of fried batter part of fried products with and without further oven heating were analyzed. Fried crust pieces were cut into small pieces. Moisture content of the fried crust was determined by measuring weight loss of fried products after drying in a hot air oven at 105°C until constant weight obtained (AOAC, 1995).. The fat content of the ground sample was determined by extracting with petroleum ether. Moisture and fat contents were expressed as percentages of original sample in weight basis (Akdeniz et al., 2006). The fat content of the fried sample was determined by extracting with petroleum ether using a Soxtec™ Avanti 2050 automated extraction system.

Sensory evaluation: The frozen pre-fried battered chicken wingsticks prepared from 2.3.2 (batter mixing ratios of WF:TS = 100:0, 75:25 and 50:50) were deep-fried at 195°C without thawing in a laboratory scale fryer with the oil volume of 3 l (FRI-1355 compact, Fritel, Belgium) for 3 min before serving. Thirty untrained panels were recruited for preference test from the staffs and students in the Department of Product Development at Kasetsart University, age range of 18-50 years old. Fried chicken wingsticks were served with water. The panel was asked to rate the liking of quality attributes according to appearance, color of product, thickness, adhesion, oil absorption, crispness and overall liking using a nine-point hedonic scale (9 = like extremely, 5 = neither like nor dislike, 1 = dislike extremely). All panel sessions were conducted in sensory panel booths under fluorescent light.

2.4 Quality of fried battered chicken wingstick prepared from wheat flour – tapioca starch blend with and without CMC

2.4.1 Batter preparation

Dry-mix formulations for batter preparation with flour blend of WF and TS (1:1) containing different concentrations of CMC (0-1.0%) were shown in Table 2.2. The amount of CMC was used to replace the flour blend in the dry-mix. The dry-mix was mixed with water (15°C) = 1:1.3 (w/w) at low speed of a mixer for 1 min to obtain homogeneous batter. The batters were kept at 10°C for at least 1 h before further step of battering. The rheological and thermal properties were evaluated using rheometer, RVA and DSC. Batter pickup determination was performed by dipping each wingstick into the batter (controlled temperature at 15°C) and weighing before and after battering. The batter pickup was calculated as a percentage of the batter weight compared to the initial weight of wingsticks (non battered).

Table 2.2 Dry-mix formulations for batter preparation with flour blend of WF and TS (1:1) containing different concentrations of CMC (0-1.0%).

Ingredients	CMC (%)				
	0	0.25	0.5	0.75	1.0
WF	45.7	45.58	45.45	45.33	45.2
TS	45.7	45.58	45.45	45.33	45.2
CMC	0	0.25	0.5	0.75	1.0
Salt	5.5	5.5	5.5	5.5	5.5
leavening agent	3.1	3.1	3.1	3.1	3.1

2.4.2 Battering and frying chicken wingsticks with batters containing CMC

The chilled chicken wingsticks (in the range of 35-40 g/piece) were washed and marinated with 10% brine (6% salt and 4% STTP) by tumbling in water and ice bath for 30 min, and drained for 30 min a refrigerator (4°C). Three pieces of wingsticks (a batch of frying were manually predusted with 3 g of WF for 10 s in a plastic bag before battering. Each wingstick was dipped into the batter suspensions maintaining at 15±1°C in an ice-water bath to control the viscosity of the batter and any excess batter was allowed to drip off for 10 s. Three chicken wingsticks were deep-fried at 180°C in a laboratory scale fryer with the oil volume of 3 l (FRI-1355, Fritel, Belgium) of refined palm olein oil for 4 min to obtain the internal temperature about 71-75 °C measured with a thermocouple at the thickest part of the wingsticks about 3 min. Fried chicken wingsticks with and without further heated in the oven (200°C) for 4 min were cooled to room temperature for 10-15 min prior to determination of moisture and fat contents of fried crust (modified from Mukprasirt et al., 2001). Cooking loss was determined. The fried crust was peeled out for moisture and fat content determination. The pre-fried battered chicken wingsticks for sensory evaluation were placed in polyethylene bag (10 pieces/bag) and kept at temperature about -18°C.

2.4.3 Batter quality evaluation

Rheological properties measurement: The apparent viscosity of the prepared batters was measured as a function of shear rate and ranged from 1 to 100 s⁻¹ at 15°C with a rheometer (Physica MCR300, Anton Paar), the concentric cylinder geometry (CC27), and a bottom plate (TEZ150P). Sample temperature was kept constant for at least 2 min before starting measurement. The flow characteristics of the batters were evaluated using a power law model.

RVA pasting measurement: The pasting properties of prepared batter mixtures containing CMC (0-1%) were evaluated using a Rapid visco-analyzer (RVA-4, Newport Scientific, Narrabeen, Australia), with dilution ratio of 1:2 with distilled water to obtain the total flour concentrations at 13.2% w/w, respectively. The total run time was 23 min with the temperature profile and agitation speed of the paddle according to the method of

Pongsawatmanit et al. (2006) as following: equilibrating the starch slurry at 50°C for 1 min, increasing the temperature to 95°C at a heating rate of 6°C/min, holding the temperature at 95°C for 5 min, decreasing the temperature to 50°C at 6°C/min, and holding at 50°C for the remainder of the run. Pasting parameters were recorded.

Differential scanning calorimetry (DSC) measurement: Gelatinization properties of batters with different CMC concentrations were evaluated using a differential scanning calorimeter (DSC822e, Mettler-Toledo GmbH, Switzerland). The prepared batters were kept constant at room temperature for 1 h before DSC measurement. About fifteen mg of dispersions were weighed directly into a 40- μ l aluminum DSC pan and the pans were hermetically sealed. The gelatinization behaviors of each batter containing different WF:TS ratios were investigated by heating the pans from 25°C to 110°C at the rate of 2°C/min. Sealed empty pan was used as a reference. Onset temperature (T_o) peak temperature (T_p) and conclusion temperature (T_c) were determined based on heating DSC thermograms. Gelatinized enthalpy expressed as J/g dry starch was evaluated based on the area of the main endothermic peak. The sample pan was weighed before and after measurements to ensure that no weight was lost during the measurement. Three freshly prepared samples were measured and each average value was reported.

2.4.4 Determination of fried product quality

Cooking loss: Chicken wingsticks were dipped into the batters containing CMC (0-1%), and excess batter was allowed to drip off for 10 s before frying at 167°C for 4 min. The weight of wingsticks was determined before and after battering. Fried samples were drained and again individually weighed. Some batches of wingsticks were further heated in the oven controlled at 190°C for 8 min. Cooking loss was calculated as a percentage of the difference between weights of battered and fried samples at the specified stages (after frying with and without further oven heating) compared to the initial weight of wingsticks (non battered) (Mukprasirt et al., 2001).

Moisture and fat contents: Moisture and fat contents of fried batter part of fried products with and without further oven heating were analyzed. Fried crust pieces containing CMC (0-1%) were cut into small pieces. Moisture content of the fried crust was determined by measuring weight loss of fried products after drying in a hot air oven at 105°C until constant weight obtained (AOAC, 1995). The fat content of the ground sample was determined by extracting with petroleum ether. Moisture and fat contents were expressed as percentages of original sample in weight basis (Akdeniz et al., 2006). The fat content of the fried sample was determined by extracting with petroleum ether using a Soxtec™ Avanti 2050 automated extraction system.

Sensory evaluation: The frozen pre-fried battered chicken wingsticks prepared from 2.4.2 (batter mixing ratios of WF:TS = 1:1) containing CMC (0, 0.5 and 1%) were deep-fried at 195°C in a laboratory scale fryer with the oil volume of 3 l (FRI-1355 series, Fritel, Belgium) for 3 min before serving. Thirty untrained panels were recruited for preference test from the staffs and students in the Department of Product Development at Kasetsart University, age range of 18-50 years old. Fried chicken wingsticks were served with water. The panel was asked to rate the liking of quality attributes according to appearance, color of product, crust thickness, adhesion between crust and chicken wingstick skin, oil absorption, crispness of crust and overall liking using a nine-point hedonic scale (9 = like extremely, 1 = dislike extremely). All panel sessions were conducted in sensory panel booths under fluorescent light.

2.5 Statistical analysis

All measurements were performed at least in triplicate and mean values were reported with standard deviation. An analysis of variance (ANOVA) was done to determine the significant difference of the treatment parameters. Duncan's multiple range test was also applied to determine the difference of mean ($p < 0.05$) from ANOVA.

3. Results and Discussion

3.1 Rheological properties of wheat flour-based batter containing tapioca starch

3.1.1 Steady shear measurement

From the steady shear measurement, batters prepared from dry-mixes consisting of 91.4% flour blend of WF and TS (WF:TS = 100:0, 75:25 and 50:50) mixed with water (dry mixes: water as 1:1.3) were determined at 10, 15, 20 and 25°C after preparation for 1 h to ensure the complete swelling of starch granules. The rheograms of the batters with different mixing ratios of flour blend were plotted between shear stress and shear rate (2.5-62.5 s⁻¹) at 10, 15, 20 and 25°C as shown in Fig. 3.1. All batters exhibited pseudoplastic behavior. At the same temperature, TS substitution in WF based batters (WF:TS = 75:25 and 50:50) decreased the shear stress at the same shear rate. When the shear stress values of batters were measured at higher temperatures, shear stress values of batters from each mixing ratio of flour blend were lower with increasing temperature.

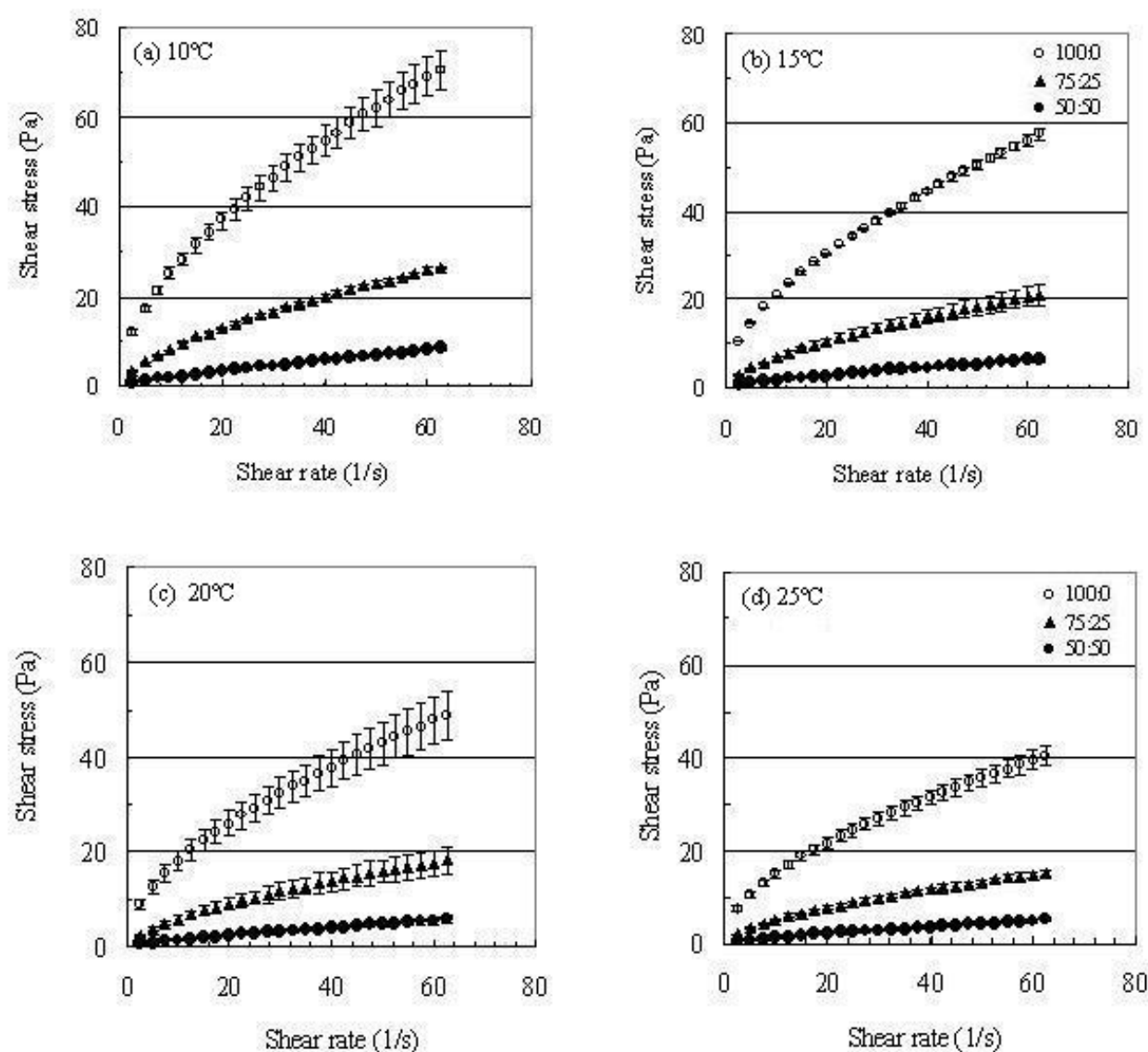


Fig. 3.1 Rheograms of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at 10°C (a), 15°C (b), 20°C (c) and 25°C (d).

The apparent viscosity of batters containing different mixing ratios of WF and TS (100:0, 75:25, 50:50) at 10 to 25°C was investigated. The apparent viscosity of batters decreased with increasing shear rate, tapioca starch substitution and temperature (Fig. 3.2). Since shear-thinning behavior in the Fig. 3.2 exhibits as in a middle region where the apparent viscosity is changing (decreasing for shear thinning) with shear rate, the power law equation is a suitable model for describing the flow behavior of these batter systems as shown in the following equation (3.1)

$$\tau = K\dot{\gamma}^n \quad (3.1)$$

Where τ = shear stress (Pa), $\dot{\gamma}$ = shear rate (s^{-1}), K = consistency coefficient ($Pa.s^n$), and n = flow behavior index (Steffe, 1996).

The power law equation was found to fit all batter formulations with different mixing ratios of WF and TS ($r^2 = 0.989 - 1.000$). Consistency coefficient values of wheat flour based batters without TS were higher than those containing TS (Table 3.1). We observed that addition of TS in the batters altered the flow behavior index of the batter from 0.5 to 0.6-0.8 (Table 3.1). The results suggested that the batters containing TS exhibited more pronounced Newtonian behavior due to the flow behavior index more closely approaching a value of $n = 1$.

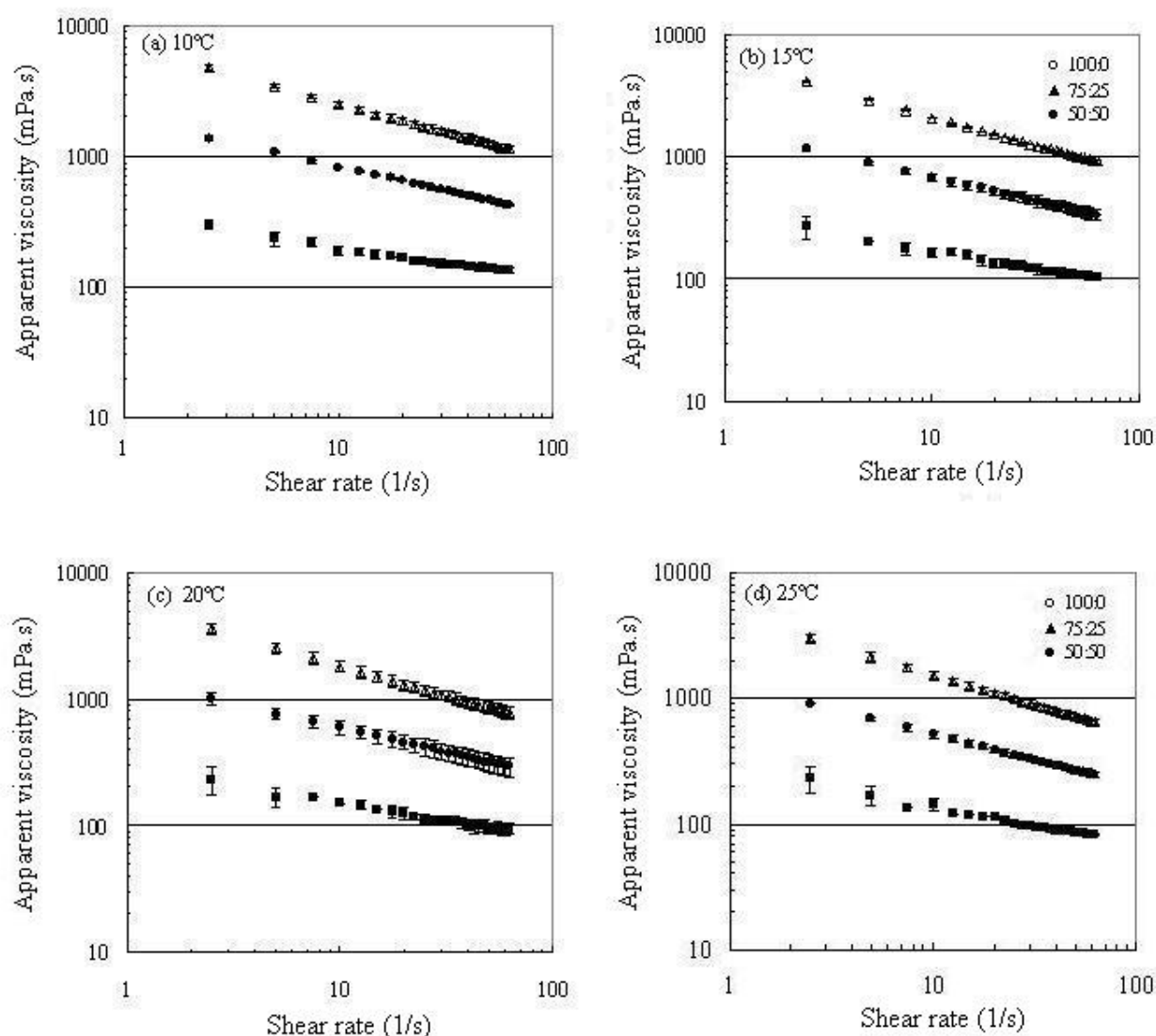


Fig. 3.2 Apparent viscosity of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at 10°C (a), 15°C (b), 20°C (c) and 25°C (d).

Table 3.1 Power law parameters (K = consistency coefficient, n = flow behaviour index) of the batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined from the shear rates ranged from 2.5 to 62.5 s⁻¹ at 10, 15, 20 and 25°C.

WF:TS	Temperature (°C)	K (Pa.s ⁿ)	n (-)	R ²
100:0	10	7.03 ± 0.19a	0.556 ± 0.009	1.000 ± 0.0003
	15	6.16 ± 0.14b	0.536 ± 0.010	0.999 ± 0.0002
	20	5.40 ± 0.58c	0.529 ± 0.009	0.999 ± 0.0003
	25	4.57 ± 0.28d	0.524 ± 0.009	0.999 ± 0.0004
75:25	10	1.94 ± 0.06e	0.633 ± 0.006	1.000 ± 0.0001
	15	1.64 ± 0.04ef	0.615 ± 0.023	1.000 ± 0.0000
	20	1.44 ± 0.11f	0.613 ± 0.022	1.000 ± 0.0001
	25	1.30 ± 0.05f	0.594 ± 0.006	0.999 ± 0.0003
50:50	10	0.347 ± 0.02g	0.761 ± 0.006	0.997 ± 0.0014
	15	0.325 ± 0.05g	0.720 ± 0.051	0.995 ± 0.0032
	20	0.281 ± 0.05g	0.729 ± 0.063	0.993 ± 0.0024
	25	0.269 ± 0.04g	0.704 ± 0.044	0.989 ± 0.0109

Mean ± standard deviation values of consistency coefficients followed by different small letters are significantly different (p < 0.05) by Duncan's multiple range test within the same column.

3.1.2 Influence of temperature on flow properties

During manufacturing of fried battered food especially at the batter coating stage, viscosity of batters plays an important role in the products. Since the influence of temperature on the apparent viscosity was examined in the previous discussion: the higher temperature provided the lower apparent viscosity of the batters. The apparent viscosity plotted against temperature of the batters revealed the lower values with increasing temperature as shown in Fig. 3.3 for all flour mixing ratios as expected. Apparent viscosity values of wheat flour based batter (mixing ratio of 100:0) decreased from 1240 to 710 mPa.s for 10 to 25°C, respectively. However, apparent viscosity of wheat flour based batter containing TS with mixing ratios of 75:25 and 50:50 decreased from 460 to 260 and 140 to 85 mPa.s, respectively.

The influence of temperature on the apparent viscosity at a specified shear rate of liquid or semi-solid foods can be calculated by using the Arrhenius equation (Pongsawatmanit et al., 2006) in equation (3.2) and (3.3)

$$\eta_a = \eta_\infty \exp\left(\frac{E_a}{RT}\right) \quad (3.2)$$

$$\ln \eta_a = \ln \eta_\infty + \left(\frac{E_a}{RT}\right) \quad (3.3)$$

Where η_a is the apparent viscosity at a specific shear rate, η_∞ is the frequency factor, E_a is the activation energy (J/mol), R is the gas constant (J/mol K), and T is the absolute temperature (K). When $\ln \eta_a$ at a shear rate of 50 s⁻¹ was plotted as a function of inverse temperature (Fig. 3.4), the change in apparent viscosity for all batters containing different mixing ratios of WF and TS with inverse temperature (1/T) obeyed the Arrhenius model and the linear regression coefficients (r^2) were higher than 0.95 (Table 3.2). The slopes of the plots were used to determine E_a from Arrhenius equation (3.2) reflecting the sensitivity of the viscosity change due to the temperature change. We found that E_a of the batters with and without TS were about 23 – 26 kJ/mol and appeared to be not significantly different (p>0.05, Table 3.2), indicating TS addition did not alter thermal stability of the batter systems.

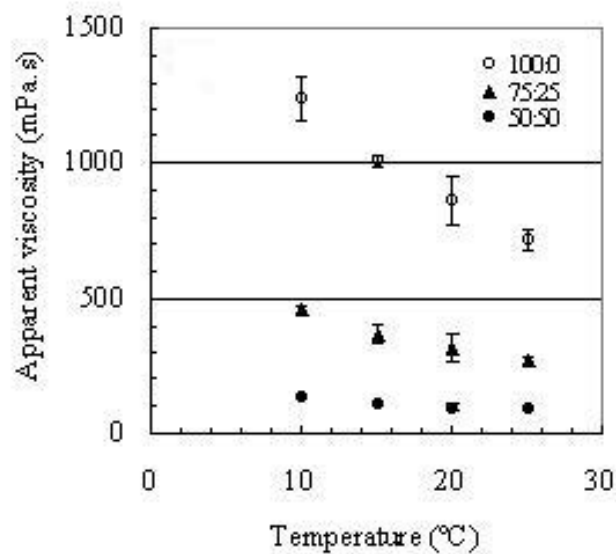


Fig. 3.3 Temperature dependence of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) at shear rate of 50 s^{-1} .

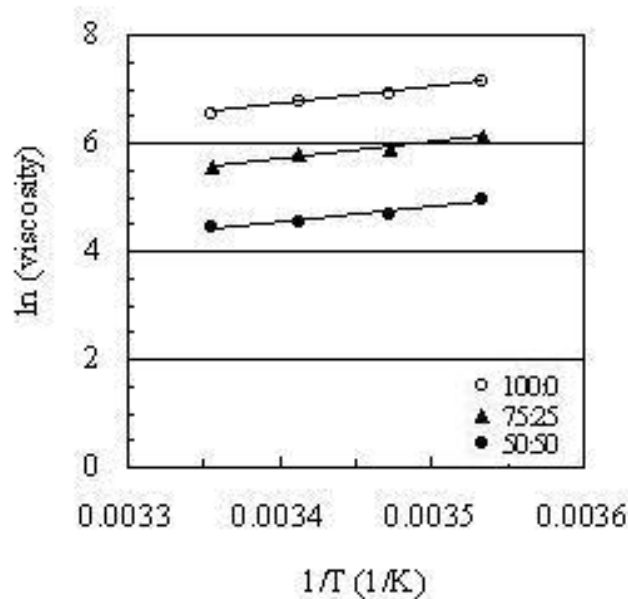


Fig. 3.4 Arrhenius plot of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) evaluated from selected shear rate at 50 s^{-1} .

Table 3.2 Activation energy of batters prepared from flour blends at different mixing ratios of WF and TS (100:0, 75:25 and 50:50) derived from the Arrhenius relationship and evaluated at shear rate of 50 s^{-1} .

Dispersion of WF: TS	Flour concentration (%)		E_a (kJ/mol)	r^2
	Wheat flour	Tapioca starch		
100:0	91.4	0.0	$25.7 \pm 6.1a$	0.998
75:25	68.55	22.85	$25.1 \pm 2.5a$	0.992
50:50	45.7	45.7	$22.7 \pm 1.0a$	0.951

Mean $\pm$ standard deviation values of activation energy followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

3.2 Effect of TS on thermal properties of batters and quality of fried battered chicken wingstick

3.2.1 RVA pasting properties of batter

RVA pasting properties were determined in order to evaluate the change in the viscosity of the batter during frying process. The total concentration of the batters to obtain RVA pasting profile should be lower than 15% from previous experiment tests. Therefore, prepared batters (WF:TS = 100:0, 75:25, 50:50) were diluted with water at the ratio of 1:2 to obtain 13.2% w/w total flour concentration. From RVA pasting profiles of diluted batter samples, RVA peak time decreased with increasing TS substitution (Table 3.3). Pasting temperatures of batters containing TS decreased significantly compared with that of WF-based batter. Peak viscosity of 13.2% batters increased with increasing TS substitution.

Table 3.3 RVA pasting parameters obtained from batters containing different flour blends of WF and TS at dilution 1:2 to obtain 13.2% total flour concentration.

Flour content	(%)	Peak Time	Pasting	Peak	Viscosity at	Final viscosity
WF	TS	(min)	temperature(°C)	viscosity (cP)	95°C 5 min (cP)	(cP)
13.2	0	11.2 ± 0.2a	85.4 ± 3.4a	4190±58d	3514 ± 149a	5915±86a
9.9	3.3	10.4 ± 0.1b	76.4 ± 0.5b	5142±37c	3474 ± 168a	5376±85b
6.6	6.6	8.7 ± 0.1c	76.1 ± 0.2b	5837±52b	2751 ± 77b	4343±68c
0	13.2	6.8 ± 0.1d	74.5 ± 0.3b	7437±69a	1871 ± 77c	3474±81d

Mean ± standard deviation values of RVA pasting parameters followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

The viscosity at the holding temperature period (95°C for 5 min) and final viscosity of 13.2% w/w total flour concentrations decreased with increasing TS substitution. The protein and gluten contents in WF was expected to play an important role in structure forming during heating. When temperature of batters increased, the aqueous protein in batter denatured leading to the unfolded protein molecules associated through intermolecular interaction to form aggregates of irreversible denatured molecules leading to gelation process (Damodaran, 1997).. The lower protein content in batter due to the higher TS substitution resulted in lower viscosity at holding the temperature at 95°C for 5 min and final viscosity at the end of RVA run.

3.2.2 Differential scanning calorimeter (DSC)

The DSC thermograms of batters prepared from mixed flour between WF and TS exhibited two main endothermic peaks (Fig.3.5). The first peak related to the gelatinization of WF fraction (T_{p1}) and gelatinization enthalpy was called ΔH_1 in this report (Table 3.4). The second peak of the DSC thermograms was the gelatinization of TS and called the peak temperature (T_{p2}) and enthalpy ΔH_2 . Since the gelatinization temperatures (T_o , T_p , T_c) of WF and TS exhibited in the range between the two main peaks leading to the first peak (WF fraction) is not completely separated from the second peak (TS fraction) (Fig. 3.5). T_{p1} and T_{p1} were about 71-72°C and 79-80°C (double peaks) whereas the batters prepared from only WF or TS exhibited the T_p at 70.6°C and 77.4°C, respectively.

. This observation of gelatinization of the batters with different mixing ratios of WF and TS from DSC measurement was different from those reported in RVA measurement due to the different concentrations and heating method, shear during heating.

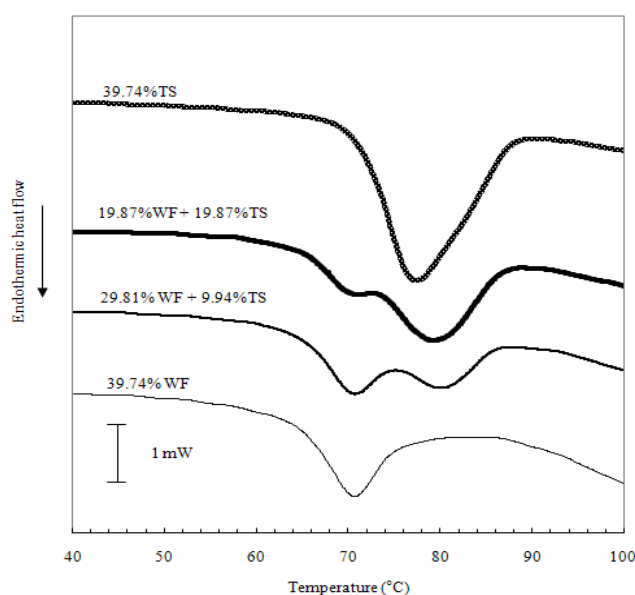


Fig. 3.5 Differential scanning calorimetry thermograms of batters prepared from flour blend containing WF and TS with different mixing ratios (100:0, 75:25, 50:50). The only TS batter was also prepared for comparison.

Table 3.4 DSC gelatinization temperatures and enthalpies of WF and TS based batters

Dispersions of WF:TS	Flour concentration (%) in batter		T_{o1} (°C)	T_{p1} (°C)	T_{p2} (°C)	T_{c2} (°C)	ΔH_1 (J/g dry starch)	ΔH_2 (J/g dry starch)
	WF	TS						
100:0	39.7	0	65.2±0.1a	70.6±0.0a	n.a.	81.9±0.1d	7.8±0.1a	n.a.
75:25	29.8	9.9	65.2±0.2a	70.7±0.1a	79.9±0.2a	85.8±0.0c	7.6±0.2a	14.4±0.5b
50:50	19.9	19.9	65.2±0.1a	71.9±1.3a	79.3±0.3b	86.6±0.1b	7.0±0.1b	15.1±0.3b
0:100	0	39.7	66.8±0.1b	n.a.	77.4±0.3c	87.5±0.2a	n.a.	16.2±0.4a

Mean ± standard deviation values of DSC gelatinization temperatures and enthalpy followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

3.2.3 Batter pickup and quality of fried battered chicken wingsticks

The batter pickup on chicken wingsticks controlled at 15 °C was selected. The result revealed that batter pickup decreased with increasing TS substitution ($p < 0.05$, Table 3.5) compared with that prepared from only WF based batter due to the lower viscosity (Fig. 3.3) due to the lower viscosity of the batters (Table 3.1). As expected, the higher WF concentration of batter cause a higher batter pickup. Cooking loss values of the fried batter chicken wingsticks with and without further oven heating after frying for 4 min from the batter containing TS were shown in Table 3.5. TS increased cooking losses of fried chicken wingsticks with and without further heating significantly compared with those without TS. The further heating of fried chicken wingsticks in the oven resulted in higher cooking loss than those without oven process but the process by lowering oil content in the fried samples.

Table 3.5 Batter pickup and cooking loss of WF based-batter formulations containing different TS contents on chicken wingstick at 15°C.

Dispersions of WF:TS	Flour concentration (%) in batter		Batter pickup (%)	Cooking loss (%)	
	WF	TS		Without oven heating	Oven heating
100:0	39.7	0	24.5 ± 0.3a	5.9 ± 0.8c	16.5 ± 1.1c
75:25	29.8	9.9	15.4 ± 0.2b	13.0 ± 0.8b	21.9 ± 2.0b
50:50	19.9	19.9	8.4 ± 0.2c	17.7 ± 0.1a	26.3 ± 1.1a

Mean ± standard deviation values of batter pickup and cooking loss followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

After the wingsticks dipped into the batters and were deep-fat fried at 167°C for 3 min to obtain the internal temperature about 75°C, the moisture of fried crust without oven heating were not significantly different with different WF and TS mixing ratios. The values exhibited the lower with increasing TS ($p < 0.05$, Table 3.6). Fat contents of pre-fried crusts obtained from 3 min frying with and without heating in oven shown in Table 3.6 and were lower with increasing TS substitution.

Table 3.6 Moisture and fat contents of fried battered crusts on chicken wingstick obtained from WF based-batter formulation containing various mixing ratios of WF and TS.

Mixing ratio of WF:TS	Flour concentration (%) in batter		Moisture content, db (%)		Fat content, db (%)	
	WF	TS	Without oven heating ^{NS}	Oven heating	Without oven heating	Oven heating
100:0	39.7	0	45.0 ± 2.6	51.2 ± 0.6a	50.3 ± 1.5a	48.7 ± 1.5a
75:25	29.8	9.9	41.4 ± 3.7	48.5 ± 2.5ab	47.6 ± 3.1a	43.4 ± 1.2b
50:50	19.9	19.9	40.7 ± 0.9	47.2 ± 0.4b	41.8 ± 0.6b	39.3 ± 0.3c

Mean ± standard deviation values of moisture and fat contents followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

From the sensory evaluation, sensory scores of appearance, color of product, thickness, adhesion, oil absorption, crispness and overall liking scores of final fried battered chicken wingsticks were shown in Table 3.7. The final fried product with TS substitution gave the higher overall liking score and oil absorption than those of WF-based batter ($p < 0.05$, Table 3.7).

Then the flour blend of WF and TS at mixing ratio of 1:1 was selected for determining the effect of hydrocolloids on the quality of fried battered chicken wingsticks.

Table 3.7 Sensory attribute scores of final fried battered chicken wingsticks

Dispersions of WF:TS	Appearance	Color of product	Thickness	Adhesion	Oil absorption	Crispness	Overall liking
100:0	5.8 ± 1.7b	5.7 ± 1.7b	6.0 ± 1.8b	5.9 ± 1.4b	4.5 ± 1.8b	7.2 ± 0.9a	6.1 ± 1.4b
75:25	7.4 ± 0.8a	7.6 ± 0.9a	7.2 ± 1.3a	7.1 ± 1.1a	5.7 ± 1.4a	7.6 ± 1.1a	7.3 ± 0.8a
50:50	7.5 ± 0.7a	7.6 ± 0.8a	7.3 ± 1.0a	7.3 ± 0.8a	6.5 ± 1.6a	7.5 ± 0.9a	7.3 ± 0.8a

Mean ± standard deviation values of sensory parameters followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

3.3 Quality of fried battered chicken wingstick prepared from wheat flour – tapioca starch blend with and without carboxymethylcellulose

Apparent viscosities of batters prepared from flour blend (WF: TS = 1:1) containing CMC (0-1%) at temperature 15°C were investigated after preparation for 1 h to ensure the complete starch swelling and fully hydration of CMC. The apparent viscosity of batters increased with increasing CMC concentration (Fig. 3.6).

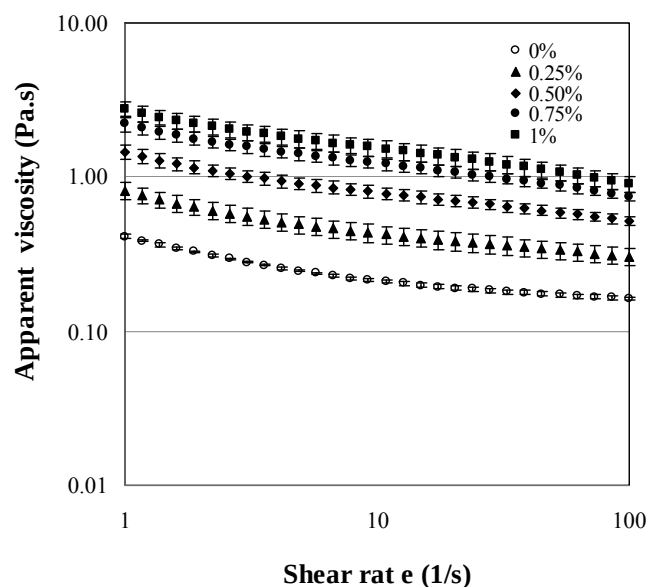


Fig. 3.6 Apparent viscosity of batters prepared from flour blend of WF and TS (1:1) and different CMC concentrations (0-1%) determined at 15°C.

The rheograms of the batters containing different CMC concentrations were plotted between shear stress and shear rate ($1-100 \text{ s}^{-1}$) at 15°C as shown in Fig. 3.7. All batters exhibited the shear-thinning behavior. The shear stress values of batters increased with increasing CMC concentrations. The power law equation (Eq. 3.1) was used to fix the flow behavior of these batter systems.

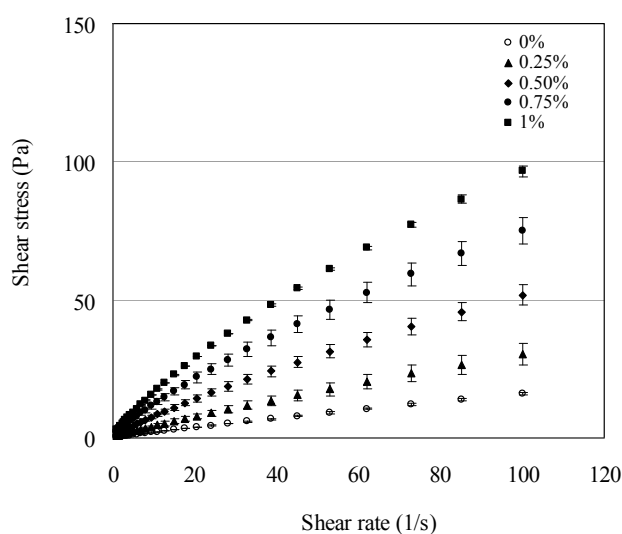


Fig. 3.7 Rheograms of batters containing CMC concentrations (0%, 0.25%, 0.5%, 0.75% and 1%) determined at 15°C

The power law equation was found to fix the batter formulations containing different CMC concentration ($r^2 > 0.99$). The consistency coefficient values of batter containing CMC were higher than batter without CMC (Table 3.8). The flow behavior index of the batters decreased with 1%CMC addition. CMC is a linear, long-chain, water-soluble hydrocolloids. Addition of water causes lower free water in the batter systems (Cancela, Alvarez and Maceiraas, 2005).

Table 3.8 Power law parameters (K = consistency coefficient, n = flow behavior index) of the batters containing CMC concentrations (0- 1%) mixing with water (1:1.3) determined from the shear rate 1-100 s^{-1} at 15°C.

CMC (%)	K (Pa.s)	$n(-)$	r^2
0	0.36±0.01e	0.806±0.010a	0.9966±0.0004
0.25	0.71±0.09d	0.801±0.004a	0.9976±0.0006
0.50	1.31±0.14c	0.794±0.007a	0.9970±0.0001
0.75	1.85±0.15b	0.793±0.009a	0.9991±0.0002
1.00	2.76±0.020a	0.778±0.004b	0.9992±0.0003

Mean $\pm$ standard deviation values of consistency coefficients followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

RVA pasting profiles were shown in Fig. 3.8 and the pasting parameters were shown in Table 3.9. The batters were diluted to obtain 13.2% total flour concentration. The additions of CMC in batters system did not alter pasting temperatures of all batters. Peak viscosity of batters decreased with CMC contents ($p < 0.05$, Table 3.9).

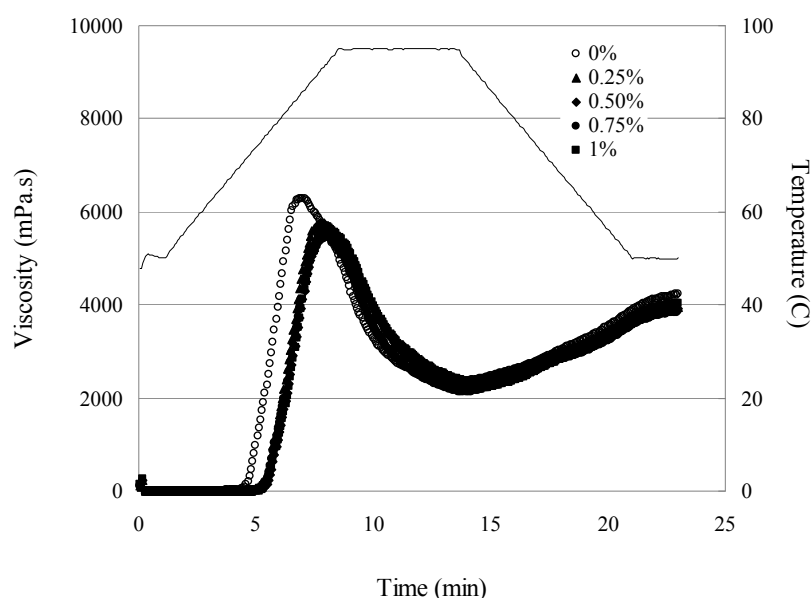


Fig. 3.8 RVA pasting properties of batters (diluted to have 13.2% total flour concentration) containing different CMC concentrations (0- 1%).

Table 3.9 The pasting properties of wheat flour and tapioca starch batter containing CMC.

CMC (%)	Peak Time (min)	Pasting Temp (°C)	Peak viscosity (mPa.s)	Final Viscosity (mPa.s)
0	7.67±0.07b	74.7±0.5a	6035±59a	4059±19a
0.25	7.80±0.07ab	75.0±0.3a	5768±3b	4019±68a
0.50	7.84±0.08a	74.9±0.2a	5748±31b	4029±20a
0.75	7.96±0.08a	74.9±0.2a	5653±11c	4017±6a
1.00	7.96±0.14a	75.1±0.4a	5631±38c	3982±67a

Mean ± standard deviation values of RVA pasting parameters followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

CMC addition (up to 1%) did not alter the double endothermic peaks of WF-TS batter (mixing ratio of 1:1) as shown in Fig. 3.9. The gelatinization temperatures (T_o , T_p , T_c) were shown in Table 3.10 without significant difference ($p > 0.05$).

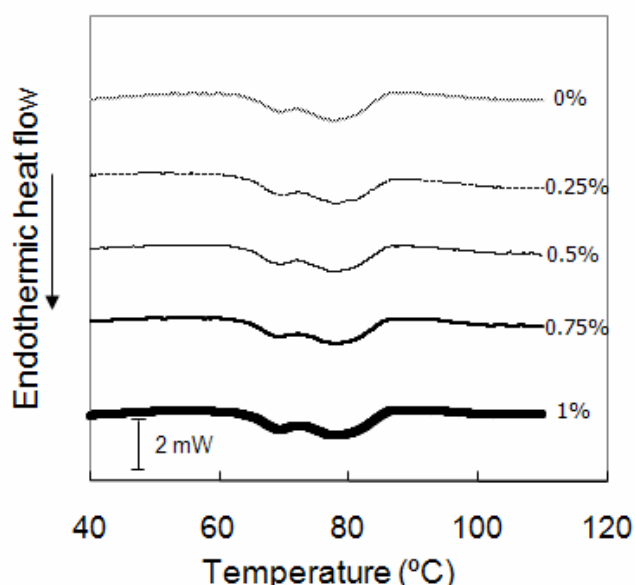


Fig. 3.9 Differential scanning calorimetry thermograms of batters prepared from flour blend WF and TS (1:1) containing different CMC concentrations at heating rate 2 °C/min.

Table 3.10 The gelatinization temperatures and enthalpy of batters containing CMC

CMC (%)	T_o (°C)	T_{p1} (°C)	T_{p2} (°C)	T_c (°C)	ΔH (J/g dry starch)
0.00	63.4±0.5a	69.4±0.5a	77.8±0.3a	85.5±0.2a	12.0±0.7a
0.25	63.5±0.3a	69.3±0.6a	77.7±0.5a	86.6±0.7a	12.4±0.4a
0.50	63.3±0.1a	69.4±0.3a	77.9±0.6a	86.2±0.2a	12.2±0.5a
0.75	63.1±0.5a	69.2±0.2a	78.3±1.3a	86.1±0.2a	12.3±0.6a
1.00	63.5±0.4a	69.6±0.1a	77.8±0.9a	86.1±0.5a	11.8±0.8a

Mean ± standard deviation values of DSC parameters followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

The batter pickup on raw chicken wingsticks (controlled temperature at 15°C) increased with increasing CMC addition (Table 3.11) compared with the batter without CMC. As expected, apparent viscosity correlated highly positively with batter adhesion on chicken wingsticks.

The moisture and fat contents of the pre-fried samples after 180°C for 4 min frying with further heating in oven (200°C for 4 min) were shown in Table 3.11. The higher concentrations of CMC addition increased the moisture content but decreased in fat content of the pre-fried chicken wingsticks.

Table 3.11 Batter pickup, moisture and fat contents of fried battered crusts on chicken wingstick obtained from flour blend of WF and TS (1:1) containing CMC.

CMC (%)	Batter pickup (%)	Moisture content (% db)	Fat content (% db)
0	8.1±0.4e	36.4±2.4c	47.2±2.3a
0.25	11.1±0.8d	37.5±6.4c	45.2±0.7ab
0.50	12.8±0.6c	42.0±2.3bc	44.1±1.5b
0.75	15.0±0.8b	47.6±1.8ab	43.1±1.5b
1.00	18.5±1.1a	53.0±5.1a	38.3±1.1c

Mean ± standard deviation values followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

After final frying the frozen pre-fried samples at 195°C for 3 min, sensory evaluation of selected treatments was carried out. The sensory scores from appearance, color of product, thickness, adhesion between crust and chicken wingstick skin, oil absorption, crispness and overall liking scores of final fried battered chicken wingstick were shown in Table 3.12. The results reveal that the overall liking scores were lowest in the product containing 1%CMC whereas those containing 0 and 0.5% CMC were not significantly different.

Table 3.12 Sensory attribute scores after frying for fried battered chicken wingsticks

CMC (%)	Appearance	Color of product	Crust thickness	Adhesion	Oil absorption	Crispness of crust	Overall liking
0	7.7±0.7a	7.6±0.8a	7.3±1.2a	7.4±1.1a	6.6±1.4a	7.5±0.8a	7.6±0.8a
0.5	7.3±1.1ab	7.5±1.2a	7.1±1.3ab	7.2±1.1a	5.4±1.9b	7.3±1.0ab	6.9±1.2a
1	6.8±1.1b	7.0±1.2a	6.4±1.6b	6.0±1.9b	3.8±1.8c	6.7±1.6b	5.8±1.8b

Mean ± standard deviation values of sensory scores followed by different small letters are significantly different ($p < 0.05$) by Duncan's multiple range test within the same column.

4. Conclusion

Flow curves of all batters prepared from 91.4% w/w flour blends at different mixing ratios of WF and TS (100:0, 75:25 and 50:50) mixed with water (flour blend: water = 1:1.3) showed shear thinning behavior. The viscosity of the batters decreased with increasing TS content as shown by steady shear measurements. The influence of temperature on the apparent viscosity of batters with and without TS can be described by the Arrhenius plot with activation energy (E_a) being not significantly different. The results from these studies provide the information related to batter pickup on the surface of the fried battered product for further application in food industry. Tapioca starch can be used in wheat flour-based batter to provide the lower batter uptake and oil content in the final fried product with the substitution up to 50%. CMC addition increase the viscosity and batter pickup with lower oil uptake. The overall liking scores were lowest in the product containing 1%CMC whereas those containing 0 and 0.5% CMC.

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14th World Congress of Food Science & Technology



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Dear Dr. Rungnaphar Pongsawatmanit,

On behalf of the Technical Program Committee, I thank you very much for your participation of the 14th World Congress of Food Science and Technology, which will be held in Shanghai on October 19-23, 2008.

Your presentation entitled "Influence Of Tapioca Starch On Properties Of Wheat Flour-Based Batter And Oil Uptake In Fried Product" (Abstract Number: T-0886) has been accepted for poster presentation by the Program Committee. Please prepare your poster within the frame of 0.9 meter wide and 1.2 meters high (the poster panel is 1.2 x 2.4 m) and see the final program for the location and time for poster setup and time of poster sessions on the Congress website.

Please log on the congress website www.iufost2008.org to register before Aug.15, 2008 to take the advantage of the early bird registration. You can also check the updates and the time of your presentation on the website once the program is finalized.

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INFLUENCE OF TAPIOCA STARCH ON PROPERTIES OF WHEAT FLOUR-BASED BATTER AND OIL UPTAKE IN FRIED PRODUCT

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Introduction:

Wheat flour is widely used as a functional ingredient in frying batter. Application of batter containing different flours provides unique flavors and textures in fried products. Tapioca starch (TS) produced from cassava roots, is a favorable thickener used in food industries due to its high viscosity, clear appearance, and low production cost, compared to other starches, especially in Thailand. Therefore, the objective of this study was to determine the effect of tapioca starch on the pasting properties of wheat flour-based batter and oil content in fried chicken wingstick.

Materials and Methods:

Commercial all-purpose wheat flour and tapioca starch were mixed at three different ratios of 100:0, 75:25 and 50:50. The dry-mixes were obtained from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%). The batters were prepared from dry-mix and water with the proportion of 1:1.3 (w/w) and kept for 1 h at 10 °C after well mixing. Chicken wingstick were dipped into batters and deep-fat fried in palm olein oil at 180 ± 5 °C for 3 min (internal temperature about 71-75°C). The RVA pasting properties of batter were evaluated by diluting with water in the ratios of 1:2 and 1:4 to obtain the total flour concentrations at 13.3 and 8% w/w, respectively. Fat content was extracted from ground battered piece samples using Soxtec extraction procedures.

Results and Discussion:

From RVA pasting profiles of diluted batter samples, peak viscosities and viscosity at the holding temperature period (95°C for 5 min) increased with increasing TS substitution for both 8 and 13.3 % w/w total flour concentrations. TS increased the moisture content and decreased fat contents (db) in the fried battered pieces. The results suggest that TS enhances the batter viscosity during heating leading to the higher moisture content and lower oil uptake in the fried product.

Rheological Properties of Wheat Flour-based Batter Containing Tapioca Starch

Soraya Ketjarut, Thongchai Suwonsichon and Rungnaphar Pongsawatmanit*

ABSTRACT

Batter properties are important in the development of fried battered products. In this study, the effects of tapioca starch (TS) and temperature on the viscosity of wheat flour-based batters were investigated. Flour blended (91.4%) from commercial all-purpose wheat flour (WF) and TS at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50), leavening powder (3.1%) and salt (5.5%) were mixed to obtain dry-mix. Batter was prepared by adding water (15°C) to the dry-mixes in the proportion of 1:1.3 (w/w) and kept for 1 h at 10°C before rheological property evaluation using a rotational viscometer at 10, 15, 20 and 25°C. The rheograms of all batters with different mixing ratios of flour exhibited shear-thinning behavior at all studied temperatures. The apparent viscosity of WF-based batter systems decreased with an increase in the substitution of TS and with temperature. The power law equation was a suitable representation of all batter formulations with different mixing ratios of WF and TS ($r^2=0.989-1.000$). Replacement of TS in batters decreased the consistency coefficient (K) but increased the flow behavior index (n). The activation energy values from the Arrhenius equation of the batters with and without TS were about 23-26 kJ/mol and not significantly different ($p>0.05$) suggesting that adding TS did not alter the thermal stability of the WF-based batters.

Key words: apparent viscosity, batter, Arrhenius equation, temperature, consistency coefficient, flow behavior index

INTRODUCTION

Batter application prior to deep-frying with fat is a widely used method for food preparation. Batter forms a continuous and uniform layer over the food surface and enhances the desired texture, flavor and appearance of foods. Usually, the batter is a liquid mixture comprised of water, flour, starch and seasonings. The consistency of the batter plays an important role in determining its performance in relation to the processes of pickup and frying, which influences

the final quality of the fried product (Hsia *et al.*, 1992; Shih and Daigle, 1999; Dogan *et al.*, 2005).

Application of batter containing different flours provides unique flavors and textures in fried products. The batter uniformity and thickness for coating on the food surface depend on the viscosity and temperature of the batter, which, in turn, determines the quality and acceptability of the fried product (Moreira *et al.*, 1999). Therefore, the viscosity of the batter applied to products deep-fried in fat is a critical coating characteristic that may affect the quantity and quality of batter

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pickup, appearance, texture, and the handling property of the coated products. Rheological property measurements are used to determine and monitor changes in the properties during batter coating and frying (Chang *et al.*, 1996). The factors that affect the rheological properties of batters are the composition and proportion of the ingredients, the solids-water relationship and temperature (Fiszman and Salvador, 2003).

Wheat flour (WF) is the most common flour used in batter systems (Loewe, 1993). However, other types of flour also have been studied in batter systems, such as rice flour (Shih and Daigle, 1999) and wheat-corn and corn-rice (Xue and Ngadi, 2007), to reduce the oil absorption after frying. Tapioca starch (TS) produced from cassava roots, is a favored thickener used in food industries due to its high viscosity, clear appearance and low production cost, compared to other starches, especially in Thailand (Pongsawatmanit *et al.*, 2006). Therefore, the objective of this study was to determine the effect of TS substitution on the viscosity of WF-based batters at different temperatures to gain more understanding of the rheological properties for further application in fried battered products.

MATERIALS AND METHODS

Materials

Commercial all-purpose wheat flour (WF), tapioca starch (TS) (Chorchaiwat Industry Co., Ltd, Thailand), leavening agent ($\text{Na}_2\text{H}_2\text{P}_2\text{O}_7/\text{NaHCO}_3$) and commercial refined salt were used

for batter preparation. Moisture contents of the WF and TS were determined as 12.65 and 11.52%, respectively, according to the methods of AOAC (1995). The protein content of WF, according to the manufacturer was 10.35%, whereas that of tapioca starch was 0.14% (AOAC, 1995).

Batter preparation

WF and TS were premixed at three different mixing ratios (WF:TS = 100:0, 75:25 and 50:50). The dry-mix was prepared from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) as shown in Table 1. Using a mixer, water (15°C) was added to the dry-mix, with the proportion of dry-mix to water being 1:1.3 (w/w) to obtain a homogeneous batter, which was kept at 10°C for at least 1 h before the measurement of rheological properties.

Rheological property measurement

The apparent viscosity of the prepared batters was measured as a function of shear rate and ranged from 2.5 to 62.5 s^{-1} at 10, 15, 20 and 25°C using a rotational viscometer (DV-III, Brookfield-RVT) with the coaxial cylinder geometry of the small sample adapter and the SC4-29 spindle. Sample temperatures were kept constant for at least 5 min before starting measurement. The flow characteristics of the batters were evaluated using a power law model. The effect of temperature on the rheological properties was determined using the Arrhenius equation.

Table 1 Dry-mix formulations for batter preparation with different mixing ratios of WF and TS.

Ingredient	Ingredients for each mixing ratio of WF and TS (%)		
	100:0	75:25	50:50
Wheat flour (WF)	91.4	68.55	45.7
Tapioca starch (TS)	0.0	22.85	45.7
Leavening powder	3.1	3.1	3.1
Salt	5.5	5.5	5.5

Statistical analysis

All measurements were performed at least in triplicate and mean values were reported with the standard deviation. Analysis of variance (ANOVA) was used to determine any significant differences among the treatment parameters associated with the rheological properties. Duncan's multiple range test was also applied to determine any differences of means ($p \leq 0.05$) from the ANOVA.

RESULTS AND DISCUSSION

Steady shear measurement

From the steady shear measurement, batters prepared from flour blends of WF and TS

(mixing ratios of 100:0, 75:25 and 50:50) mixed with water (dry-mix:water ratio = 1:1.3) were determined at 10, 15, 20 and 25°C after preparation for 1 h to ensure the complete swelling of starch granules. The rheograms of the batters with different mixing ratios of flour blends were plotted for shear stress and shear rate ($2.5\text{--}62.5\text{ s}^{-1}$) at 10, 15, 20 and 25°C as shown in Figure 1. All batters exhibited pseudoplastic behavior. At the same temperature, TS substitution in WF-based batters (WF:TS = 75:25 and 50:50) decreased the shear stress at the same shear rate. When the shear stress values of batters were measured at higher temperatures, shear stress values of the batters from each mixing ratio of flour blends were lower with increasing temperature.

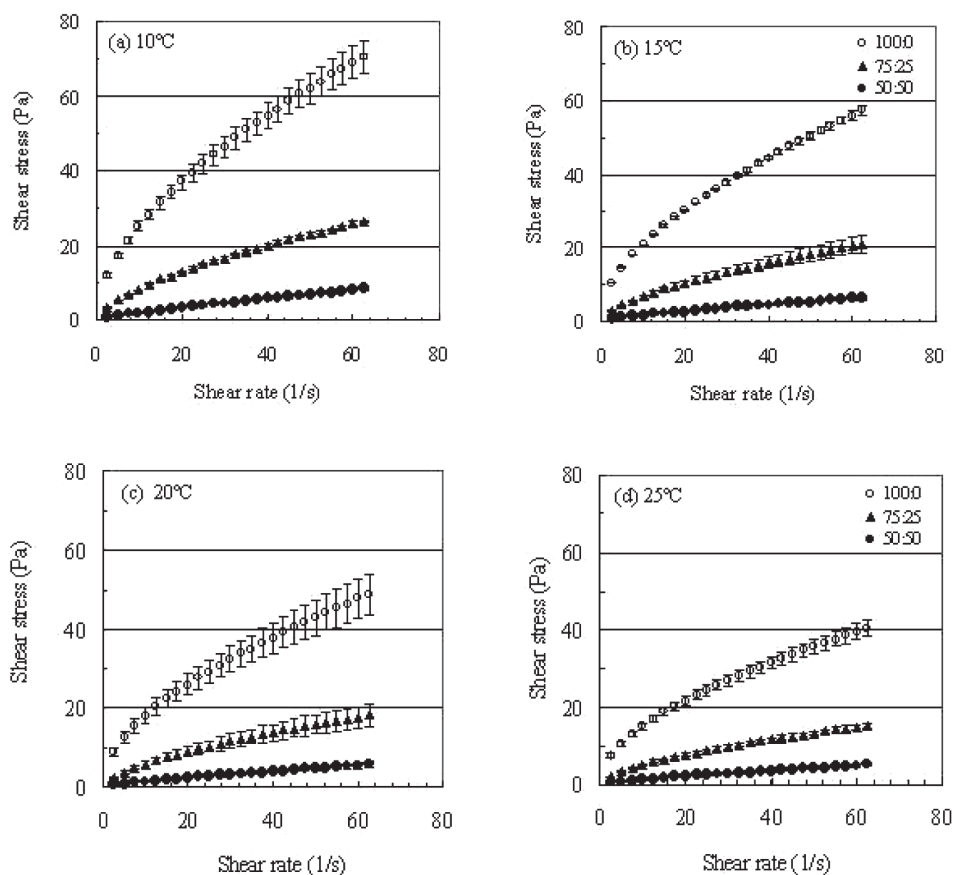


Figure 1 Rheograms of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at: (a) 10°C; (b) 15°C; (c) 20°C; and (d) 25°C.

The apparent viscosity of batters containing different mixing ratios of WF and TS (100:0, 75:25, 50:50) were investigated at temperatures ranging from 10 to 25°C. The apparent viscosity values of all batters decreased with increasing shear rate, TS substitution and temperature (Figure 2). The shear-thinning behavior (Figure 2) was exhibited in the middle region where the apparent viscosity was changing (decreasing for shear thinning) with shear rate. Thus, the power law equation (Equation 1) was suitable to describe the flow behavior of these batter systems.

$$\tau = K \dot{\gamma}^n \quad (1)$$

where τ = shear stress (Pa), $\dot{\gamma}$ = shear rate (s^{-1}), K = consistency coefficient ($\text{Pa}\cdot\text{s}^n$), and n = flow behavior index (Steffe, 1996).

The power law equation was found to model all batter formulations with different mixing ratios of WF and TS ($r^2 = 0.989 - 1.000$). The consistency coefficient values of WF-based batters without TS were higher than those containing TS (Table 2). The addition of TS in the batters altered the flow behavior index of the batter from 0.5 to 0.6-0.8 (Table 2). The results suggested that the batters containing TS exhibited more pronounced Newtonian behavior due to the flow behavior index more closely approaching a value of $n = 1$.

Influence of temperature on flow properties

During manufacturing of fried battered food, especially at the batter-coating stage, the viscosity of batters plays an important role in the quality of the fried products. The apparent

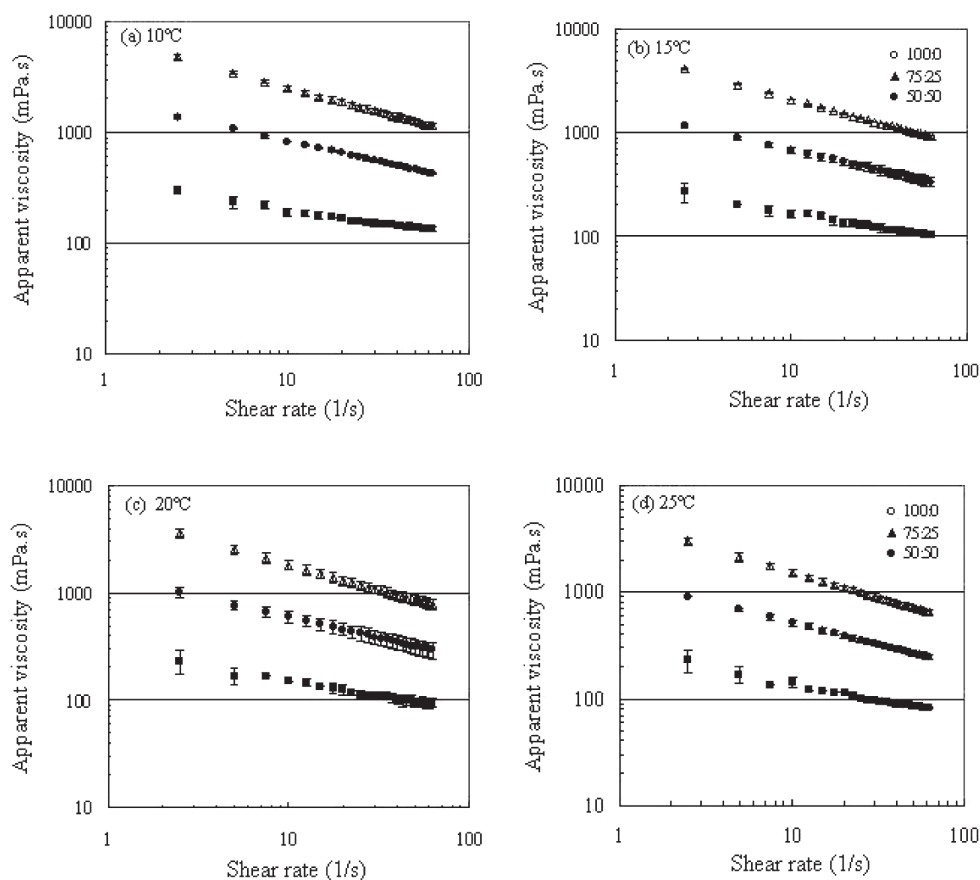


Figure 2 Apparent viscosity of batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined at: (a) 10°C; (b) 15°C; (c) 20°C; and (d) 25°C.

viscosity plotted against the temperature of the batters revealed that the viscosity was lowered with increasing temperature for all flour mixing ratios (Figure 3). The apparent viscosity values of the WF-based batter (mixing ratio = 100:0) decreased from 1,240 to 710 mPa.s as temperature was increased from 10 to 25°C, respectively. However, the apparent viscosity of WF-based batter containing TS with mixing ratios of 75:25 and 50:50, decreased from 460 to 260 and from 140 to 85 mPa.s, respectively.

The influence of temperature on the apparent viscosity at a specified shear rate of liquid or semi-solid foods can be calculated using the Arrhenius equation (Pongsawatmanit *et al.*, 2006) in Equations (2) and (3):

$$\eta_a = \eta_\infty \exp\left(\frac{E_a}{RT}\right) \quad (2)$$

$$\ln \eta_a = \ln \eta_\infty + \left(\frac{E_a}{RT}\right) \quad (3)$$

where η_a is the apparent viscosity at a specific shear rate, η_∞ is the frequency factor, E_a is the

activation energy (J/mol), R is the gas constant (J/mol K), and T is the absolute temperature (K).

When $\ln \eta_a$ at a shear rate of 50 s⁻¹ was plotted as a function of 1/ T (Figure 4), the change in apparent viscosity for all batters containing

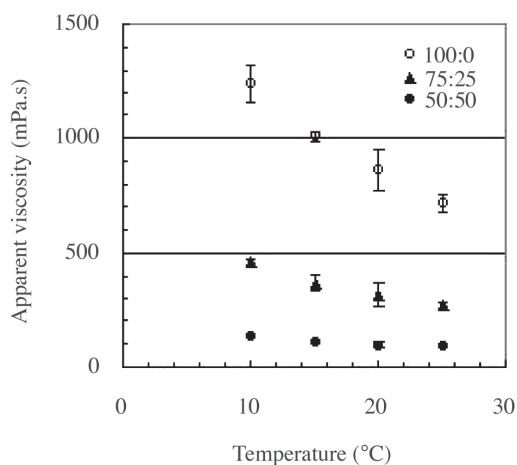


Figure 3 Temperature dependence of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) at shear rate of 50 s⁻¹.

Table 2 Power law parameters (K = consistency coefficient, n = flow behaviour index) of the batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) determined from the shear rate ranged from 2.5 to 62.5 s⁻¹ at 10, 15, 20 and 25°C.

WF:TS	Temperature (°C)	K (Pa.s ^{n})	n (-)	r^2
100:0	10	7.03 ± 0.19a	0.556 ± 0.009	1.000 ± 0.0003
	15	6.16 ± 0.14b	0.536 ± 0.010	0.999 ± 0.0002
	20	5.40 ± 0.58c	0.529 ± 0.009	0.999 ± 0.0003
	25	4.57 ± 0.28d	0.524 ± 0.009	0.999 ± 0.0004
75:25	10	1.94 ± 0.06e	0.633 ± 0.006	1.000 ± 0.0001
	15	1.64 ± 0.04ef	0.615 ± 0.023	1.000 ± 0.0000
	20	1.44 ± 0.11f	0.613 ± 0.022	1.000 ± 0.0001
	25	1.30 ± 0.05f	0.594 ± 0.006	0.999 ± 0.0003
50:50	10	0.347 ± 0.02g	0.761 ± 0.006	0.997 ± 0.0014
	15	0.325 ± 0.05g	0.720 ± 0.051	0.995 ± 0.0032
	20	0.281 ± 0.05g	0.729 ± 0.063	0.993 ± 0.0024
	25	0.269 ± 0.04g	0.704 ± 0.044	0.989 ± 0.0109

Mean ± standard deviation values of consistency coefficients within the same column followed by different lower case letters are significantly different ($p < 0.05$) by Duncan's multiple range test.

different mixing ratios of WF and TS followed the Arrhenius model and the linear regression coefficients (r^2) were higher than 0.95 (Table 3). The slopes of the plots were used to determine E_a from the Arrhenius equation (Equation 3), reflecting the sensitivity of the viscosity to temperature. The E_a values of the batters, with and without TS, were about 23-26 kJ/mol and were not significantly different ($p > 0.05$, Table 3), indicating the addition of TS did not alter the thermal stability of the batter systems.

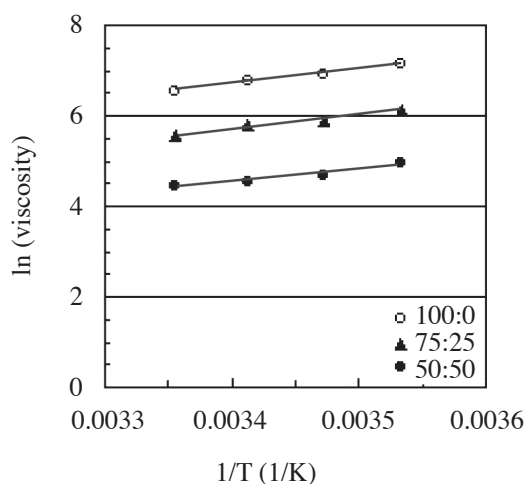


Figure 4 Arrhenius plot of apparent viscosity for batters prepared from flour blends (WF:TS = 100:0, 75:25 and 50:50) evaluated from selected shear rate at 50 s^{-1} .

CONCLUSION

Flow curves of all batters prepared from dry-mixes containing flour blends of WF and TS at different mixing ratios (100:0, 75:25 and 50:50) showed shear thinning behavior. The viscosity values of the batters decreased with increasing TS content as shown by steady shear measurements. The influence of temperature on the apparent viscosity of batters, with and without TS, could be described by the Arrhenius equation and the activation energy (E_a) was not significantly different. The results from these studies have provided information related to batter pickup on the surface of fried battered products that could be further applied in the food industry.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge financial support from the Thailand Research Fund (TRF) through the Royal Golden Jubilee Ph.D. Program and the Kasetsart University Research Development Institute (KURDI), Kasetsart University.

Table 3 Activation energy of batters prepared from flour blends at different mixing ratios of WF and TS (100:0, 75:25 and 50:50) derived from the Arrhenius relationship and evaluated at shear rate of 50 s^{-1} .

Dispersions of WF: TS	Flour concentration (%)		E_a (kJ/mol)	r^2
	Wheat flour	Tapioca starch		
100:0	91.4	0.0	$25.7 \pm 6.05a$	0.998
75:25	68.55	22.85	$25.1 \pm 2.50a$	0.992
50:50	45.7	45.7	$22.7 \pm 1.01a$	0.951

Mean $\pm$ standard deviation values of activation energy values within the same column followed by different lower case letters are significantly different ($p < 0.05$) by Duncan's multiple range test.

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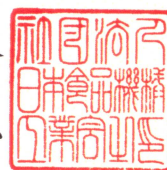
表 彰 状

Kasetsart University
Rungnaphar Pongsawatmanit 殿

FOOMA JAPAN 2009 アカデミックプラザに
おいて厳正なる審査の結果 貴研究室の研究発表
タピオカデンプン混合小麦粉バターのレオロジー特性
がフライドチキン品質に及ぼす影響について
が優秀であると認められました
よってここに FOOMA AP 特別賞を授与
いたします

2009 年 6 月 11 日

社団法人 日本食品機械工業会
会 長 尾 上 昇





Summary report of the Academic Plaza 2009

June 9~12 2009, TOKYO BIG SIGHT

Organized by JAPAN FOOD MACHINERY MANUFACTURERS' ASSOCIATION (JFMA)

Participating laboratory : 71 laboratories

Preparation booth : 66 booths

Oral announcement : 35 sessions

(The auditor of an oral announcement : 1,975 persons of a total)

1 . About a participating laboratory

Participation of 71 laboratories (joint statement 5 it contains) which serve as the greatest ever number of participation following last year was obtained, and 66 booths were prepared.

Overseas to participation was 13booths among them. (The United States 2, Canada 1, China 2, South Korea 6, Thailand 1, and New Zealand 1)

Moreover, new participation was 7 laboratories.

[Transition of a participating laboratory]

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Booths	43	49	50	54	54	57	59	60	60	66
Laboratories	48	51	52	59	60	65	66	72	70	71
Overseas	6	9	10	13	13	13	15	12	14	15



3.FOOMA AP Prize

6 laboratories were chosen based on vote by the technical committee of JFMA, the visitor, and the representative of each participating laboratory.

The commendation ceremony was held in the academic plaza friendship party held on the evening of June 11.



[Award laboratories]

*Grand Prix

Group of Three-dimensional Bio-Structure Modeling, College of Bioresource Sciences Nihon University

Three-Dimensional Measuring Technique of Water, Bubbles and Structure in Foods Electricity

*Semi Grand Prix

Laboratory of Food Engineering, Department of Biofunctional Science and Technology, Graduate School of Biosphere Science, Hiroshima University

Development of in-line system for deterioration extent measurement of fly oil

Department of materials science and chemical engineering, Shizuoka University

Drying in Superheated Steam Fluidized Bed under Reduced Pressure

ITOH Lab., Shock Wave and Condensed Matter Research Center, Kumamoto Univ.

WATANABE Lab., Dept. of Ocean Mechanical Eng., National Fisheries Univ.

IYAMA Lab., Dept. of Mechanical and Electrical Eng., Yatsushiro National College of Tech.

Food processing technology that uses shockwave

*Special Theme Award

Lab. of Food Process Engineering, Dept. of Bioscience and Biotechnology, Kyushu University

Rapid Hygrothermal Pasteurization by Using Water Vapor at Saturation

*Special Award

Department of Product Development, Faculty of Agro-Industry, Kasetsart University

Rheological properties of wheat flour-based batters containing tapioca starch on the quality of fried chicken wingsticks

5 .The zone of a theme specially

A study about “Food safety and sterilization technology, we need for our bright future” was made into the theme of a special zone.

This theme had many requests of a visitor every year, and 15 laboratories participated this year.



F O O M A J A P A N 2009

International Food Machinery and Technology Exhibition 2009

アカデミックプラザ

Academic Plaza

研究発表要旨集 VOL.16

The Summaries of Research Announcements Vol.16

会 期：2009年6月9日(火)～12日(金)

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Rheological properties of wheat flour-based batters containing tapioca starch on the quality of fried chicken wingsticks

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Abstract

Batter properties are important for developing better qualities of fried products. In this study the effect of tapioca starch addition on viscosity of batters and oil content in fried chicken wingstick was investigated. Commercial all-purpose wheat flour and tapioca starch were premixed at three different mixing ratios of 100:0, 75:25 and 50:50. The dry-mix prepared from flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) was mixed with cool water in the proportion of 1:1.3 (w/w) to obtain batter and kept for 1 h at 10 °C before battering. The viscosity of batters decreased with increasing temperature and tapioca starch content. The percentage of batter pickup on chicken wingstick decreased with increasing tapioca starch substitution in wheat flour based batter. After frying battered wingsticks at 180±5 °C for 3 min, the substitution of TS decreased fat contents in the fried battered pieces. Fat contents in fried products revealed the lower values with further oven heating and more tapioca starch substitutions.

Introduction

Batter is a liquid mixture comprised of water, flour, starch, and seasonings. Food products are usually dipped into the batter prior to deep-fat frying aimed at sealing the food in order to retain all flavors and juiciness under a crisp crust (Rosana et al., 1999; Fiszman et al., 2003). However, for more sophisticated foods in food industry, automation of manufacturing and product diversification, the concern to develop fried product with less oil content are important in product development stage.

Application of batter containing different flours provides unique flavors and textures in fried products. The amount of batter coating on food surface depending on viscosity and temperature of batter determines the quality of fried product. Tapioca starch (TS) produced from cassava roots, is a favorable thickener used in food industries due to its high viscosity, clear appearance, and low production cost, compared to other starches, especially in Thailand (Pongsawatmanit et al., 2006). Therefore, the objective of this study was to determine the effect of tapioca starch on the viscosities of wheat flour-based batters at different temperatures and oil uptake in fried chicken wingsticks.

Materials and methods

Commercial all-purpose wheat flour and tapioca starch were mixed at different ratios (100:0, 75:25 and 50:50). The obtained flour blend (91.4%), leavening powder (3.1%) and salt (5.5%) were mixed with water at the proportion of 1:1.3 (w/w) and kept for 1 h at 10 °C after well mixing. Viscosity values of the batters were measured as a function of shear rate at 10, 15, 20 and 25 °C using Brookfield viscometer (DV-III). Batter pickup of batter maintaining at 15 °C coated on chicken wingsticks used as

a food model was determined before frying according to the method of Mukprasirt (2001). The battered wingsticks were deep-fat fried in palm olein oil at 180 ± 5 °C for 4 min (to obtain the internal temperature about 75°C) with and without oven heating (150 °C for 8 min). Oil uptake was determined from ground fried battered pieces by extracting with petroleum ether using Soxtec™ Avanti 2050 automated extraction system.

Results and discussion

The apparent viscosities of batters containing different mixing ratios of wheat flour and tapioca starch (100:0, 75:25, 50:50) at temperature 10 to 25°C were investigated after preparation for 1 h to ensure the complete swelling of starch granules. The apparent viscosity of batters decreased with increasing tapioca starch substitution and the temperature (Fig.1).

The batter pickup on chicken wingsticks controlled at 15 °C was selected. The result revealed that batter pickup decreased with increasing tapioca starch substitution ($p < 0.05$, Table 1) compared those prepared from only wheat flour based batter due to the lower viscosity (Fig. 1).

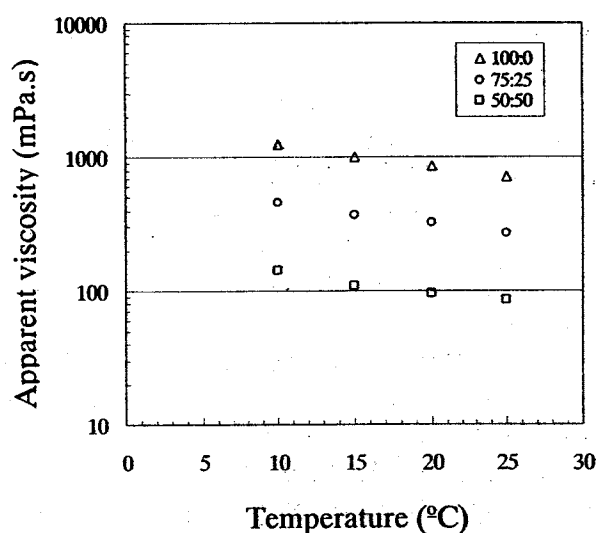


Figure 1 Apparent viscosity as a function of temperature of batters prepared from various mixing ratios of wheat flour and tapioca starch (100:0, 75:25, 50:50) at shear rate 50 s^{-1} .

Table 1 Batter pickup of wheat flour based-batter formulation containing tapioca starch on chicken wingstick at 15°C (the batter prepared from 91.4% total flour blend, 3.1% leavening powder and 5.5% salt and mixed with water at the proportion of 1:1.3)

Flour blend mixes (%)		Batter pickup (%)
Wheat flour	Tapioca starch	
100	0	$24.50 \pm 0.31\text{a}$
75	25	$15.35 \pm 0.17\text{b}$
50	50	$8.41 \pm 0.21\text{c}$

* Means $\pm$ SD values ($n = 3$) followed by different letters within the same column are significantly ($p < 0.05$) different.

After the battered wingsticks were deep-fat fried at 180 ± 5 °C for 4 min to obtain the internal temperature about 75°C, fat contents in the fried crust were determined. The result revealed that oil uptake decreased with increasing tapioca starch substitution. Further oven heating at 150 °C for 8 min showed a lower fat contents in ground fried crusts and showed a lower oil uptake with higher substitution of tapioca starch (Table 2).

Table 2 Fat contents of fried battered crusts on chicken wingstick obtained from wheat flour based-batter formulation containing various mixing ratios of wheat flour and tapioca starch.

Flour blend mixes (%)		Fat content (% db)	
Wheat flour	Tapioca starch	Without oven heating	Oven heating
100	0	$50.32 \pm 1.51a$	$48.67 \pm 1.54a$
75	25	$47.64 \pm 3.07a$	$43.42 \pm 1.23b$
50	50	$41.79 \pm 0.59b$	$39.31 \pm 0.26c$

* Means $\pm$ SD values (n = 3) followed by different letters within the same column are significantly (p < 0.05) different.

Conclusion

Tapioca starch can be used in wheat flour-based batter to provide the lower batter uptake and oil content in the final fried product.

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