Effects of microwave rendering on the yield and characteristics of chicken fat from broiler abdominal fat tissue

Liyan Zhang · Bi Yin · Hanming Rui

Revised: 2 June 2011 / Accepted: 16 June 2011 / Published online: 29 June 2011

© Association of Food Scientists & Technologists (India) 2011

Abstract Microwave rendering process and effects of rendering conditions on yields and characteristics of chicken fat from broiler abdominal fat tissue were studied. Microwave rendering process could be divided into three phases: warming-up, constant temperature and heating-up phases. Increasing microwave power increased the rate of temperature rise and final temperature of chicken fat, shortened the duration of warming-up and constant temperature phase, and decreased the moisture content of chicken fat. Longer irradiation time resulted in higher final temperature, lower moisture content and darker, browner color of chicken fat. The chicken fat rendered at power level of 2.75 W/g for 10 min had the highest yield (70.55%) with the lowest peroxide value, acid value and thiobarbituric acid value ($p < 0.05$). The major fatty acids in chicken fat obtained at optimum conditions were oleic acid (45.73%), palmitic acid (26.13%), linoleic acid (15.12%), palmitoleic acid (6.07%), and stearic acid (5.81%).

Keywords Broiler abdominal fat · Microwave rendering · Process · Yield · Characteristic

Introduction

Chicken fat can be used as cooking oil to increase the taste of dishes or as raw materials to manufacture chicken powder (Lin 1998) and biodiesel fuel (Ding et al. 2007). In food industry, chicken fat is usually rendered from chicken depot fat tissue including abdominal fat tissue or skin fat (Li and Bi 2009) etc.

Rendering can refer to the processing of whole animal fatty tissue into purified fats like lard or tallow. There are various rendering methods, including dry rendering, wet rendering and frying (Hui 2001; Pereira et al. 1976; Sheu and Chen 2002). Nowadays, wet rendering is more popular than dry rendering in industry and the fat yielded has less free fatty acids (Hui 2001). It is more energy efficient and allowed the re-use of process vapors to pre-heat or dry the materials during the process. But the production and separation of emulsion layer are the main problems affecting the application of wet rendering. Microwave rendering is a good method to render fat with high quality. There is no emulsion layer and it is easier to separate the fat from greaves. Sheu and Chen (2002) compared the yield and quality of chicken fat by microwave rendering from broiler skin with dry rendering, wet rendering and frying. The results showed that the highest yield and the lightest colored broiled skin fat could be obtained by microwave rendering, and the oxidation during rendering was weaker.

Few researches on microwave rendering of animal fat were carried out in recent years. Broiler abdominal fat tissue is a by-product from poultry industry and it can be rendered for the manufacture of chicken fat. The aim of the present study was to investigate the microwave rendering process and the effects of conditions (microwave power

Supported by 2010 fund project of Industry-Universities- Research Institutes Collaboration, which is co-sponsored by Guangdong Provincial Government and Chinese Ministry of Education (2010B 090400475).

L. Zhang (✉) · B. Yin · H. Rui
Department of Food Engineering, College of Light Industry and Food Sciences, South China University of Technology,
Guangzhou 510640 Guangdong Province, China
e-mail: zhly_ziyu@yahoo.com.cn

level and irradiation time) on the yields and characteristics of chicken fat from broiler abdominal fat issue.

Materials and methods

Materials

Broiler abdominal fat tissue (BAF) was kindly supplied by Liuhe Co., Ltd, Shandong Province, China. The BAF was grinded, mixed thoroughly and stored at -20°C . Before rendered, the frozen BAF was thawed for about 3 h at room temperature. All other chemicals and solvents used were purchased from commercial sources and were analytical grade.

Microwave rendering of BAF

Grinded BAF was placed evenly into a round ceramic container and irradiated in a Microwave Work Station (FISO Technologies Inc., Canada). The temperature during rendering was determined by fiber optic sensors and recorded by FISO Commander Workstation Software. Microwave (MW) power level and irradiating time were the key factors affecting the yield and characteristics of fat from the BAF. The power levels selected in this study were 2.00 W/g, 2.25 W/g, 2.50 W/g, 2.75 W/g and 3.00 W/g respectively. At the power level of 2.75 W/g, BAF was irradiated for 6, 8, 10, 12 and 14 min respectively.

Yields of chicken fat

The yield of chicken fat (CF) was defined as the percentage of the weights of CF rendered in the weights of raw BAF.

Measurement of moisture content in BAF and CF

BAF or CF samples (7.5 g) were weighed into an aluminum dish and dried at 105°C to a constant weight. The percentage of moisture was then calculated (Sheu and Chen 2002). The measurements were conducted in three replications.

Assay of acid value, peroxide value of CF

Standard AOAC (1995) method was used to assay the acid value (AV) and peroxide value (PV) of CF. The measurements were conducted in three replications.

Assay of 2-thiobarbituric acid value of CF

TBA (thiobarbituric acid) assay was based on the reaction between TBA and MDA (malondialdehyde) and the production of a colored pigment (Fasseas et al. 2007). A distillation method described by Witte et al. (1970) was

followed to assay the TBA value of CF. The TBA values were expressed by mg malondialdehyde (MDA) per 1 kg CF. All measurements were conducted in triplicate.

Colour measurement of CF

The CIE coordinates L^* , a^* , b^* of raw and cooked muscle samples were directly measured with a tristimulus colorimeter (Minolta, Osaka, Japan) equipped with a CR 400 measuring head, a CIE C light source and the observer at 25°C . The colorimeter was calibrated on a standard white tile ($L^*=93.5$; $a^*=0.3114$; $b^*=0.3190$) before each series of measurements. All measurements were conducted in triplicate.

Measurement and analysis of fatty acid composition from BAF and CF

Fat extraction in BAF was carried out according to the modified procedure described by Wang et al. (1993). A BAF sample (10 g) was mixed with 30 ml of $\text{CHCl}_3\text{-CH}_3\text{OH}$ (2:1) and incubated at 60°C for 1 h. Then the mixture was centrifuged at 3000 r/min for 5 min. The upper phase was separated and esterified by methyl. The CF rendered was filtrated and esterified directly.

The method of methyl esterification was modified as described by Cobos et al. (2000). A fat sample (20 μl) was mixed with 5 ml of 0.5 M KOH aqueous solution and incubated at 70°C for 10 min. After cooled, the sample was esterified in 3 ml of 14% $\text{BF}_3\text{-CH}_3\text{OH}$ at 70°C for 5 min. The fatty acid methyl ester was extracted by adding 2 ml of hexane and 2 ml of saturated NaCl solution, and fractionated by using a gas chromatograph equipped with a mass spectrometric (GC-MS) analysis.

A 50% cyanopropyl methyl polysiloxane (0.25 mm $\times$ 30 m $\times$ 0.25 μm) column was used in gas chromatograph (GC) analysis. The column was operated at 175°C and injector temperature was kept at 250°C . The helium was used as carrier gas at a flow rate of 4.8 ml/min and a pressure of 11.72 psi. The conditions of mass-spectrograph (MS) was set as follow: energy, 70 eV; mass source temperature, 230°C ; low mass, 33; max mass, 400; ms database, NIST05a.

Statistical analysis

All measurements were conducted in triplicate except the measurement of fatty acid composition from BAF and CF. The data were analyzed by the Analysis of Variance procedure (ANOVA) of the Statistical Product and Service Solutions software package (SPSS). Duncan's multiple range test (Duncan 1955) was used to separate the means when significant differences occurred.

Fig. 1 Temperature curves of samples at various microwave power levels for 10 min. Each value represents the mean of three observations

Results and discussion

Influence of MW power level on the yield and characteristics of CF rendered

Temperature curves at various MW power levels

Like MW drying in food and agricultural industry, MW rendering is mainly influenced by irradiation time and MW power (Abhijit et al. 2003, 2004; Adedeji et al. 2009; Li et al. 2010; Sheu and Chen 2002). Those two factors significantly affect the rendering parameters, including rendering temperature, rendering curve, rendering speed, rendering efficiency and the quality of final fat. The temperatures of BAF and CF during MW irradiation at various power levels were recorded and shown in Fig. 1. Since MW is irradiated like pulses in the workstation used in this research, the temperature curves displayed like waves.

The curves in Fig. 1 implicated that at a fixed MW power level, the whole MW rendering process could be divided into three phases like MW drying according to the temperature variations: warming-up phase, constant temperature phase and heating-up phase (Bilbao-Sáinz et al. 2006; Cheng et al.

2006.; Li et al. 2010; Lu et al. 1999). In warming-up phase (Phase I), the temperature of BAF increased from room temperature (about 13 °C) to about 98–100 °C in a time between 111.2 s (3.00 W/g) and 148.8 s (2.00 W/g), and the rates of temperature rise at those five power levels were all faster than 0.60 °C/s (Table 1). Water in BAF was the major medium that absorbed the microwave energy and transformed it to sensible heat for temperature rise in phase I. During the constant temperature phase (Phase II), temperature of sample (mixture of BAF and CF) was kept at about 100 °C for a few minutes. In phase II, the heat transformed from MW energy was mainly used as latent heat for the water evaporation in sample. With the moisture content in sample decreasing and the structure of fat tissue being destroyed, fat was exuded from the tissue. In the heating-up phase (Phase III), since the moisture content in BAF and CF was low, part of the heat transformed was used to heat the CF. This was the reason why the temperature of samples increased slowly. Compared with phase I, it was CF that mainly absorbed the microwave energy and transformed it to sensible heat for the temperature rise in phase III. Because the dielectric constant and loss factor of food material increased with increasing water content (Datta and Anantheswaran 2001), the rate of temperature rise in phase I was much higher than that in phase II in which the rates of temperature rise ranged from 0.15 °C/s to 0.22 °C/s at the power levels from 2.00 W/g to 3.00 W/g (Table 1). It could also be observed from Fig. 1 and Table 1 that the stronger the MW power was, the faster the temperature rise, the higher the final temperature of CF and the shorter the duration of phase I and II were ($P < 0.05$). There were no significant differences between the rates of temperature rise at power levels of 2.75 W/g and 3.00 W/g in phase I and III ($P < 0.05$).

Yields and characteristics of CF rendered at various power levels

The yields of CF increased as MW power increased. The highest yield of CF, 70.78%, was obtained at power level of

Table 1 Rates of temperature rise, duration of three phases and final temperature of samples at various MW power levels for 10 min^{a,b}

Power level (W/g)	Rates of temperature rise (°C/s)		Duration (s)			Final temperature (°C)
	Phase I	Phase III	Phase I	Phase II	Phase III	
2.00	0.61±0.012 ^d	0.15±0.006 ^d	148.8±1.2 ^a	358.0±2.5 ^a	95.6±1.8 ^c	113.8±1.0 ^d
2.25	0.63±0.006 ^c	0.17±0.006 ^c	142.0±1.4 ^b	296.0±1.8 ^b	164.4±3.2 ^d	129.7±4.0 ^c
2.50	0.66±0.009 ^b	0.19±0.004 ^b	123.2±0.7 ^c	271.2±1.2 ^c	208.0±0.7 ^c	133.7±2.1 ^c
2.75	0.76±0.001 ^a	0.21±0.003 ^a	113.6±1.4 ^d	258.6±2.5 ^d	230.2±1.8 ^b	146.0±3.0 ^b
3.00	0.77±0.008 ^a	0.22±0.006 ^a	111.2±0.7 ^e	215.2±0.7 ^e	276.0±0.0 ^a	162.3±8.0 ^a

^a Each value represents the mean of three observations

^b abc Means within a row with different superscript letters are different ($p < 0.05$)

Fig. 2 The yields of CF rendered at various power levels for 10 min. Each value represents the mean of three observations. Values with different letters were significantly different ($P < 0.05$)

2.75 W/g. No difference in yield was observed between 2.75 W/g and 3.00 W/g (Fig. 2, $P < 0.05$). Since the crude fat content in BAF was about 72–73% that was measured by Soxhlet extraction, the result of yields implied that almost all fat was rendered from BAF at the power level from 2.75 W/g to 3.00 W/g. In this study, the fat recover rate of CF from BAF was 96.5% which was higher than that from broiler skin fat (92.2%) reported by Sheu and Chen (Sheu and Chen 2002).

The moisture content, AV, PV and TBA values of CF obtained at various power levels were shown in Table 2. During microwave irradiation, the water in BAF exuded out with CF or evaporated especially when the temperature was exceeded 100 °C. The water evaporation and removal were related with temperature which was affected by MW power. It was obvious that with power level increasing, the temperature of samples increased and the moisture content

Table 2 Characteristics of CFs rendered at various power levels for 10 min^{a,b}

Power level (W/g)	Moisture content (%)	TBA ^c value	PV ^d (meq/kg)	AV ^e (mgKOH/g)
2.00	2.33±0.06 ^a	0.43±0.011 ^a	7.49±0.12 ^a	1.60±0.07 ^a
2.25	1.57±0.06 ^b	0.32±0.002 ^b	5.52±0.12 ^b	1.57±0.02 ^a
2.50	1.50±0.10 ^b	0.11±0.009 ^c	4.34±0.12 ^c	1.33±0.10 ^b
2.75	–	0.08±0.003 ^d	3.39±0.04 ^d	1.39±0.01 ^b
3.00	–	0.10±0.015 ^c	3.47±0.16 ^d	1.55±0.47 ^a

^a Each value represents the mean of three observations

^b abc Means within a row with different superscript letters are different ($p < 0.05$)

^c TBA, thiobarbituric acid

^d PV, peroxide value

^e AV, acid value

– Not detected

Table 3 Color parameters of CFs rendered at various power levels^{a,b}

Power level (W/g)	<i>L</i> *	<i>a</i> *	<i>b</i> *
2.00	42.8±0.14 ^a	−4.1±0.16 ^c	31.0±1.03 ^a
2.25	39.8±0.29 ^b	−1.3±0.14 ^d	29.7±0.28 ^b
2.50	38.7±0.46 ^c	−0.5±0.25 ^c	29.4±0.41 ^b
2.75	36.8±0.32 ^d	0.7±0.02 ^b	26.8±0.69 ^c
3.00	35.9±0.05 ^e	1.9±0.02 ^a	25.3±0.07 ^d

^a Each value represents the mean of three observations

^b abc Means within a row with different superscript letters are different ($p < 0.05$)

decreased at the same time (Fig. 1, Tables 1 and 2). For instance, the moisture content of CF decreased from 2.33% to 1.50% when the power level increased from 2.00 W/g to 2.50 W/g (Table 2). While there was no moisture left in CF after rendered at power level of 2.75 W/g and 3.00 W/g for 10 min, which met the recommendation of Nair 1964 who indicated that the moisture content of poultry fat should not exceed 0.25% (Table 2, $P < 0.05$).

The CF obtained at power level of 2.00 W/g had the highest TBA value (0.43), PV (7.49) and AV (1.60) followed by the CF obtained at 2.25 W/g and 2.50 W/g. While the CF obtained at 2.75 W/g had the lowest TBA value (0.081), PV (3.39) and AV (1.29). When the power level was stronger than 2.75 W/g, i.e. 3 W/g, the TBA value and AV increased. While the PVs of CFs rendered at 2.75 W/g and 3 W/g were not different significantly (Table 2, $p < 0.05$).

The PV, AV and TBA value of CF were influenced by the degree of oxidation. Oxidation of oils contributes to the degradation of nutritional quality and the formation of rancid flavors. So the oxidation level of oil and fat is an important

Fig. 3 Yields of CF rendered from 6 min, 8 min, 10 min, 12 min and 14 min at power level of 2.75w/g. Each value represents the mean of three observations. Values with different letters were significantly different ($P < 0.05$)

quality criteria for food industry (Muik et al. 2005). In general, oxygen content in interface, water activity (Aw) and temperature of food have significant effects on oxidation. When the Aw of food was lower than 0.1, the rate of oxidation was very high. If the Aw of food was between 0.1 and 0.3, rate of oxidation decreased gradually (Gopala Krishna and Prabhakar 1992; Kahl et al. 1988; Karel 1980). On the other side, the rate of oxidation also increased with temperature increasing (Fennema 2003; Mishra et al. 2011). Table 2 implicated that if CF contained water, the moisture content determined the variation of TBA value, PV and AV. When there was no water left in CF, temperature rise resulted in the increasing of TBA value, PV and AV of CF. Since MW rendering was carried out in an opening system in this study, high PV of CFs yielded at various power levels may be attributed to oxygen incorporation and moisture in CFs (Table 2) (Pereira et al. 1976).

Table 3 showed the color changes of CF rendered at various MW power levels. The CF obtained at power level of 2.00 W/g was lighter and more yellow in color than other CFs since the CIE L^* and b^* values were the highest, while a^* value was the lowest among the samples (Table 3, $p<0.05$). With MW power increasing, the L^* and b^* values decreased and a^* value increased indicating that high temperature aggravated the destroying of pigment and Maillard browning in CF (Sheu and Chen 2002).

Influence of irradiation time on yield and characteristics of CF

Yield of CF rendered for different time

At MW power level of 2.75 W/g, CF rendered for 10 min had the highest yield (70.55%) followed by 8 min (68.9%)

Table 4 Characteristics of CFs rendered for different time at power level of 2.75 W/g^{a,b}

Irradiation time (min)	Moisture content (%)	TBA ^c value	PV ^d (meq/kg)	AV ^e (mgKOH/g)
6	16.67±0.25 ^a	0.14±0.007 ^a	7.09±0.31 ^a	1.49±0.006 ^a
8	2.57±0.11 ^b	0.11±0.001 ^b	4.73±0.15 ^b	1.47±0.004 ^b
10	–	0.08±0.000 ^c	3.43±0.04 ^c	1.37±0.006 ^c
12	–	0.10±0.020 ^d	3.55±0.02 ^c	1.43±0.011 ^d
14	–	0.12±0.001 ^c	3.99±0.06 ^c	1.45±0.008 ^c

^a Each value represents the mean of three observations

^b abc Means within a row with different superscript letters are different ($p<0.05$)

^c TBA, thiobarbituric acid

^d PV, peroxide value

^e AV, acid value

– Not detected

Table 5 Color parameters of CFs rendered for different time at power level of 2.75 W/g^{a,b}

Irradiation time (min)	L^*	a^*	b^*
6	42.3±0.07 ^a	−3.8±0.04 ^c	30.4±0.21 ^a
8	41.4±0.30 ^b	−2.7±0.06 ^d	30.8±0.23 ^a
10	36.8±0.32 ^c	0.7±0.02 ^c	26.8±0.69 ^b
12	33.6±0.05 ^d	3.3±0.04 ^b	23.6±0.13 ^c
14	30.9±0.11 ^c	4.9±0.02 ^a	20.6±0.15 ^d

^a Each value represents the mean of three observations

^b abc Means within a row with different superscript letters are different ($p<0.05$)

and 6 min (57.88%) rendering. No significant differences in CF yield were observed among 10, 12 and 14 min rendering (Fig. 3, $p<0.05$).

It can be clearly seen from Fig. 1 that the 6 min rendering at MW power level of 2.75 W/g only had phase I and II. The temperature of the mixture of BAF and CF was about 110 °C at the end of irradiation, which resulted in the lowest yield of CF (Fig. 3, $p<0.05$). When the irradiation time was prolonged to 14 min, the final temperature of CF increased to 197.18 °C, and the yield of CF was up to 70.46% (Fig. 3).

Characteristics of CF rendered for different time

The content of residual water in CF rendered for 6 min and 8 min was 16.67% and 2.57%. No moisture was detected in the CF rendered for 10 min, 12 min and 14 min (Table 4).

The CF obtained from 6 min rendering had the highest TBA value (0.14), PV (7.09) and AV (1.49) followed by 8 min and 10 min rendering (Table 4, $p<0.05$). When CF

Table 6 Fatty acid compositions of CF rendered at microwave power of 2.75 W/g for 10 min and extracted by Soxhlet extraction

Fatty acid	MW rendering (%)	Soxhlet extraction (%)
C14:0	0.53	0.51
C16:0	26.1	24.4
C16:1	6.1	6.6
C18:0	5.8	6.2
C18:1	45.7	44.5
C18:2	15.1	16.6
C18:3	0.61	0.61
Total saturated	32.5	31.2
Total unsaturated	66.5	68.3
Total unsaturated/ total saturated	2.1	2.2

was irradiated for a longer time (12 min and 14 min), the TBA value and AV increased significantly, but the rise of PV was not so obvious (Table 4, $p < 0.05$). Table 4 and Fig. 3 also suggested that moisture content and temperature of CFs affected the oxidation of fat. Furthermore, since the above quality parameters were assayed after CFs cooled down, Table 4 indicated that higher moisture content in CFs caused stronger oxidation during cooling even at a lower temperature ($p < 0.05$).

The color parameters of CFs rendered for different time were shown in Table 5. The CF obtained from 6 min rendering at power level of 2.75 W/g was lighter and more yellow in color as implicated by the highest CIE L^* and b^* values and the lowest a^* value (Table 5, $p < 0.05$). With MW irradiation time prolonging, the L^* and b^* values decreased and a^* value increased indicating that the CF became darker and browner.

Fatty acid profile of CF rendered

There were seven fatty acids in CF from BAF, and the fatty acid compositions of CF obtained by MW rendering and Soxhlet extraction were similar (Table 6). In the CF rendered by MW at 2.75 W/g for 10 min, the five major fatty acids were oleic acid (45.73%), palmitic acid (26.13%), linoleic acid (15.12%), palmitoleic acid (6.07%) and stearic acid (5.81%). Similar fatty acid compositions could be found in the CF from chicken skin (Sheu and Chen 2002). The total amount of unsaturated fatty acids was 66.53% and ratio of total unsaturated fatty acids to total saturated fatty acids was 2.05 in CF by MW rendering. Compared with other animal fats from goat, sheep/lamb, beef, lard and donkey, CF was healthier due to higher amounts of unsaturated and essential fatty acids (Banskalieva et al. 2000; Hui 2001; You et al. 2008).

Conclusion

MW rendering is a prospective method to produce fat with high quality and yield. By using an opening microwave heating system, MW rendering process could be divided into three phases: warming-up phase, constant temperature phase and heating-up phase. MW power and irradiation time were the main factors affecting the temperature and water content of CF, which influence the yields and characteristics of CF from BAF. CF obtained at power level of 2.75 W/g for 10 min had the highest yield (70.55%) and recover rate (96.5%) with the lowest PV, AV and TBA value compared with the CFs rendered at other conditions in this study ($p < 0.05$). The fatty acid compositions of CF by MW rendered were similar to the crude CF obtained by Soxhlet extraction and CF from chicken skin.

Acknowledgments This work was supported by 2010 fund project (2010B 090400475) of Industry-Universities- Research Institutes Collaboration, which is co-sponsored by Guangdong Provincial Government and Chinese Ministry of Education (China)

References

- Abhijit K, Pitam C, Rajender P, Samuel DVK, Khurdiya DS (2003) Comparison of different methods of drying for banana (*Dwarf Cavendish*) slices. *J Food Sci Tech* 40(4):378–381
- Abhijit K, Pitam C, Rajender P, Sanjaya KD (2004) Microwave drying characteristics of button mushroom (*Agaricus bisporus*). *J Food Sci Tech* 41(6):636–641
- Adedeji AA, Ngadi MO, Raghavan GSV (2009) Kinetics of mass transfer in microwave precooked and deep-fat fried chicken nuggets. *J Food Eng* 91(1):146–153
- Banskalieva V, Sahlu T, Goetsch AL (2000) Fatty acid composition of goat muscles and fat depots: a review. *Small Ruminant Research* 37:255–268
- Bilbao-Sáinz C, Andrés A, Chiralt A, Fito P (2006) Microwaves phenomena during drying of apple cylinders. *J Food Eng* 74:160–167
- Cheng WM, Raghavan GSV, Ngadi M, Wang N (2006) Microwave power control strategies on the drying process II. Phase-controlled and cycle-controlled microwave/air drying. *J Food Eng* 76:195–201
- Cobos A, Veiga A, Diaz O (2000) Chemical and fatty acid composition of meat and liver of wildducks (*Anas platyrhynchos*). *Food Chem* 68:77–79
- Datta AK, Anantheswaran RC (2001) Handbook of microwave technology for food applications. Marcel Dekker, Inc., New York, p 103
- Ding L, Wang YZ, Liu CG (2007) Preparation of bio-diesel using chicken oil. *Journal of the Chinese Cereals and Oils Association* 22(4):111–113
- Duncan DB (1955) Multiple range and multiple Ftests. *Biometrics* 11:1–42
- Fasseas MK, Mountzouris KC, Tarantilis PA, Polissiou M, Zervas G (2007) Antioxidant activity in meat treated with oregano and sage essential oils. *Food Chem* 106:1188–1194
- Fennema OR (2003) Food chemistry, 3rd edn. Translated by Wang, Z. et al. Chinese Light Industry Press, Beijing, pp 226–227
- Gopala Krishna AG, Prabhakar JV (1992) Effect of water activity on secondary products formation in autoxidizing methyl linoleat. *J Am Oil Chem Soc* 69:178–183
- Hui H (2001) Bailey's industrial oil and fat products, vol 1, 5th edn. Translated by Xu, S.G., Qiu, A. Y.Y.. Chemical Industry Press, pp 6–9
- Kahl JL, Artz WE, Schanus EG (1988) Effects of relative humidity on lipid autoxidation in a model system. *Lipids* 23:275–279
- Karel M (1980) Lipid oxidation, secondary reactions, and water activity of foods. In: Simic MS, Karel M (eds) Autoxidation in food and biological systems. Plenum Press, New York, pp 191–206
- Li H, Bi YY (2009) Extraction and refining of chicken oil. *China Oils and Fats* 34(10):18–20
- Li Z, Raghavan GSV, Orsat V (2010) Temperature and power control in microwave drying. *J Food Eng* 97:478–483
- Lin T (1998) The process of a new seasoning-chicken powder. *Food Ind* 5:21
- Lu L, Tang J, Ran X (1999) Temperature and moisture changes during microwave drying of sliced food. *Dry Technol* 17:413–432

- Mishra R, Sharma HK, Sarkar BC, Singh C (2011) Thermal oxidation of rice bran oil during oven test and microwave heating [J]. *J Food Sci Tech*. doi:[10.1007/s13197-011-0274-7](https://doi.org/10.1007/s13197-011-0274-7)
- Muik B, Lendl B, Molina-Díaz A, Ayora-Cañada MJ (2005) Direct monitoring of lipid oxidation in edible oils by Fourier transform Raman spectroscopy. *Chem Phys Lipids* 134:173–182
- Nair JH (1964) Dry soup and other dry mixes. In: Van Arsdel WB, Copley MJ (eds) *Food dehydration* (vol. II). The AVI Publishing Co., Inc., West port
- Pereira AS, Evans RW, Stadelman WJ (1976) The effect of processing on some characteristics, including fatty acid composition of chicken fat. *Poultry Sci* 55:510–515
- Sheu KS, Chen TC (2002) Yield and quality characteristics of edible broiler skin fat as obtained from five rendering methods. *J Food Eng* 55:263–269
- Wang SM, Chen SL, Cui YB (1993) On the procedures of chloroform-methanol extraction for the determination of lipid content of fish samples. *Acta Hydrobiol Sin* 17(2):193–196
- Witte VC, Krause GF, Bailey ME (1970) A new extraction method for determining 2-thiobarbituric acid values of pork and beef during storage. *J Food Sci* 35:582–585
- You J, Luo YK, Zhang YC, Zhen Z (2008) Analysis and evaluation of fatty acid composition of donkey fat. *Nutr Sci China* 9 (9):55–56