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Effect of wheat flour protein compositions on the quality of deep-fried gluten balls

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Abstract

Wheat flours milled from five different varieties of wheat and collected at an extraction rate of 60% were used as raw materials in this study. The proximate compositions, dough Farinographic and Extensographic properties, and the quality indices of deep-fried gluten balls prepared from these flours were measured. The proteins of these five different wheat flours were extracted and analyzed using the electrophoretic method, and the effect of protein composition on the quality of deep-fried gluten balls prepared from these flours was investigated. In this study, the proteins in each sample were divided into six groups, and the molecular weights of the proteins in these six groups are as follows: (I) 205.0–97.4 kDa; (II) 97.4–66.2 kDa; (III) 66.2–45.0 kDa; (IV) 45.0–36.0 kDa; (V) 24.0–19.7 kDa; (VI) 14.4–6.5 kDa, respectively. The results show that the protein contents of groups I, II, and V are negatively correlated to peak force and Hunter *b* value of deep-fried gluten balls, but positively correlated to Hunter *L* value and sensory evaluation score of appearance. The above results reveal that the high-molecular weight glutenin subunits, ω-gliadins, and albumins/globulins of wheat flour have a profound effect on the quality of deep-fried gluten balls.

Keywords: Deep-fried gluten ball; Electrophoresis; Gliadins; Glutenins; Wheat protein; Wheat flour

1. Introduction

The protein mixture of wheat flour is very complex and contains many molecular species with different sizes, structures, and conformations (Pence, Nimmo, & Hepbum, 1964; Stone & Hamdy, 1964). Proteins in flour can be mainly grouped into three main categories: glutenin, gliadin and albumin/globulin. Some researchers may further divide them into more detailed subgroups which are HMW glutenin subunit, ω-gliadin, LMW glutenin subunit, α-, β-, γ-gliadin and albumin/globulin (Ciaffi, Tozzi, & Lafiandra, 1996; Kasarda, Woodard, & Adalsteins, 1998; Mimouni, Robin, Azanza, & Raymond, 1998). Gliadin has a good extensibility, but lacks elasticity. Glutenin has a better elasticity but a low extensibility (Cheftel, Cug, & Lorient, 1985). Blending both of them in the dough brings a specific elasticity and extensibility, which can then be used in the processing of different flour products. When flour is mixed with water, glutenin swells and incorporates gliadin, and some water-soluble albumins and globulins. Along with mixing processes, a network structure of gluten is gradually developed (Bietz & Wall, 1980; Huebner, 1977). Many studies indicate that gluten plays a key role in determining the quality of wheat flour (MacRitchie, 1992, 1994; Shewry & Tatham, 1997). Gluten proteins substantially control the quality of wheat flour products (Finney, 1943; MacRitchie, 1984).

Deep-fried gluten balls are a traditional food in Taiwan. They are made using wheat flour as a raw material. At first, the flour is washed with water to obtain wet

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gluten, which is then cut and shaped into balls and fried in oil to obtain deep-fried gluten balls (Chang, Chen, & Wu, 1996; Chen, Chen, Wu, & Chang, 1998). While the flour is mixed with water, the network structure of gluten is gradually formed during concomitant stirring (Bietz & Wall, 1980; Huebner, 1977). The network structure of gluten is co-stabilized by disulfide bonds, hydrogen bonds, and hydrophobic interactions (Huebner, 1977; L'asztity, 1972). Much research reports that the elasticity and the extensibility of the dough prepared from wheat flour are determined by the quantity and quality of the proteins in flour (He & Hoseney, 1992). In this study, the flours from different varieties of wheat, which were milled on a laboratory mill and collected at an extraction rate of 60%, were used as raw materials. We prepared deep-fried gluten balls from these flour materials and analyzed their quality. In addition, we extracted proteins from flours, analyzed the protein compositions using electrophoresis, and discussed the relationships between quality of deep-fried gluten ball and flour protein composition.

2. Materials and methods

2.1. Experimental materials

Wheat flours used in this study were provided by Chiafha Co., Ltd. (Ching-Shuei, Taichung, Taiwan). Five sources of flour are American hard red spring wheat (AHRS), American hard red winter wheat (AHRW), American soft white wheat (ASW), Australia prime hard wheat (APW), and Canadian western red spring wheat (CWRS). The wheat was milled on a laboratory mill (Buhler MLU-202, Type 71-14-R4b). Each flour sample was obtained by mixing the flours from B3, B2, B1, C1, C2, and C3 milling streams of the mill at an extraction rate of 60%. The frying oil is soybean oil, purchased from a local oil-manufacturing plant in Taichung.

2.2. Analysis of dough rheological properties

Dough rheological properties, farinograph and extensograph, were determined by AACC methods 54-21 and 54-10 (AACC, 1983), respectively.

2.3. Protein extraction

According to the methods provided by Danno (1981), Singh, Donovan, Batey, and MacRitchie (1990) Chang, Shyong, and Chang (1997), flour was suspended in a 0.05 M phosphate buffer (pH 6.9) containing 2% SDS with a solid/liquid ratio of 1:20. The suspension was treated with a sonicator (Ultrasonic Processor XL, Misonix Inc., USA) for 5 min at a 38 W output. During sonication, a 25 °C water bath was used to cool the suspension to prevent its temperature from exceeding 50 °C. After sonication, the suspension was stirred with a magnetic stirrer for 2 h and then centrifuged at 12,000*g* for 20 min. The supernatant was collected as our protein extract liquid.

2.4. Protein analysis by SDS–PAGE electrophoresis

Our approach followed the method provided by Gupta and MacRitchie (1991) with a minor modification. The equipments used here were an Electrophoresis apparatus Model AE-6450 (ATTO, Japan) and a power supply PS500XT with a 2.5 A input (Hoefer scientific instruments, USA). Ten μl of the protein sample liquid was added with 10 μl lysis buffer containing 0.5 M Tris (pH 6.8), 2% bromophenol blue, 10% SDS, 75% glycerol, β-mercaptoethanol, and distilled water. The sample was then loaded in a 15% acrylamide gel (gel concentration: stacking gel 4.5%, resolving gel 15%). Electrophoresis started at 70 V and was tuned up to 140 V after a tracer dye entered the resolving gel. This voltage was held until the tracer reached the bottom of the gel before the power was turned off. The gel was then immersed in coomassie blue for 2 h and the color was stripped by a solution containing 7% methanol and 7% acetic acid.

2.5. Quantification of protein composition

The color-stripped gel was scanned by a TLC scanner (Camag, Sweden) at 597 nm. The scanned peaks were categorized into six groups according to their molecular weights, which were indicated by standard proteins. Relative protein content in each group was determined by the ratio of the peak's area in each group over the peak's area in the overall six groups.

2.6. Preparation of wet gluten

The method developed by Oda, Yasuda, Okazaki, Yamauchi, and Yokoyama (1980) was used to prepare wet gluten (Oda et al., 1980). The flour was washed with water to remove starch. The obtained wet gluten (water content was around 67%) was then immersed in the water for 30 min before cutting and shaping into balls.

2.7. Frying of gluten balls

The frying of gluten balls was modified from the method of Chen et al. (1998). One hundred grams of wet gluten balls were fried continuously through three consecutive deep-frying pans. Each pan (34 cm i.d. × 26 cm h) contained about 10 l of soybean oil. The frying time in the first, second and third pans were 120, 90, and 70 s, respectively. The temperature of the first, second, and third pans were 135 ± 3, 157 ± 3, and 190 ± 3 °C, respectively.

2.8. Sensory evaluation analysis of deep-fried gluten balls

Organoleptic evaluation of the deep-fried gluten balls was conducted using the method of Chen, Shyong, and Chang (1997) and by presenting the samples to a panel comprised of 30 members. The trained of panelists are from the manufacturing factory. The items of the sensory evaluation analysis for the deep-fried gluten balls included: appearance, total acceptance and texture scores. The appearance score is an index of consumer preference with respect to the outlook of the gluten balls in the sensory evaluation. The texture score is an index of consumer preference in terms of the texture of the gluten ball in the sensory evaluation. A gluten ball of firm texture (tough) is not welcomed by the consumer. The total acceptance score was designed in the sensory evaluation to measure the consumers' overall feeling, by tasting and looking, about gluten balls of different qualities (puffiness, hardness and color).

Appearance and total acceptance scores were analyzed by a hedonic test, and texture score was analyzed by a comparison test. In the analysis of the texture of the samples, three reference samples were used for comparison, which were scored at 2, 5, and 8, respectively. These three reference samples for sensory evaluation were chose according to the preference of consumers from a marketing survey. The panelists were asked to record the scores of the samples analyzed for these three items using a scale from 1 to 9. The samples with a score of 9 were considered the best quality, and those with a score of 1 were considered the worst quality. Generally speaking, for the reference samples in this study, a score of 4–5 will be considered acceptable for commercial canning.

2.9. Determination of the expansion volume of deep-fried gluten balls

The expansion volume of deep-fried gluten ball was determined following the method of Chen et al. (1997). Thirty deep-fried gluten balls were put into a cylinder, and then the void spaces were filled with rapeseeds to a certain volume (V_1). The deep-fried gluten balls were picked out carefully. The volume of the remaining rapeseeds in the cylinder was then recorded as V_2. The volumetric difference ($V_1 - V_2$) is the volume of the fried gluten balls. Using the same method, the volume of the wet gluten balls before frying could also be obtained. The expansion volume of the deep-fried gluten balls was obtained as the volume difference between the fried and the wet gluten balls.

Generally speaking, a puffy deep-fried gluten ball gives a soft and crispy sensation simply by looking at it. Consequently, higher expansion volume will result in higher sensory evaluation score of appearance, and at the end, higher sensory evaluation score of total acceptance. However, if the expansion volume is too large, it will create big air spaces within the deep-fried gluten ball, and easily cause textural collapse during handling after preparation. Therefore, for the same weight, although a larger volume indicates a softer texture that will be preferred by the consumer, it is also harmful to the quality of the commercial deep-fried gluten ball products. The preferable expansion volume variable should therefore be at intermediate values.

2.10. Texture measurement of deep-fried gluten balls

The texture of the deep-fried gluten balls was analyzed following the method of Chen et al. (1997). A rheometer (Sun Cr-200d, Sun Scientific Co., Ltd., Japan), mounted with a plunger (adapter no. 14), was used to analyze the texture of the samples. The flat base, on which the sample was placed, moved upward to the plunger at a speed of 60 mm/min to measure the peak force and brittleness breakdown as the indices of the sample's texture. The compression distance of the plunger on the sample was 12 mm. The measured values of 30 of the deep-fried gluten balls were averaged.

Peak force and brittleness breakdown measured by a rheometer were used as quality indices of the product. Peak force is a measure of hardness of the deep-fried gluten balls. Brittleness breakdown is a measure of crispiness of the deep-fried gluten balls. Both quantities are related to the texture of the product. Although they represent different mouth feels (hardness and crispiness) in the sensory evaluation, in this case, they present very similar patterns of variations. For deep-fried gluten balls, peak force and brittleness breakdown appeared to be strongly correlated. However, the discussion of correlation is beyond the scope of this study.

According to our studies on the analytical method for the quality of the deep-fried gluten ball, too tough a gluten ball is not preferred by the consumers. Peak force/brittleness breakdown ratio is negatively correlated to expansion volume, since small expansion volume (for the same weight of gluten ball) reflects firm structure, which will result in higher peak force/brittleness breakdown ratio. These quantities should be minimized.

2.11. Determination of the color of deep-fried gluten balls

The color of the deep-fried gluten balls was measured using a colorimeter (Color Analyzer, Color Mate OEM, Milton Roy Co., USA). Three determinations were conducted randomly on the surface of each deep-fried gluten ball. The measured values of 30 of the deep-fried gluten balls were averaged.

The Hunter b value, among the three parameters, namely Hunter L, a, and b, was found to be most significantly correlated to sensory appearance, texture, and total acceptance scores (Chen et al., 1997). In the

sensory evaluation study (Chen et al., 1997), panelists commented that they felt deep-fried gluten balls of light yellow color gave them a feeling that the frying oil used was fresh and the gluten ball was not over-fried. Therefore, Hunter *b* value was negatively correlated to sensory evaluation scores of appearance and total acceptance. On the other hand, a dark yellow color indicates that the frying temperature was too high and/or the frying time was too long; both will result in firm texture. Consumers tend to subjectively think that a dark yellow color resulted from bad quality oil. Hunter *b* value was also found to be negatively correlated to sensory evaluation score of texture. Hunter *b* value should be minimized.

2.12. Statistics

Results in this study were analyzed by one-way ANOVA, correlation, and stepwise regression functions in SAS (SAS, 1985).

3. Results and discussion

3.1. Composition analysis of different wheat flours

Table 1 shows the proximate compositions of five different wheat flours. These flours have significant differences in their compositions ($P < 0.05$) and therefore serve as our experimental samples. The ash contents of the flour samples were ranged between 0.35% and 0.39%. Because wheat ash is mostly located in the bran, the small quantity of ash reveals that the flour samples are less contaminated with bran. Samples AHRS and CWRS had the highest contents of protein, AHRW and APW had the next, and ASW had the lowest one. Many researchers have reported that soft wheat has low protein content and therefore leads to weaker dough gluten (Bettge, Rubenthaler, & Pomeranz, 1989; Johnson, Griffey, & Harris, 1999; Souza, Kruk, & Sunderman, 1994). Sample ASW is an example of this kind of wheat. The dry gluten and wet gluten were valued in a same way as the crude protein.

3.2. Analysis of dough farinographic and extensographic properties of different wheat flours

Table 2 shows the dough farinographic properties of five different wheat flours. These five flour samples had significant differences in their dough farinographic properties ($P > 0.05$). The water absorption (WA) was found to be in the following order: AHRS > CWRS > APW > AHRW > ASW. Some reports pointed out that protein content controlled water absorption (Dexter, Preston, Martin, & Gander, 1994; Tipples, Meredith, & Holas, 1978). Sample ASW had the lowest protein content and hence had the lowest water absorption. Sample ASW also had the lowest PT and DT, and the highest WE values. These data reveal that sample ASW had the least tolerance to stirring, and

Table 1
Proximate compositions of five different wheat flours

Sample	Moisture (%)	Crude protein (%)	Ash (%)	Wet gluten (%)	Dry gluten (%)
AHRS[A]	14.24[a,B]	13.66[a]	0.35[b]	3.75[b]	1.30[b]
AHRW	14.14[ab]	11.04[b]	0.35[b]	3.08[d]	1.03[d]
ASW	13.27[c]	7.11[c]	0.36[b]	2.05[e]	0.70[c]
APW	12.35[d]	11.21[b]	0.39[a]	3.21[c]	1.08[c]
CWRS	13.95[b]	13.54[a]	0.39[a]	3.94[a]	1.33[a]

[A] AHRS, American hard red spring wheat; AHRW, American hard red winter wheat; ASW, American soft white wheat; APW, Australia prime hard wheat; CWRS, Canadian western red spring wheat.
[B] Means with identical letter in the same column are not significantly different at ($p > 0.05$).

Table 2
The dough farinographic properties of five different wheat flours

Sample	Farinographic properties[C]						
	WA	AT	PT	DT	VV	WE	ST
AHRS[A]	70.33[a,B]	17.00[a]	28.00[a]	40.00[a]	100.00[a]	20.00[bc]	23.00[b]
AHRW	61.80[c]	1.23[c]	14.00[b]	31.33[b]	88.17[b]	15.00[c]	30.10[a]
ASW	57.73[d]	1.60[c]	1.17[e]	6.67[d]	36.67[e]	76.70[a]	5.07[d]
APW	65.93[b]	2.33[bc]	7.33[d]	17.50[c]	68.83[d]	41.70[b]	15.17[c]
CWRS	67.13[b]	3.00[b]	10.67[c]	30.00[b]	83.17[c]	1.67[c]	27.00[ab]

[A] Samples AHRS, AHRW, ASW, APW, and CWRS are the same as those shown in Table 1.
[B] Means with identical letter in the same column are not significantly different at $p > 0.005$.
[C] Farinographic properties: WA, water absorption; AT, arrival time; PT, peak time; DT, departure time; VV, valorimeter value; WE, weakness; ST, stability.

could not be expanded well during deep-frying. This point was supported by the fact that the gluten balls made from sample ASW had a small expansion volume, high peak force and brittleness breakdown, and low sensory evaluation scores (see Table 4). In Table 2, we also found that sample AHRS had relatively high arrival time (AT), peak time (PT), departure time (DT), valorimeter value (VV), and stability (ST). This revealed that the dough made from sample AHRS was more tolerant to stirring than other flour samples. The gluten balls made from sample AHRS had a big expansion volume, small peak force and brittleness breakdown, and high sensory evaluation scores (see Table 4).

Table 3 shows dough extensographic properties of five different wheat flours. Different agieng times caused different resistance to extension (R_m). Basically, longer ageing time led to greater R_m and smaller extensibility (E), which might be caused by the intensive interaction between protein molecules, and resulted in a stronger dough as increasing the ageing time (Bloksma & Bushuk, 1988). The values of extensographic properties of five flours were changed irregularly. Sample ASW had the lowest R_m, E, and A values, this revealed that weak interaction between protein molecules occurred in ASW dough. The gluten balls made from sample ASW had the worst quality (Table 4).

3.3. Quality of the deep-fried gluten balls prepared from different flours

Deep-fried gluten balls are a traditional food in Taiwan. Chen et al. (1998) found that the peak force and the brittleness values, obtained using a rheometer, were significantly and negatively correlated to consumers' preference. Table 4 shows the quality indices of the deep-fried gluten balls prepared from five different wheat flours. The gluten balls prepared from the flour samples AHRS and CWRS had the highest sensory evaluation score, and their rheological values (peak force and brittleness breakdown) were also in accordance with the results of the study on the quality of deep-fried gluten balls by Chen et al. (1997).

3.4. Protein compositions of different wheat flours analyzed using SDS–PAGE

Proteins in five flour samples were extracted using a 0.05 M phosphate buffer (pH 6.9) solution containing 2% SDS. The proteins collected were subjected to SDS–PAGE (15% acrylamide gel) analysis. The results are shown in Fig. 1. The color-stripped gel was scanned using a TLC scanner at 597 nm, and the scanned peaks are shown in Fig. 2. These peaks were categorized into six groups according to their molecular weights, which

Table 3
The dough extensographic properties of five different wheat flours

Sample	Extensographic properties[C]											
	R_m45 (g)	R_m90 (g)	R_m135 (g)	E45 (mm)	E90 (mm)	E135 (mm)	R/E45 (g/mm)	R/E90 (g/mm)	R/E135 (g/mm)	A45 (g/mm)	A90 (g/mm)	A135 (g/mm)
AHRS[A]	592.50^{a,B}	853.33^{a}	913.33^{a}	142.20^{bc}	101.80^{d}	99.30^{c}	4.21^{a}	8.53^{a}	9.63^{a}	123.17^{b}	112.00^{c}	101.50^{c}
AHRW	451.67^{b}	732.83^{b}	777.50^{b}	155.20^{b}	119.30^{c}	113.20^{bc}	2.92^{b}	6.19^{b}	7.00^{b}	125.33^{b}	114.17^{c}	104.50^{c}
ASW	339.17^{c}	479.00^{c}	498.67^{c}	132.80^{c}	117.70^{c}	121.20^{b}	2.57^{b}	4.09^{c}	4.13^{cd}	69.50^{c}	79.83^{d}	80.17^{d}
APW	334.50^{c}	453.33^{c}	483.33^{c}	205.50^{a}	188.70^{a}	172.80^{a}	1.63^{c}	2.41^{d}	2.84^{d}	143.00^{ab}	157.83^{b}	142.67^{b}
CWRS	370.00^{c}	634.67^{b}	735.83^{b}	199.50^{a}	167.20^{b}	157.50^{a}	1.87^{c}	3.86^{c}	5.14^{c}	165.00^{a}	185.50^{a}	176.67^{a}

[A] Samples AHRS, AHRW, ASW, APW, and CWRS are the same as those shown in Table 1.
[B] Means with identical letter in the same column are not significantly different at ($p > 0.05$).
[C] R_m = maximum resistance to extension after 45-, 90-, and 135-min ageing. E = extensibility after 45-, 90-, and 135-min ageing. A = area after 45-, 90-, and 135-min ageing.

Table 4
The quality indices of deep-fried gluten balls prepared from five different wheat flours

Wheat flour	Quality indices								
	Expansion volume (cm^3)	Peak force (g)	Brittleness breakdown (g)	Hunter			Appearance score	Texture score	Total acceptance score
				L	a	b			
AHRS[A]	11.00^{b,B}	1158.33^{c}	1263.00^{c}	53.32^{b}	−0.87^{d}	9.78^{d}	7.42^{a}	6.58^{ab}	7.29^{a}
AHRW	9.70^{c}	1685.00^{b}	1860.00^{b}	50.20^{c}	0.16^{b}	12.35^{b}	4.77^{c}	6.06^{b}	5.39^{b}
ASW	9.64^{c}	2371.67^{a}	2577.33^{a}	55.19^{a}	0.96^{a}	15.35^{a}	2.45^{d}	4.90^{c}	3.58^{c}
APW	15.28^{a}	1210.33^{c}	1444.33^{c}	48.98^{c}	0.28^{b}	10.99^{c}	5.74^{b}	6.13^{b}	5.77^{b}
CWRS	11.91^{b}	1251.00^{c}	1567.00^{bc}	53.19^{b}	−0.48^{c}	10.89^{c}	7.97^{a}	7.13^{a}	7.61^{a}

[A] Samples AHRS, AHRW, ASW, APW, and CWRS are the same as those shown in Table 1.
[B] Means with identical letter in the same column are not significantly different at ($p > 0.05$).

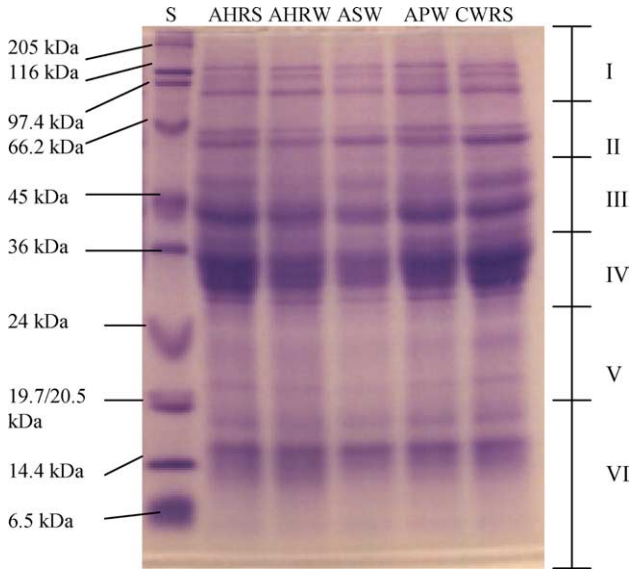

Fig. 1. SDS–PAGE (15% acrylamide gel) patterns of proteins extracted with 0.05 M phosphate buffer (pH 6.9) containing 2% SDS from five different wheat flours: Lane S, standard (205.0, 116.0, 97.4, 66.2, 45.0, 36.0, 24.0, 19.7/20.5, 14.4, and 6.5 kDa); Lane AHRS, American hard red spring wheat; Lane AHRW, American hard red winter wheat; Lane ASW, American soft white wheat; Lane APW, Australia hard white wheat; Lane CWRS, Canadian hard red spring wheat.

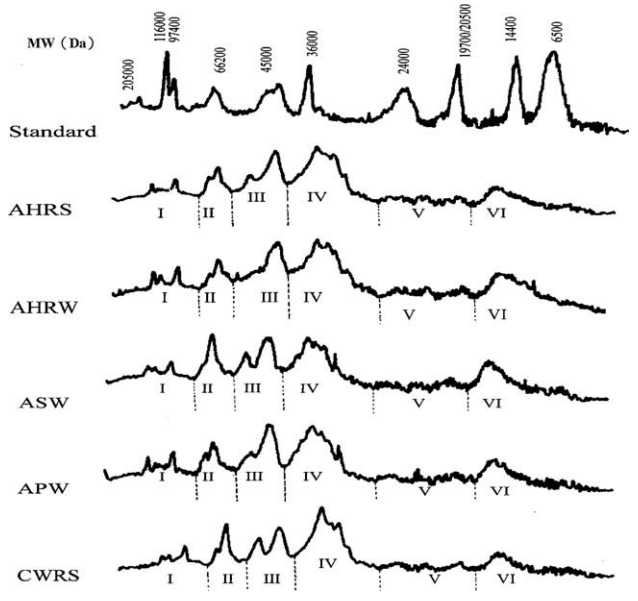

Fig. 2. SDS–PAGE electropherograms of protein standards and the proteins from wheat flours (Standard, AHRS, AHRW, ASW, APW, and CWRS) used in this study. Sample AHRS, AHRW, ASW, APW and CWRS are the same as shown in Fig. 1.

were: (I) 205.0–97.4 kDa; (II) 97.4–66.2 kDa; (III) 66.2–45.0 kDa; (IV) 45.0–36.0 kDa; (V) 24.0–19.7 kDa; (VI) 14.4–6.5 kDa. Comparing the SDS–PAGE studies done by Singh et al. (1990), Batey, Gupta, and MacRitchie (1991), Pasaribu, Tomlinson, and McMaster (1992), Kasarda et al. (1998) and Mimouni et al. (1998) with acrylamide gel concentrations 10%, 12%, 12%, 4–12% and 10–20%, respectively, we assumed that group I contained HMW glutenin subunit, group II contained a little HMW glutenin subunits and ω-gliadins group III contained LMW gluten subunits group IV contained α-, β-, and γ-gliadins, and groups V and VI contained albumin/globulin. Percentage compositions are also shown in Table 5. The protein contents in these samples were different in different molecular weight groups.

3.5. Relationship between flour protein composition and quality indices of deep-fried gluten balls

The correlation coefficients between the contents of 6 protein groups and the measured quality indices of the deep-fried gluten balls prepared from the flour samples are shown in Table 6. It was clear that groups I, II, and V were negatively correlated to peak force and Hunter *b*value, but positively correlated to Hunter *L* value. As previously stated, consumer do not like gluten balls with a texture that is too tough (high peak force) or that is too dark yellow in color (high Hunter *b* value). The results in Table 6 imply that the flours with higher contents of HMW glutenins (group I-proteins), ω-gliadins (group II-proteins), and albumin/globulin (group V-proteins) can produce higher quality deep-fried gluten balls.

Table 6 shows that groups I, II, and V are positively correlated to sensory evaluation score of acceptance. It is also clear in Table 6 that the correlation coefficients between groups I, II, and V and sensory evaluation scores of texture and total acceptance are apparently higher than other protein groups, even though they are not significant. It reveals again that protein groups I, II, and V play a key role in determining the quality of deep-fried gluten balls.

Although there are few reports concerning the relationship between wheat protein composition and deep-fried gluten balls' quality, many reports show that wheat proteins play a very important role in the quality of flour products. Huang and Khan (1997a, 1997b) reported that HMW glutenins profoundly affect the quality of baked flour products. Branlard and Dardevet (1985) found that gliadins were significantly correlated to the quality of bread. Hussain and Lukow (1997) also found that the addition of gliadins could improve the flour dough extensibility, and pointed out that some Canadian western red spring wheats were rich in gliadins. In constrast to the flour samples used in this study, the sample CWRS had the largest amount of ω-gliadins (group II-1.31 g/100 g flour, shown in Table 5) and produced the highest quality of deep-fried gluten balls (shown in Table 4). This implies ω-gliadins also play an important role in the quality of deep-fried gluten balls.

Table 5
Protein contents (g/100 g flour) of five different wheat flours analyzed by electrophoresis

Sample	Protein contents (g/100 g flour)					
	I[A]	II	III	IV	V	VI
AHRS[B]	2.03[a,C]	1.27[a]	2.31[a]	3.68[a]	2.08[a]	2.29[a]
AHRW	1.68[ab]	1.00[c]	1.79[b]	2.71[b]	1.77[b]	2.09[bc]
ASW	1.19[b]	0.72[d]	1.13[c]	1.63[c]	1.10[c]	1.35[d]
APW	1.79[a]	1.07[b]	1.89[b]	2.85[b]	1.67[b]	1.95[c]
CWRS	1.98[a]	1.31[a]	2.21[a]	3.81[a]	2.02[a]	2.21[ab]

[A] The protein compositions are grouped according to the results of electrophoresis: (I) 116.0–97.4 kDa; (II) 66.2 kDa; (III) 45.0 kDa; (IV) 36.4–24.0 kDa; (V) 24.0–19.7 kDa; (VI) 19.7–6.5 kDa.
[B] Samples AHRS, AHRW, ASW, APW, and CWRS are the same as those shown in Table 1.
[C] Means with identical letter in the same column are not significantly different at ($p > 0.05$).

Table 6
The correlation coefficients between the quality indices of deep-fried gluten balls and the contents (g/100 g flour) of different proteins in wheat flour

Protein group	Quality indices								
	Expansion volume (cm^3)	Peak force (g)	Brittleness breakdown (g)	Hunter			Appearance score	Texture score	Total acceptance score
				L	*a*	*b*			
I	−0.9678**	−0.9246*	−0.6754	0.9790**	0.9763**	−0.9674**	0.9018*	0.6824	0.5676
II	−0.8590	−0.9906**	−0.8556	0.9263*	0.9178*	−0.9908**	0.9848**	0.7273	0.7529
III	0.5719	0.1957	−0.2651	−0.5702	−0.5878	0.3310	−0.1413	0.2535	0.4751
IV	0.4459	0.0128	−0.4389	−0.4144	−0.4343	0.1541	0.0443	0.3625	0.6244
V	−0.8988**	−0.9430*	−0.8016	0.8984*	0.8907*	−0.9521*	0.9308*	0.8348	0.7505
VI	0.0390	−0.3182	−0.6648	−0.0517	−0.0709	−0.1960	0.3503	0.6883	0.8170

* Correlation is significant at $p = 0.05$ level.
** Correlation is significant at $p = 0.01$ level.

4. Conclusion

Deep-fried gluten balls are a traditional food in Taiwan. They are made using clear flours as raw materials due to their richness in gluten protein and can thus reduce the production cost. The quality of deep-fried gluten balls is not only affected by the manufacturing procedure, but also by the protein compositions of the flours used. Chang et al. (1996) discovered that there are significant correlations between the *P*, *L*, *P*/*L* and *W* values of dough alveographic properties and the quality of deep-fried gluten balls, and the *P*/*L* values should fall into a range of 1.38–2.43 to obtain deep-fried gluten balls with acceptable quality. This reveals that the flour used to prepare fried gluten balls should have an appropriate ratio of glutenin and gliadin that are responsible for elasticity and extensibility, respectively. The results of this study agree with the research results obtained by Chang et al. (1996) and also demonstrate that protein composition is a key factor affecting the quality of wheat flour products, particularly deep-fried gluten products.

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