JFBE 4(2): 186-192, 2021

Journal of Food and Bioprocess Engineering

Journal homepage: https://jfabe.ut.ac.ir

Original research

Utilization of fermented whey protein concentrate and whey permeate in beard loaf making

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A B S T R A C T

The fermented whey protein concentrate (FWPC) and whey permeate (WP) at the levels of 0 (control), 25, 50, 75 and 100% were separately substituted instead of water (v/v) used for dough preparation in bread loaf making. The effect of incorporation of WP or FWPC was measured on dough properties (falling number, dough handling and water absorption) and bread making quality (loaf volume, loaf height, specific volume and baking loss). The results clearly showed that incorporation of increasing amount of WP and FWPC had contrary effect on falling number and significantly reduced and increased falling number values, respectively. Incorporation of WP and FWPC at increasing levels during dough preparation showed significant increase in water absorption in comparison to control and handling of dough for all treatments was smooth except for samples contain 100% FWPC which the dough was slightly sticky. Increasing WP up to 50% increased volume, height and specific volume of loaves ($p>0.05$) and thereafter slightly reduced it, while increasing the level of FWPC, except at level 25%, progressively decreased these parameters ($p < 0.05$). Independent of whey type (WP or FWPC) and incorporation levels, baking loss of bread decreased significantly with WP or FWPC fortification compared to the control, indicating higher moisture retained in supplemented breads. Based on results of this study, by incorporation of 50% WP or 25% FWPC, a loaf bread could be produced with the appropriate dough properties (with smooth and flexible texture) and baking qualities (acceptable loaf volume and baking loss).

Keywords: FWPC; WP; Dough handling; Loaves; Bread quality

Received 14 December 2021; Revised 26 December 2021; Accepted 29 December 2021

1. Introduction

Whey, the greenish-yellow liquid that separates from the curd during manufacture of cheese and casein, has long been considered by the dairy industry to be a waste by-product and, thus, a disposal problem (Jooyandeh, 2009a). The organic matter in cheese whey causes a high chemical oxygen demand (COD) in the range of 40–70 g/l (Lee et al., 2003). Cheese and casein production and the resultant worldwide whey and permeate, which is annually more than 160 million tonnes (Nooshkam et al., 2018), has been one of the main alone noticeable sources of potential pollution.

Dairy wastes should be viewed as an inexpensive potential source of raw material (more than 1.2 and 7.3 million tonnes whey protein and lactose, respectively) from which valuable products can be produced. This can be achieved through development of new products which would utilize a significant amount of whey or whey solids and reformulating the existing products to incorporate whey and whey solids. The development of new techniques particularly membrane separation has revolutionized the processing of whey into many high valued products (Farkye & Vedamuthu, 2002). There are many possible products (whey protein concentrate, whey protein isolate, mineral powder, lactose etc.) and manufacturing processes (ultrafiltration, diafiltration, reverse osmosis, ion exchange, etc.) for utilization of whey constituents. However, these techniques are expensive and are possible and economical only when adapted on large scale. In Iran, white brined cheese (Iranian Feta type cheese) is not only produced in large factories, but also produced by many small factories, dairy shops and even at home scale level. Since gathering of cheese whey in this way is not

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https://doi.org/10.22059/jfabe.2021.335604.1102

possible and sensible, application of a simple method for isolation and utilization of valuable whey proteins is thus necessary.

In last few years, whey and whey products are considered as appropriate ingredients for promoting functional properties, nutritive value and organoleptic characteristics of many food products (Jooyandeh & Minhas, 2009; Kouravand et al., 2017; Danesh et al., 2018; Torabi et al., 2021). However, a large quantity of whey is still discarded and only some amount of whey obtained from non UF Feta cheese making is converted to powder with a low quality. In many regions, cheese manufacturers cannot sell their whey due to high distance between them and whey powder factories. So they always dispose it which has created serious pollution problems.

Fermented Whey Protein Concentrate (FWPC) is a semi-concentrated whey protein with more than 3.5% protein and acidity about 60-90 ºD i.e. 0.6-0.9 per cent lactic acid (Jooyandeh et al., 2009). The fresh FWPC has a white colour and lactic aroma which is achieved by a very cheap and simple way. This whey product can be used in the different varieties of foods especially dairy and baking products (Jooyandeh, 2009b). Whey proteins are capable to produce mesoscopic construction in batter and create suitable properties like tension strengthening which is essential to have a dough-like mixture (van Riemsdijk et al., 2011).

Bread is one of the most consumed staple food in Iran and many countries. Consequently, as bread and cereal-based products play an important role to provide a healthy balanced diet, its quality improvement has been well documented. In recent years, many researchers have tried to improve baking properties, organoleptic characteristics, nutritional value and extension of the shelf-life of loaf wheat and gluten-free breads (van Riemsdijk et al., 2011; Gonçalves, 2017; Ferreyra et al., 2021). Whey protein concentrate (WPC) improves the nutritional value of bread by providing vital amino acids such as lysine, methionine and tryptophan (Warren et al., 1983). Erdogdu-Arnoczky et al. (1996) reported that addition of heat-treated acid whey protein increased the loaf volume and reduced the extent of staling. Gallagher et al. (2003) declared that incorporation of 6% whey protein powder in gluten-free bread heightened its protein content two times but had no influence on its dietary fiber extents. Ferreyra et al. (2021) reported that WPC interestingly had an adverse impact on the specific volume of bread fermented with yeast but not when sourdough was used. They also stated that WPC improved the protein content of bread and its vitro protein digestibility.

Utilization of whey as incorporation of FWPC as well as permeate in different food products will be a simple and economical way, which seems to be applicable method for utilization of whey to increase their yield, biological value, and other qualities. Therefore, the study was undertaken on the effect of fermented whey protein concentrate (FWPC) and whey permeate (WP) on dough properties and bread making qualities.

2. Material and Methods

2.1. Materials

2.1.1. Preparation of WP and FWPC

WP and FWPC were produced from sweet whey obtained during Feta cheese making in the laboratory according to the method of Jooyandeh and Minhas (2009). After collection of whey during preparation of Feta cheese, the whey was heated at 85ºC for 15 min. This heat treatment caused protein denaturation and coagulation which was required for proper precipitation of whey proteins during fermentation. Indeed, the partial unfolding of the whey proteins by heat represents extra water holding capacity that are unreachable in these proteins at their natural forms (Danesh et al., 2017).

After heating, the whey was cooled to 35ºC and inoculated with 1-2% of the same mixed starter cultures mesophyll and thermophile (1:1) used in preparation of Feta cheese. The mesophilic culture (CHOOZIT 230, Bulk cultures, Danisco, Germany) contained two organisms *Lactococcus lactis* subsp. *lactis* and *Lactococcus lactis* subsp. *cremoris* and thermophilic cultures (YO-MIX 532, Bulk cultures, Danisco, Germany) was yoghurt cultures containing *Streptococcus thermophilus* and *Lactobacillus delbruckii* subsp. *bulgaricus*. After about 8 h fermentation at 35ºC, the pH of fermented whey reduced to 4.5 and fermented whey protein concentrate was separated from the whey permeate (the whey permeate was pasteurized, cooled and kept in refrigerator for bread making). The precipitate usually contained about 10 to 11% total solids. This fermented product was used in bread making after adjustment of its total solids to 10%.

2.1.2. Other ingredients and chemicals

The commercial refined wheat flour of 70% extraction was used for bread making. Sodium chloride of high purity was used in the study for making bread. Hydrogenated fat (Gagan brand, manufactured by Gagan Vanaspati Ltd.), which had melting point of 37ºC was used as shortening in the formulation of bread. Crystal cane sugar was procured from the local market and powdered by grinder-mixer before use in bread making. Baker's yeast, i.e. prestige brand (*Saccharomyces cerevisiae)* manufactured by SAF yeast Co., Mumbai was obtained and kept in refrigerator for bread making.

2.2. Chemical analysis

Cow milk, whey, whey permeate and FWPC were analyzed for pH, acidity, total solids, total nitrogen/protein, fat, carbohydrates, and ash content according to AOAC (2000). Viscosity of milk, whey, WP and FWPC were measured by Brookfield viscometer (Model LVT, Brookfield Engineering Laboratories, INC. USA) according to Jooyandeh and Minhas (2009).

2.3. Bread making

Straight dough method (AACC, 2010) with procedure Irvine and McMullan (1960) was followed for bread making (Table 1). The ingredients were mixed in a dough mixer (National MFG Co., Lincoln, USA) and baking schedule was followed as Table 1. Fermentation and proofing were done at a proofer cabinet (National MFG Co., Lincoln, USA) providing 30 ± 1°C (86 ± 2°F) and 85% relative humidity. The doughs were fermented in plastic bowls (800 ml) and after sheeting and molding it transferred to low-form tin grazed pans, with inside diameter according to Table 1.

After proofing, bread making was followed by baking for 25 min at 232°C (450°F) in a rotary electric oven. The loaves were depanned and allowed to cool for 120 min on cooling racks at room temperature.

Table 1. The formula of loaf breads and baking schedule for experimental breads.

Formula of loaf breads		
No	Ingredients	Quantity (g)
1	Wheat Flour, 14% moisture basis	100.0
2	Compressed Active Yeast	3.0
3	sugar	2.5
4	Bakery Shortening	1.0
5	Salt, Chemically pure NaCl	1.0
6	Potassium Bromate	10 ppm
7	Water	Optimum
Baking schedule for bread making		
1	Mixing	Optimum
2	Fermentation	1 hour 15 min
3	Remixing	25 sec
4	Recovery	20 min
5	Sheeting and Moulding	------
6	Proofing	50 min
7	Baking	25 min

	Length (cm)	Width (cm	Depth (cm)
Top	11.5	7.0	5.0
Bottom	9.5	5.5	

2.4. Dough evaluation

2.4.1. Falling number

Falling number method is a simple and fast test for assessing α-amylase activity of wheat meal. This method is used extensively in grain classification and bread-making quality control. By enhancing α-amylase activity, the falling number decreases. In case of considerable α-amylase activity, the obtained dough become sticky and amount of water absorption increases. Contrary, with lower α-amylase activity, the dough texture become inflexible and firm which result in inappropriate dough performance.

For measuring of falling number, a slurry comprise of 7 g flour with 25 mL of water (replaced at 25, 50, 75, and 100% levels with whey permeate and FWPC) was prepared and the falling number values (sec) were determined according to AACC (2010).

2.4.2. Dough handling and water absorption

The dough appropriate for bread making requires stretching properly in reply to the extension of leavening gas. Dough layers that trap the CO_2 bubbles must have an adequate strength to avoid downfall and the same time to enable extending without cracking (Singh & MacRitchie, 2001). Therefore, the dough should be smooth and have a stretchable/flexible texture, but it not to be much sticky. In the current study, during dough preparation, dough characteristics\handling (smoothness and sickness) and water absorption (%) by flour were monitored.

2.5. Quality parameters of loaf bread

The next day of baking, loaves were removed from polyethylene bags and their weight, baking loss, height, volume (by rapeseed displacement method), loaf specific volume (cc/g) and baking loss were measured.

Specific volume was performed based on substitution of rapeseeds by bread in a certain volume container and using following formula (AACC, 2010):

$$Specific\ volume = \frac{Volume\ of\ bread}{Weight\ of\ bread} \quad (1)$$

Baking loss was measured according to Kim et al. (2003) using following formula:

$$Baking\ loss = \frac{WDBB - WBAB}{WDBB} \times 100 \quad (2)$$

where, WDBB was weight of dough before baking and WBAB was weight of bread after baking.

2.6. Statistical analysis

All treatments were made in triplicate. The data collected from studies were analyzed through factorial design using SPSS version 20 (SPSS Inc., Chicago, IL). One way analysis of variance (ANOVA) was carried out to determine significant differences between treatments and two way analysis was performed to determine significant differences between main factors and their interactions. Duncan's multiple-comparison test was used as a guide for pair comparisons of the treatment means. The level of significant for all analysis was considered at α =5%.

3. Results and Discussion

3.1. Composition of bread ingredients

As it is indicated in Table 2, FWPC has higher protein, fat, total solids, acidity and lower carbohydrate than whey and whey permeate. According to US Food and Drug Administration (FDA), whey protein concentrate (WPC) is defined as a substances obtained by the removal of sufficient non-protein constituents from whey so that the finished dry product contains not less than 25% proteins (Renner & Abd El-Salam, 1991). So, the high amount of protein in the FWPC, which is more than 40% protein in dry basis, is in agreement with this definition.

FWPC had higher viscosity than whey and whey permeate (Table 2) and its appearance resembled in stirred yoghurt/culture. The formation of protein aggregates due to denaturation of whey proteins during preparation of FWPC increases the volume occupied by the proteins and thus enhances viscosity (Jayaprakasha & Brueckner, 1999). The flour used for the preparation of loaf bread had a chemical composition comprising 14.24% moisture, 10.08% protein, 0.59% ash, 0.86% fat and 74.23% carbohydrate.

3.2. Effect of WP and FWPC on dough properties

3.2.1. Falling number

The data related to the effect of whey permeate (WP) and fermented whey protein concentrate (FWPC) at different substitution levels (25, 50, 75 and 100%) on falling number is presented in Table 3. The data showed that addition of whey (WP or FWPC) caused significant differences in falling number values.

Table 2. Mean values (± SD) of physico-chemical composition of milk, milk by-products, and flour.

Samples	Total solids (%)	Viscosity (cp)	pH	Acidity[a] (°D)	Protein (%)	Fat (%)	MSNF[b] (%)	Ash (%)	Carbohydrate (%)
Milk	10.65	3.4	6.65	15.2	3.17	2%	8.65	0.66	4.68
SD	0.12	0.01	0.01	0.18	0.03	0.00	0.12	0.10	0.18
Sweet whey	6.48	2.8	6.04	13.95	0.91	0.15	6.33	0.52	4.72
SD	0.20	0.02	0.04	0.18	0.03	0.02	0.18	0.07	0.23
FWPC[c]	10.00	440	4.55	63.02	4.34	1.21	8.79	0.54	3.91
SD	0.00	26.11	0.22	6.26	0.14	0.09	0.05	0.05	0.13
Whey Permeate	5.99	2.9	4.41	34.83	0.43	Nil	0.43	0.52	4.49
SD	0.15	0.01	0.11	2.78	0.05		0.05	0.06	0.21
Wheat Flour	85.76	-----	-----	-----	10.08	0.86	-----	0.59	74.23[d]
SD	0.37				0.15	0.09		0.08	1.42

[a] One Dornic degree (°D) is equal to 0.01% lactic acid.
[b] Milk solids non fat.
[c] Fermented whey protein concentrate.
[d] Total carbohydrate content (%) of flour was calculated by difference.

Table 3. Effect of different levels of whey permeate (WP) and fermented whey protein concentrate (FWPC) on Falling number, dough handling, and water absorption of flour used for bread making.

Treatments	Level (%)	Falling number (s)	Dough handling	Water addition (mL)*	Water absorption (%)**
Control	0	475 ± 27[d]	Smooth	57.6 ± 0.4[e]	58.83 ± 0.41[NS]
Whey permeate	25	430 ± 28[e]	Smooth	58.67 ± 1.17[de]	59.04 ± 1.19
	50	416 ± 21[ef]	Smooth	59.9 ± 1.47[cde]	59.42 ± 1.48
	75	406 ± 24[ef]	Smooth	61.23 ± 1.35[bcd]	59.70 ± 1.36
	100	383 ± 24[f]	Smooth	63.03 ± 0.85[b]	60.85 ± 0.85
FWPC	25	493 ± 21[cd]	Smooth	59.60 ± 2.02[cde]	59.40 ± 2.05
	50	522 ± 23[bc]	Smooth	61.50 ± 2.21[bc]	59.87 ± 2.22
	75	551 ± 19[ab]	Smooth	63.73 ± 1.40[ab]	60.68 ± 1.40
	100	573 ± 31[a]	Slightly sticky	65.9 ± 1.14[a]	61.22 ± 1.37

[a-f] Means in the same column having different letters are significantly different ($p < 0.05$).
*Amount of water or mixture of water and whey permeate/FWPC added during dough preparation.
** Base on 14% flour moisture; NS: Non significant (Duncan test: $\alpha = 0.05$).

Table 4. Effect of different levels of whey permeate (WP) and fermented whey protein concentrate (FWPC) on bread making quality.

Treatments	Level (%)	Loaf vol. (cc)	Loaf height (cm)	Specific vol. (cc/g)	Baking loss (%)
Control	0	572 ± 16[a]	8.6 ± 0.42[a]	4.25 ± 0.15[ab]	19.02 ± 1.09[a]
Whey permeate	25	583 ± 23[a]	8.8 ± 0.21[a]	4.30 ± 0.22[ab]	18.44 ± 0.65[ab]
	50	622 ± 35[a]	9.2 ± 0.40[a]	4.46 ± 0.27[a]	16.91 ± 1.04[bcd]
	75	615 ± 23[a]	9.1 ± 0.44[a]	4.38 ± 0.120[ab]	17.13 ± 1.49[bcd]
	100	595 ± 22[a]	8.9 ± 0.47[a]	4.15 ± 0.13[ab]	16.38 ± 0.91[cd]
FWPC	25	583 ± 43[a]	8.7 ± 0.62[a]	4.22 ± 0.31[ab]	17.75 ± 0.76[abc]
	50	542 ± 46[ab]	8.5 ± 0.60[a]	3.85 ± 0.35[bc]	16.90 ± 0.91[bcd]
	75	492 ± 79[b]	7.7 ± 0.55[b]	3.40 ± 0.55[cd]	15.95 ± 0.73[cd]
	100	475 ± 52[b]	7.4 ± 0.51[b]	3.23 ± 0.38[d]	15.83 ± 0.68[d]
Sig. (≤ 0.05) between	*Volume*	*Loaf height*	*Specific vol.*	*Baking loss*	
Type of whey (WP and FWPC)	0.000**	0.000**	0.000**	0.183	
levels	0.225	0.050*	0.012*	0.000**	
Interactions	0.026*	0.034*	0.023*	0.808	

[a-d] Means in the same column having different letters are significantly different ($p < 0.05$), *Significant at 5%, **significant at 1%.

Control had high falling number value (475 s) indicating lower α-amylase activity than optimal level, i.e. 250 to 300 s. However, increasing the level of WP significantly improved the falling number values and all samples containing WP had significantly lower values than control, ranged from 383 to 430 s. On the other hand, incorporation of increasing amount of FWPC into the control led to progressive increase in falling number, probably because of increase in viscosity of slurry due to high viscosity of FWPC. The values in these samples varied from 493 to 573 s. In a study, Brar (2000) observed that samples containing whey had higher falling number value than control. The similar falling number for control (489 and 449 for two different type of flour) was reported by him.

3.2.2. *Dough handling and water absorption*

Incorporation of WP and FWPC at increasing levels during dough preparation showed significant increase in water absorption in comparison to control whereas handling of dough for all treatments was smooth except for samples contain 100% FWPC which was slightly sticky. Kadharmestan et al. (1998) also reported that wheat flour fortified with heat- or HHP-treated commercial whey protein concentrate produced crumby dough after mixing which had good sheeting properties.

It can be inferred from Table 3 that samples contained FWPC showed higher water absorption than samples contained WP. The mean values of percentage of water absorption for control, samples containing WP and FWPC were 58.83, 59.75 and 60.29%, respectively. The increase in water absorption in supplemented samples was due to whey proteins and lactose incorporation. Whey proteins have high water binding capacity and denaturation, e.g. as the form of FWPC, considerably increases this ability (Kadharmestan et al., 1998; Jayaprakasha & Brueckner, 1999).

The higher percentage of water absorption in FWPC samples as compare to WP samples was due to higher level of denatured whey proteins in FWPC (4.34%) than whey permeate (0.43%). Increase in dough water absorption by adding denatured whey proteins are well documented (Erdogdu-Arnoczky et al., 1996; Kadharmestan et al., 1998; Jayaprakasha & Brueckner, 1999). In samples containing WP, water absorption varied from 58.67 to 63.03 while in samples containing FWPC varied from 59.6 to 65.9%.

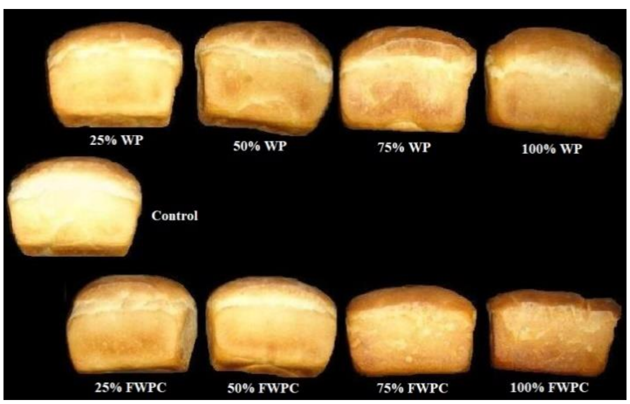

Fig. 1. Loaves of bread supplemented with different levels of whey permeate (WP, above) and fermented whey protein concentrate (FWPC, below).

3.3. *Effect of WP and FWPC on bread making quality*

Statistically significant variations were observed in loaf volume, loaf height, specific volume and baking loss when breads were prepared with different level of supplementation and different type of whey (WP and FWPC) (Table 4). Increasing WP up to 50% increased volume and height of loaves but thereafter slightly decreased (Figs. 1 and 2). However, all breads supplemented with WP had higher volume and height as compare to control. Contradictory to WP, increasing the level of FWPC, except at level 25%, progressively decreased loaf volume and height. Bread samples containing 75 and 100% FWPC had significantly lower loaf volumes and heights than control and other supplemented samples, while the differences between other samples were non-significant (Table 4). The highest loaf volume (622 cc) and loaf height (9.2 cm) were recorded for breads containing 50% WP, while the lowest (475 cc and 7.4 cm) were recorded for bread samples containing 100% FWPC.

Increase of loaf volume and height of bread by supplementation of whey and whey proteins have been comprehensively reported (Erdogdu-Arnoczky et al., 1996; Kadharmestan et al., 1998; Jayaprakasha & Brueckner, 1999; Brar, 2000). In agreement with our results, Brar (2000) found that addition of whey up to 15% (substitution base on total solids of flour) increases loaf volume, and further incorporation (up to 20%) slightly reduces this parameter. The decrease in loaf volume in bead fortified at higher levels of FWPC could be expected from the dilution of wheat gluten by nonglutenous proteins in FWPC (Kadharmestan et al., 1998).

The impact of different levels of WP and FWPC on specific volume of bread is shown in Table 4. As compare to control, supplementation with WP up to level 50% enhanced specific volume and thereafter slightly decreased. However, differences between supplemented breads with WP and control were not significant. The specific volume of control and supplemented breads with WP at levels 0, 25, 50, 75 and 100% were 4.25, 4.30, 4.46, 4.38 and 4.15% cc/g, respectively.

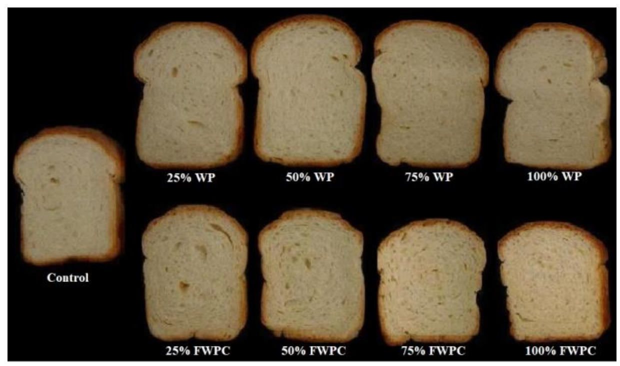

Fig. 2. Cut portions of loaves supplemented with different levels of whey permeate (WP, above) and fermented whey protein concentrate (FWPC, below).

Supplementation with FWPC had adverse effect on specific volume of loaf breads and incorporation of increasing amount of FWPC into the control led to progressive decrease in specific volume. This indicated that incorporation of FWPC in bread gives a compact texture to bread (Fig. 2). The higher hardness in FWPC fortified breads probably is due to the higher acidity and the superior protein content which both led to more protein aggregation and form rigid gel structure (Lupano, 2000; Yu et al., 2018). The specific volume of supplemented breads with FWPC for levels 25, 50, 75 and 100% were 4.22, 3.85, 3.40 and 3.23 cc/g, respectively. The results relating to effect of FWPC on specific volume of bread are in agreement with those reported by Gelinas and Lachance (1995) who observed that incorporation of fermented milk-whey ingredients significantly reduces specific volume of bread by 20%. Ferreyra et al. (2021) similarly reported that WPC had a negative impact on the specific volume of bread fermented with yeast.

Independent of whey type (WP or FWPC) and incorporation levels, baking loss of bread decreased significantly with WP or FWPC fortification compared to the control, indicating higher moisture retained in supplemented breads. The highest baking loss was related to control with 19.02%, while the lowest monitored for supplemented breads with 100% FWPC with 15.83%. It can be observed from Table 4 that baking loss in both supplemented breads with WP and FWPC was not significantly different. However, breads supplemented with FWPC had lower baking loss than other supplemented breads because of higher whey proteins. Kenny et al. (2000) stated that whey protein is an appropriate functioning agent that can utilize in bread making to enhance water absorption and nutritional value. Gonçalves et al. (2017) showed that bread containing 10 whey protein had appropriate textural parameters (hardness, chewiness and gumminess). Jooyandeh (2009a) also reported that utilization of FWPC in cheese making created cheeses with greater moisture leading to softer cheeses and higher yield. However, Rantamäki et al. (2006) contrary reported that utilization of whey protein fractions and high heat skim milk powder in bread loaves cause considerable baking loss.

4. Conclusion

Whey particularly in the form of concentrate\isolate is as amusing source of proteins with various food functionalities. In making some foods, whey products have find good applications since they contain valuable constituents, which results in better quality. However, commercial advantages of these whey products have not been renowned due to a restricted uses, absence of practical industrial technologies for fractionation and variation in product quality. Therefore, the present investigation was carried out on preparation and utilization of fermented whey protein concentrate (FWPC) and whey permeate (WP) in bread making to improve their yield and quality. Incorporation of WP and FWPC at increasing levels (25, 50, 75 and 100%) during dough preparation significantly increased water absorption and samples contained FWPC showed higher water absorption than samples contained WP. Levels and type of whey had significant impact on falling number and though incorporation of increasing amount of WP into the bread led to progressive decrease in falling number, addition of FWPC had adverse effect and falling number significantly increased. Increasing of WP up to 50% increased volume and height and specific volume of loaves and thereafter slightly decreased. However, all breads supplemented with WP had higher volume and height as compared to control (without WP or FWPC). Contradictory to WP, increasing the level of FWPC, except at level 25%, progressively decreased loaf volume and height. Bread samples containing 75 and 100% FWPC had significantly lower loaf volume, height and specific volume than control and other supplemented sample. Independent of whey type (WP or FWPC) and incorporation levels, baking loss of bread decreased significantly with WP or FWPC fortification compared to the control, indicating higher moisture retention in supplemented breads. Our results revealed that incorporation of whey in the form of WP or FWPC improve dough handling and bread quality. Therefore, utilization of WP/FWPC may be effectively applied in bread and even other baking products, not only to improve their quality, but also to enhance their nutritional values and to fulfill the request of consumers concerned in healthy diets.

Acknowledgment

Not applicable.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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