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Effect of honey powder on dough rheology and bread quality

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ABSTRACT

The effects of honey powder on dough rheology and bread quality were studied using sugar as controls. Farinographic studies showed that there were higher water absorption, shorter development time and stability time as honey powder increased, and small degree of softening were obtained for the dough containing 5% honey powder. Extensograph measurements showed that resistance to extension and R/E increased while energy value and extensibility decreased at level of 10% honey. Sensory evaluation showed that the largest total scores were obtained at level of 10% honey. Texture analysis showed that honey breads had low hardness, adhesiveness, gumminess, chewiness and high springiness, cohesiveness. The differences of the crust and crumb colour between honey breads and the control were significant ($P<0.05$). In conclusion, honey powder could be potentially a useful ingredient as a dough improver. Honey usage in the bread formulation supported an improvement in dough rheology, better sensory and texture properties of bread as compared to control formulation. Addition of 5%–10% honey powder significantly improved the baking quality of breads.

1. Introduction

Honey is a natural biological product that comprises of simple sugars (glucose and fructose: 70–80%), water (10–20%), and other minor constituents such as organic acids, mineral salts, vitamins, proteins, phenolic compounds, and free amino acids (Ouchemoukh et al., 2007). It is ordinarily liked by consumers for its nutraceutical value, characteristic flavor, sweetness, and texture (Subramanian et. al., 2007; Umesh Hebbar, & Rastogi, 2007). Honey can be used in bread formulation to increase overall quality of the product and to extend its shelf life. However, liquid honey is viscous and difficult to disperse in the dough, limiting its use in the food industry (Glabe, Anderson, & Goldman, 1970). By contrast, honey powder (dry honey) made from liquid honey can be dispersed easier, and so it has been more widely used in bread-baking industry for improving bread quality.

Bread is one of the most widely consumed food products in the world and bread making technology is one of the oldest technologies known. This technology has been evolving continuously as new materials, equipment and processes are being developed (Selomulyo & Zhou, 2007). The impacts of various ingredients on sensory and nutritional quality of bread have been widely studied (Barcenas & Rosell, 2005; Plessas et. al., 2005; Pherson, Bekatou, Nigam, & Koutinas, 2005). Addo (1997) examined the effects of honey on the rheological properties of frozen wheat flour dough and found that at 4–6% (flour basis) liquid or dry honey improved the rheological properties of frozen dough and the freshness of bread by increasing both the R/E values (Resistance to extension/Extensibility values) and moisture. Freshness is one of the characteristics that consumers most appreciate in bread (Fiszman et al., 2005). Fresh bread typically presents an appealing tan crust, pleasant roasted aroma, fine slicing characteristics, soft and elastic crumb textures, and a moist mouthfeel. The loss of bread freshness is characterized by increased crumb hardness and decreased flavour and aroma. In general, loss of moisture and starch retrogradation are accepted as the two main mechanisms leading to the firming of the crumb (Selomulyo & Zhou, 2007).

During the formulation of bakery products, honey powder is included in dough formulation in order to improve their nutritional, sensory and keeping quality. It also has a significant effect on dough rheological properties. Honey powder contributes to yellowy crumb and golden brown crust, increases fermentation or mixing tolerance of dough, and causes baked products to remain fresher and more moist. So enhancement of the fresh quality and/or inhibition of staling of bakery products can be achieved by using honey powder. The objective of this study is to investigate the effects of honey powder on dough rheology and bread quality, to understand its characteristics well and then to use it effectively. Quality parameters (volume, colour, texture, smoothness, springiness, and mouthfeel) of breads formulated with different honey powder levels are also compared.

2. Materials and methods

2.1. Materials

Commercial bread flour (Pang Thai 1650 high-grade Bread Flour) was provided by COFCO Industry Pang Thai Co.Ltd. (Qin Huang Dao,

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China). Honey powder (include 25% starch in it) was provided by Yancheng Huamei Honey Products Co. Ltd. (Yancheng, China). Bread improver (M III model) and dry baker's yeast were obtained from Meishan Mauri Yeast Co., Ltd. (Panyu, China). Butter oil substitute was provided by Chang Guann Co., Ltd. (Taiwan, China). Milk powder, sugar, eggs, salt and food bag were purchased at a local market. Chemicals used were of reagent grade.

2.2. Bread preparation

Bread samples were prepared using a straight dough method (GB/T 14611-93) with slight modification. The compositions of the selected dough formulation used in control bread comprised of 500 g flour, 240 g water, 90 g sugar, 40 g butter oil substitute, 20 g milk powder, 6 g dry baker's yeast, 6 g bread improver 5 g fine salt, and one egg (total about 50 g). For the fifteen bread samples containing honey powder, the dough formulation was identical with that of the control bread except that the sugar was replaced by honey powder. Sugar and honey contents varied from 1 to 15% on flour basis.

Flour, fine sugar, honey powder, milk powder were uniformly mixed in a stirrer (SM-5D model, Sinmag Machine Co. Ltd., Wuxi, China) using a dough hook, followed by the addition of yeast and bread improver. The dough was prepared in the stirrer for 1 min at 40 rpm, and 10 min at 70 rpm after egg and water were added. Final dough temperature was 28 °C. The dough was rested in bulk for 10 min, divided into pieces of 100 g, rounded by hand (ball shape), and submitted to an extra fermentation period of 10 min (intermediate proof). The dough was then kneaded, put in well-greased pans, proofed at 37 °C and 85% relative humidity for 2 h and baked in an electric oven set at upper temperature 170 °C and down temperature 220 °C for 20 min. Bread was removed from the pans and cooled at 25 °C for 1 h before testing.

2.3. Analysis of dough

2.3.1. Farinograph measurements of dough

Properties of dough were investigated using a farinograph-E (Brabender, Duisburg, Germany) according to a standard method (GB/T 14614-2006, China). The 300 g mixing bowl was used and the mixing was at the standard speed of 63 rpm at 30 °C. Water absorption, development time, stability time, degree of softening (12 minute after maximum), and mixing tolerance index of the samples were recorded.

2.3.2. Extensograph measurements of dough

Brabender extensograph-E (Brabender, Duisburg, Germany) was used to study the effects of honey powder on the energy value, resistance to extension, extensibility and R/E value in 45 min according to a Chinese national standard (GB/T 14615-2006, China).

2.4. Analysis of bread

2.4.1. Physical properties of bread

Loaf weights and volumes were measured 1 h after removal from the oven. Loaf was weighed using an electronic balance and loaf volume was measured using the rapeseed displacement method (Plessas et al., 2005). The specific volume was calculated by dividing loaf volume by loaf weight. The moisture content of samples was determined by AACC 44-15A standard method (American Association of Cereal Chemists, 2000). The data reported were the averages of three replicates of each formulation.

2.4.2. Sensory evaluation of bread quality

The sensory evaluation was performed using a descriptive profile test based on a Chinese national standard (GB/T 14611-93, China). A panel consisting of 9 trained university students from the School of Food Science in Jiangnan University performed the sensory evaluation of bread samples. The total mark of sensory evaluation for one sample was 100 points including volume 35, crust colour 5, crust texture 5, crumb colour 5, crumb texture 25, smoothness 10, springiness 10 and mouthfeel 5. The intensity of attributes was scored by a scale of 1 (extremely low) to highest score of index point (extremely high). The vocabulary of the descriptions and the intensity level of references for all attributes were generated through consensus. Sensory evaluation was made after storage of 1, 2, 3, 4 and 5 days at 22 ± 2 °C and 75 ± 5% RH. Bread was sliced utilizing a Sinmag slice machine (Wuxi, China). Each bread slice was served on a plate and covered with odorless plastic film. The experiment was conducted and based on randomized complete block design and a new random number was assigned to each bread treatment at each testing session to prevent bias. Each panelist evaluated 16 breads in one occasion. The tasted samples were disgorged and plain water was used for rinsing the palate between samples. Tests were replicated 3 times.

2.4.3. Texture of crumb

Texture profile analysis (TPA) of bread was done using a TA.XT 2i model texture analyzer (Stable Micro System Co. Ltd., Surrey, England) equipped with a 5 kg load cell 1 day after baking. A cylindrical probe of 25 mm in diameter was attached to the crosshead. The instrument test parameters were set as following: the pre-test speed: 2.0 mm/s; crosshead speed: 1 mm/s; post-test speed 10.0 mm/s; rupture test distance 1%; distance 50%; and time 5.00 s. Bread loaves were cut into slices of 15 mm thick each and the ends were discarded. Textural properties (hardness, adhesiveness, springiness, chewiness, gumminess, cohesiveness, and resilience) of bread slices were evaluated as per Bourne (2002). All the tests were conducted in triplicate, and average values were reported.

Bread slices were compressed twice to give a TPA from which three primary textural parameters (Pons & Fiszman, 1996) were obtained: hardness (bread firmness), springiness, and cohesiveness, as calculated by the texturometer software. Hardness values 1 and 2 were the maximum peak forces (g) during the first and second cycles, respectively. Cohesiveness was the ratio between the second cycle area and the first cycle area, and adhesiveness was the negative force area recorded during the first cycle, representing the work necessary to pull the compression plunger away from the sample. Springiness was defined as the height in mm the food sample recovered during the time that elapsed between the end of the first cycle and the start of the second cycle. Gumminess was the product of hardness 1 and cohesiveness. Modulus was the slope of the rising curve during the first cycle. Means and standard deviations for TPA parameters were calculated and used for correlation analysis.

2.4.4. Crust and crumb colour

Crust and crumb colours were determined using a Konica Minolta CR-400 chromameter (Konica Minolta Co., Ltd, Osaka, Japan). Crust colour was measured at the surface of bread crust and crumb colour was measured at the center part of crumb after the bread was cut into half pieces. Averages of three measurements of L (brightness), a (redness), b (yellowness) values and ΔE (the total colour difference) were recorded.

2.5. Statistical analysis

Analysis of variance (ANOVA) was conducted using the SPSS 12.0 General Linear Model procedure (SPSS inc., USA). The calculated mean values were compared using Duncan's multiple range test with significance level of $P < 0.05$ (Anil, 2007).

3. Results and discussion

3.1. Farinograph results

The farinograph results of doughs were given in Table 1, showing several interesting observations. First, water absorbtion ( ) decreased

Table 1
Farinograph data of doughs containing sugar or honey power.[a]

Sugar/flour(%) or honey power/flour(%)	Water absorption (%)	Development time (Min)	Stability time (Min)	Degree of softening (FU)
Sugar/flour				
0	63.2 ± 0.2	13.2 ± 0.1	17.1 ± 0.3	11 ± 0.2
5	63.0 ± 0.3	12.2 ± 0.2	15.0 ± 0.2	8 ± 0.2
10	62.8 ± 0.1	11.8 ± 0.3	13.3 ± 0.3	6 ± 0.1
15	60.8 ± 0.3	10.9 ± 0.2	11.3 ± 0.3	2 ± 0.1
Honey powder/flour				
0	63.2 ± 0.2	13.2 ± 0.1	17.1 ± 0.3	11 ± 0.2
5	65.1 ± 0.1	9.8 ± 0.1	11.5 ± 0.2	2 ± 0.1
10	67.6 ± 0.4	7.2 ± 0.2	10.0 ± 0.2	15 ± 0.1
15	71.1 ± 0.2	8.2 ± 0.1	4.5 ± 0.1	34 ± 0.3

[a] 300 g flour.

as sugar level increased while it increased as honey powder level increased. This was because fructose and starch in honey powder could absorb more water in dough than sugar. Secondly, development time and stability time of dough containing honey powder was shorter than that of dough containing sugar. Thirdly, degree of softening decreased as sugar level increased, but it would have more complicated changes as honey powder level increased. Degree of softening decreased when a small amount of honey powder(≤5%) was added into dough and it increased when the amounts of honey powder was more than 5%. However, too much honey powder (>10%) could weaken the intension of dough and could cause dough stickiness problem during kneading, making the dough difficult to work. Thus, higher quality of bread with looseness and tenderness could be made with the dough containing certain level of honey powder (5–10%) contrasted with the control.

3.2. The result of extensograph measurements

The extensographic properties of dough samples containing sugar or honey powder were given in Table 2. When no sugar or honey powder was added into the flour, area (energy value) of dough was 130 cm^2. It increased slowly as sugar level increased, while it decreased as honey powder increased until honey powder/flour was 10%. Resistance to extension was 616 EU and extensibility was 144 mm, so R/E value was 4.3 for control dough. Resistance to extension, extensibility and R/E did not change dramatically as the sugar content increased during 45 min aging for the dough containing sugar. As shown in Table 2, R/E values reached a maximum when honey powder/flour was 10%. The addition of honey powder at <10% level strengthened the dough rheological properties, so the honey powder led to a perceptible change of maturity of the dough during aging with increasing R and R/E values as compared with the control. On the other hand, high level of honey powder (>10%) would weaken dough rheological properties.

3.3. The results of sensory evaluation

The effects of honey powder on the sensory evaluation of bread were shown in Table 3. The bread formulated with 5–10% honey powder displayed good sensory quality as compared to the control. Sensory attributes (volume, crust colour, crust texture, crumb colour, crumb texture, smoothness, springiness, and mouthfeel) of bread were improved as honey powder increased up to 10% honey powder/flour level.

Honey powder bread had larger volume than sugar bread, this was because honey could accelerate yeast growth to generate a high amount of gas. Breads containing honey powder had yellow crumb and yellow brown crust colours, which was due to the high amount of fructose in honey powder to promote Maillard reaction.

The quality changes of bread containing sugar or honey powder after 2 days storage were shown in Table 4. Quality attributes of sugar bread deteriorated considerably after storage in just 2 days, especially, crust texture, smoothness, springiness and mouthfeel. Their total scores varied from 88.79 to 84.67. However, when sugar was partially substituted by honey powder, the sensory qualities of bread were improved, and the total scores of honey bread were significantly higher than sugar bread after 2 days storage. Because fructose in honey powder tends to absorb more moisture than sugar, the incorporation of honey powder resulted in higher retention of moisture in bread crumbs, thereby retardating staling and extending the shelf life.

3.4. The results of texture analyzer of bread quality

Hardness, adhesiveness, gumminess, chewiness, springiness, cohesiveness and resilience were texture attributes of bread. These attributes of bread could be determined by TPA. The results of texture profile analyzer of breads containing honey powder were shown in Table 5. After cooling and before storage, there was no obvious difference in crumb hardness (data not shown) between honey and the control bread samples. However, the sugar bread became harder than the honey breads after storage. Table 5 indicated that honey breads had lower hardness, adhesiveness, gumminess, chewiness, but higher springiness, cohesiveness than the control bread after 1 day storage. It is also worth noting that increasing honey powder level decreased hardness, adhesiveness, gumminess and chewiness. On the other hand, springiness and cohesiveness attributes were increased, although changes in resilience were not significant. The increased bread softness as the honey powder content increased may be attributed to the fructose present in honey was more hygroscopic than sugar. This is reflected to the higher moisture content of honey bread after storage (data not shown). The positive effect of honey powder on yeast activity and gas production during fermentation, in combination with the softening effect promoted by fructose on the gluten proteins led to increase in volume of loaves and longer shelf life. It appeared that honey powder had a softening effect on crumb hardness. The other results of the stored bread indicated that there were significantly ($P<0.05$) different adhesiveness, gumminess, chewiness, springiness, cohesiveness between the honey breads and the control bread, but resilience did not obviously change. The lower hardness, adhesiveness, gumminess, chewiness and higher springiness, cohesiveness and resilience would give honey bread good quality.

3.5. Crust and crumb colour

The colour of bread is related to physico-chemical characteristics of the raw dough and chemical reactions that take place during baking which are

Table 2
Extensograph data of doughs containing sugar or honey power.[a]

Sugar/flour(%) or honey power/flour(%)	Area (Energy value) (cm^2)	Resistance to extension (EU)	Extensibility (mm)	R/E (EU/mm)
Sugar/flour				
0	146 ± 2	616 ± 3	144 ± 2	4.3 ± 0.1
5	166 ± 1	682 ± 5	142 ± 3	4.8 ± 0.2
10	161 ± 2	556 ± 4	159 ± 2	3.5 ± 0.1
15	176 ± 1	588 ± 5	155 ± 3	3.8 ± 0.1
Honey powder/flour				
0	146 ± 2	616 ± 3	144 ± 2	4.3 ± 0.1
5	102 ± 1	798 ± 6	111 ± 2	7.2 ± 0.2
10	87 ± 2	771 ± 4	101 ± 1	7.6 ± 0.2
15	99 ± 1	643 ± 2	116 ± 3	5.6 ± 0.2

[a] 300 g flour.

Table 3
Results of sensory evaluation of bread containing different amounts of honey powder.[a]

H/F (%)	Volume (35)	Crust colour (5)	Crust texture (5)	Crumb colour (5)	Crumb texture (25)	Smoothness (10)	Springiness (10)	Mouthfeel (5)	Total
0	29.8 ± 0.1	4.3 ± 0.1	4.4 ± 0.1	4.6 ± 0.0	23.1 ± 0.1	9.2 ± 0.1	9.2 ± 0.0	4.4 ± 0.0	89.0 ± 0.5
1	30.0 ± 0.0	4.4 ± 0.0	4.4 ± 0.1	4.6 ± 0.1	23.1 ± 0.1	9.3 ± 0.1	9.2 ± 0.1	4.4 ± 0.1	89.4 ± 0.5
2	30.6 ± 0.1	4.5 ± 0.1	4.5 ± 0.1	4.8 ± 0.1	23.2 ± 0.0	9.4 ± 0.2	9.2 ± 0.1	4.6 ± 0.1	90.8 ± 0.8
3	31.2 ± 0.1	4.5 ± 0.1	4.6 ± 0.1	4.7 ± 0.2	23.4 ± 0.1	9.5 ± 0.1	9.4 ± 0.1	4.7 ± 0.1	92.0 ± 0.9
4	32.7 ± 0.1	4.7 ± 0.0	4.6 ± 0.1	4.9 ± 0.1	23.3 ± 0.1	9.4 ± 0.1	9.3 ± 0.2	4.6 ± 0.1	93.5 ± 0.8
5	35.0 ± 0.1	4.7 ± 0.1	4.5 ± 0.1	4.8 ± 0.1	23.4 ± 0.1	9.3 ± 0.0	9.3 ± 0.1	4.5 ± 0.1	95.5 ± 0.7
6	35.0 ± 0.0	4.8 ± 0.1	4.4 ± 0.1	4.9 ± 0.1	23.4 ± 0.2	9.4 ± 0.1	9.3 ± 0.1	4.5 ± 0.0	95.7 ± 0.7
7	35.0 ± 0.1	4.8 ± 0.1	4.5 ± 0.1	4.9 ± 0.1	23.5 ± 0.1	9.5 ± 0.1	9.4 ± 0.1	4.5 ± 0.1	96.1 ± 0.8
8	35.0 ± 0.0	4.8 ± 0.1	4.5 ± 0.1	4.9 ± 0.0	23.4 ± 0.1	9.4 ± 0.1	9.2 ± 0.1	4.5 ± 0.1	95.7 ± 0.6
9	35.0 ± 0.2	4.9 ± 0.1	4.6 ± 0.1	4.9 ± 0.1	23.4 ± 0.1	9.5 ± 0.1	9.4 ± 0.1	4.6 ± 0.1	96.3 ± 0.9
10	35.0 ± 0.0	4.9 ± 0.1	4.8 ± 0.1	4.9 ± 0.1	23.7 ± 0.0	9.3 ± 0.1	9.3 ± 0.1	4.6 ± 0.0	96.5 ± 0.5
11	33.3 ± 0.0	4.8 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	23.6 ± 0.1	9.5 ± 0.1	9.3 ± 0.1	4.7 ± 0.1	94.8 ± 0.7
12	31.5 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	4.8 ± 0.0	23.8 ± 0.1	9.3 ± 0.0	9.3 ± 0.0	4.6 ± 0.1	92.9 ± 0.5
13	32.4 ± 0.1	4.7 ± 0.0	4.6 ± 0.1	4.7 ± 0.1	23.7 ± 0.2	9.5 ± 0.1	9.4 ± 0.1	4.7 ± 0.0	93.7 ± 0.7
14	32.3 ± 0.0	4.7 ± 0.1	4.7 ± 0.1	4.7 ± 0.1	23.7 ± 0.1	9.5 ± 0.1	9.5 ± 0.1	4.7 ± 0.1	93.8 ± 0.7
15	32.3 ± 0.3	4.7 ± 0.1	4.6 ± 0.1	4.6 ± 0.2	23.6 ± 0.3	9.5 ± 0.1	9.4 ± 0.2	4.7 ± 0.1	93.4 ± 1.4

[a] H/F: Honey powder/flour.

dependent on operating conditions, such as Maillard reactions and caramelization which cause browning of baked products during baking.

The effects of honey powder on the bread colour were shown in Table 6. The crust of the honey powder breads had significantly higher L values and b values, lower a values and ΔE values as compared with those of the control bread. The more glucose and fructose in honey powder caused a greater extent of Maillard browning reaction in the crust, thereby intensifying the crust colour of honey breads.

The honeyed breads showed a yellower crumb than the control bread, again due to Maillard browning reaction of reducing sugars in honey with protein in the flour. Compared with the crust, the crumb of the honey bread gave much higher L values, but much lower a values, b values and ΔE values. This lighter colour was due to the lower extent of Maillard Browning reactions that take place in the crumb than crust. Crumb L value and ΔE value decreased, crumb a value and crumb b value increased as honey powder level increased.

4. Conclusion

Farinograph results showed that honey powder had a significant weakening effect on dough rheological properties. The farinograph results for dough samples containing honey powder showed that water absorption increased as honey powder increased, while development time, stability time and degree of softening were at acceptable range. Based on the results of extensograph, resistance to extension/extensibility (R/E) of dough containing honey powder increased over the control dough. On the other hand, over loading of honey powder (>10%) could cause the dough to develop stickiness problem during kneading.

Honey powder could potentially be used as a dough improver. Honey powder usage in the bread formulation supported an improvement in dough rheology, better sensory attributes, and enhanced texture properties of bread as compared to the control formulation. The addition of honey powder at 5 to 10% level improved the baking quality by retarding staling and increasing shelf life. They also had a desirable effect on the colour development of crust and crumb of bread. When honey powder was incorporated into the bread, the products had higher volume, softer crumb, and yellower colour. Sensory evaluation by a consumer panel also revealed that the panel preferred the breads made from dough containing 5–10% honey powder and were equally satisfied with either the fresh breads or the breads after 2 days storage. The breads containing 5–10% honey powder had the highest total sensory evaluation scores. Based on these results, 5–10% honey powder addition could be recommended in bread making as a substitute of sugar. Additional studies would be required to elucidate the role of honey powder on other quality characteristics of breads.

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Table 4
The quality changes of bread containing sugar or honey powder after 2 days storage.[a]

Days	Volume (35)	Crust colour (5)	Crust texture (5)	Crumb colour (5)	Crumb texture (25)	Smoothness (10)	Springiness (10)	Mouthfeel (5)	Total
#1	29.8 ± 0.1	4.3 ± 0.1	4.4 ± 0.1	4.6 ± 0.0	23.1 ± 0.1	9.2 ± 0.1	9.2 ± 0.0	4.4 ± 0.0	88.8 ± 0.5
#2	29.8 ± 0.1	4.2 ± 0.1	3.9 ± 0.0	4.6 ± 0.1	22.7 ± 0.1	9.0 ± 0.0	9.0 ± 0.1	4.3 ± 0.1	87.4 ± 0.6
#3	29.8 ± 0.1	4.2 ± 0.1	3.2 ± 0.1	4.6 ± 0.1	21.7 ± 0.3	8.9 ± 0.1	8.9 ± 0.0	3.6 ± 0.1	84.7 ± 0.9
#4	29.8 ± 0.1	4.2 ± 0.0	2.7 ± 0.2	4.5 ± 0.0	18.4 ± 0.1	8.9 ± 0.2	8.7 ± 0.1	3.1 ± 0.2	80.1 ± 0.9
#5	29.8 ± 0.0	4.1 ± 0.1	2.0 ± 0.1	4.5 ± 0.1	16.6 ± 0.2	8.7 ± 0.1	8.5 ± 0.1	2.9 ± 0.1	77.0 ± 0.8
0	35.0 ± 0.0	4.9 ± 0.1	4.8 ± 0.1	4.9 ± 0.1	23.7 ± 0.0	9.3 ± 0.1	9.3 ± 0.1	4.6 ± 0.0	96.5 ± 0.5
1	35.0 ± 0.0	4.9 ± 0.1	4.6 ± 0.1	4.9 ± 0.1	23.8 ± 0.1	9.2 ± 0.1	9.2 ± 0.1	4.8 ± 0.1	96.4 ± 0.7
2	35.0 ± 0.1	4.8 ± 0.1	4.6 ± 0.1	4.8 ± 0.1	23.6 ± 0.1	9.2 ± 0.0	9.2 ± 0.1	4.7 ± 0.1	95.9 ± 0.7
3	35.0 ± 0.0	4.9 ± 0.1	4.6 ± 0.0	4.8 ± 0.0	23.2 ± 0.3	9.0 ± 0.1	9.0 ± 0.0	4.7 ± 0.1	95.2 ± 0.6
4	35.0 ± 0.0	4.8 ± 0.0	4.5 ± 0.1	4.8 ± 0.1	22.9 ± 0.1	8.8 ± 0.1	8.8 ± 0.1	4.5 ± 0.0	94.1 ± 0.5
5	35.0 ± 0.1	4.8 ± 0.1	4.5 ± 0.1	4.8 ± 0.1	22.0 ± 0.2	8.8 ± 0.1	8.8 ± 0.2	4.4 ± 0.1	93.1 ± 1.0

[a] The first five lines marked with # were breads containing sugar.

Table 5
The results of texture profile analyzer of breads containing honey powder.[a]

H/F(%)	Hardness (g)	Adhesiveness	Springiness	Cohesiveness	Gumminess	Chewiness	Resilience
0	130.3 ± 0.2	0.0046 ± 0.0001	1.45 ± 0.01	0.51 ± 0.01	66.9 ± 0.1	98.4 ± 0.0	0.37 ± 0.01
1	124.4 ± 0.1	0.0040 ± 0.0001	1.46 ± 0.02	0.51 ± 0.02	63.8 ± 0.2	93.3 ± 0.1	0.37 ± 0.01
2	109.7 ± 0.3	0.0032 ± 0.0003	1.46 ± 0.01	0.51 ± 0.01	56.3 ± 0.1	82.0 ± 0.1	0.35 ± 0.02
3	103.4 ± 0.1	0.0018 ± 0.0001	1.50 ± 0.01	0.53 ± 0.01	54.4 ± 0.2	81.6 ± 0.3	0.37 ± 0.01
4	98.4 ± 0.1	0.0010 ± 0.0002	1.51 ± 0.04	0.52 ± 0.03	51.3 ± 0.1	77.6 ± 0.1	0.38 ± 0.01
5	95.7 ± 0.0	0.0006 ± 0.0001	1.64 ± 0.01	0.53 ± 0.01	51.1 ± 0.1	84.0 ± 0.1	0.37 ± 0.01
6	79.7 ± 0.1	0.0005 ± 0.0001	1.67 ± 0.03	0.54 ± 0.01	42.9 ± 0.2	71.8 ± 0.3	0.39 ± 0.03
7	89.8 ± 0.1	0.0008 ± 0.0002	1.67 ± 0.01	0.55 ± 0.01	49.1 ± 0.1	82.0 ± 0.1	0.40 ± 0.01
8	84.0 ± 0.1	−0.0006 ± 0.0001	1.71 ± 0.01	0.55 ± 0.02	46.8 ± 0.1	79.0 ± 0.1	0.43 ± 0.01
9	89.7 ± 0.1	−0.0010 ± 0.0001	1.63 ± 0.01	0.56 ± 0.01	49.8 ± 0.1	80.9 ± 0.2	0.40 ± 0.02
10	87.7 ± 0.0	−0.0013 ± 0.0	1.62 ± 0.02	0.57 ± 0.01	49.5 ± 0.2	80.4 ± 0.1	0.38 ± 0.01
11	96.7 ± 0.1	−0.0009 ± 0.0001	1.60 ± 0.01	0.56 ± 0.01	48.7 ± 0.1	77.9 ± 0.1	0.37 ± 0.01
12	94.3 ± 0.3	−0.0017 ± 0.0001	1.61 ± 0.01	0.56 ± 0.03	46.9 ± 0.3	75.5 ± 0.2	0.34 ± 0.0
13	80.3 ± 0.1	−0.0014 ± 0.0005	1.72 ± 0.01	0.55 ± 0.01	44.5 ± 0.1	76.4 ± 0.1	0.36 ± 0.01
14	80.1 ± 0.1	−0.0029 ± 0.0001	1.70 ± 0.03	0.57 ± 0.01	45.3 ± 0.1	77.1 ± 0.1	0.37 ± 0.02
15	80.0 ± 0.4	−0.0016 ± 0.0002	1.72 ± 0.01	0.57 ± 0.01	44.9 ± 0.4	77.1 ± 0.2	0.36 ± 0.01

[a] Texture profile analysis (TPA) was done 1 day after baking. H/F: Honey powder/flour.

Table 6
The results of crust colour or crumb colour of bread containing honey powder.[a]

H/F (%)	Crust colour				Crumb colour			
	L	a	b	ΔE	L	a	b	ΔE
0	46.4 ± 0.3	18.9 ± 0.1	34.9 ± 0.0	57.3 ± 0.1	76.0 ± 0.0	− 1.5 ± 0.1	13.2 ± 0.2	19.8 ± 0.0
2	47.8 ± 0.1	18.7 ± 0.2	33.2 ± 0.1	57.1 ± 0.5	75.6 ± 0.1	− 1.2 ± 0.2	14.6 ± 0.1	19.4 ± 0.1
4	47.5 ± 0.1	18.7 ± 0.1	33.0 ± 0.1	56.5 ± 0.1	74.0 ± 0.3	− 0.8 ± 0.1	14.0 ± 0.3	19.0 ± 0.2
6	47.9 ± 0.2	18.5 ± 0.3	37.3 ± 0.2	56.1 ± 0.1	73.3 ± 0.1	− 0.8 ± 0.2	14.5 ± 0.2	16.0 ± 0.2
8	49.1 ± 0.1	17.5 ± 0.1	35.9 ± 0.1	42.3 ± 0.3	71.2 ± 0.1	− 0.7 ± 0.2	17.2 ± 0.1	12.5 ± 0.1
10	51.8 ± 0.1	17.7 ± 0.1	36.2 ± 0.1	41.8 ± 0.1	71.3 ± 0.2	− 0.5 ± 0.1	15.7 ± 0.5	12.2 ± 0.4
12	53.3 ± 0.5	17.2 ± 0.0	33.2 ± 0.3	41.3 ± 0.2	69.9 ± 0.1	− 0.4 ± 0.1	16.6 ± 0.1	11.7 ± 0.1
14	59.4 ± 0.1	15.7 ± 0.1	37.5 ± 0.1	39.0 ± 0.1	68.3 ± 0.1	− 0.4 ± 0.1	16.7 ± 0.2	11.4 ± 0.5

[a] H/F: Honey powder/flour.

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