Selcuk Journal of Agriculture and Food Sciences

http://sjafs.selcuk.edu.tr/sjafs/index

Research Article

SJAFS
(2022) 36 (3), 399-404
e-ISSN: 2458-8377
DOI:10.15316/SJAFS.2022.052

Effects of Replacing Breadcrumbs with Buckwheat, Chickpea, Corn and Millet Flour in Gluten-Free Meatball Formulation

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ARTICLE INFO

Article history:
Received date: 12.08.2022
Accepted date: 29.09.2022

Keywords:
Celiac disease
Cooking yield
Meat product
Meatball quality
Sensory

ABSTRACT

The objective of this study was to evaluate the effects of different gluten-free flours on the physicochemical, textural and sensory properties of meatballs. Five different groups of meatballs were produced: C: control meatballs with breadcrumbs, Gf1: meatballs with buckwheat flour, Gf2: meatballs with chickpea flour, Gf3: meatballs with corn flour and Gf4: meatballs with millet flour. The chickpea flour increased the protein content of raw meatballs ($P < 0.05$). The cooking yield results were higher in gluten-free meatballs than in control samples ($P < 0.05$). Chickpea flour (Gf2) and corn flour (Gf3) were the most effective flours for reducing the diameter of meatballs ($P < 0.05$). The highest antioxidant activity was found in the meatballs with buckwheat flour (Gf1) ($P < 0.05$). The chickpea flour improved the texture of the meatball samples ($P < 0.05$), while corn and millet flour increased the hardness and chewiness values of the meatballs ($P < 0.05$). Millet flour decreased the flavour score compared to the control ($P < 0.05$), whereas the other gluten-free flours had no significant effect on all sensory properties of the meatballs ($P > 0.05$). This study suggests that chickpea flour had a better effect on the quality characteristics of meatballs among gluten-free flours.

1. Introduction

Meatballs are one of the restructured meat products that can be made from ground beef, pork, chicken or fish. Meatballs are very popular in all walks of life around the world and are made in both domestic and commercial meat processing plants. A meatball is minced meat rolled into a small ball, usually together with other ingredients such as breadcrumbs or bread, chopped onions, eggs, butter and spices (Kartikawati & Purnomo 2019; Saba et al 2018). Breadcrumbs or bread are made from wheat flour, which contains about 60% gluten (Jackson et al 2006). Celiac disease is one of the most notable gluten-related diseases, affecting about 1% of the world's population (Cui et al 2017). Celiac disease is a genetically predisposed autoimmune problem. People with celiac disease often suffer adverse reactions to products containing gluten (Larrosa et al 2013). As the only treatment option for celiac disease is a lifelong gluten-free diet (Gobbetti et al 2018), it is of great importance to improve gluten-free food alternatives that can meet sensory and nutritional quality requirements (Kerimoğlu & Serdaroğlu 2019). Therefore, it is necessary to advance the new ingredients and formulations, especially to produce gluten-free meat products. Buckwheat (*Fagopyrum esculentum* Moench), a type of pseudo-cereal, has been suggested as a good alternative for celiac patients because it contains bio-quality proteins, high levels of dietary fiber, flavonoids and essential minerals (Park et al 2016). The chickpea (*Cicer aeritinum* L.) is the most consumed legume in the world. The chickpea is a cheap and gluten-free legume with nutritious components such as carbohydrates, proteins, lipids, vitamins and minerals, and with high protein digestibility and low glycaemic index properties (Gobbetti et al 2018; Sofi et al 2020). Corn (*Zea mays* subsp.) flour has proven to be one of the most suitable flours for developing gluten-free products. This could be due to its soft taste, easily digestible carbohydrate content, low prolamin content and hypoallergenic properties (Marco & Rossell 2008). Millet (*Panicum miliaceum*), a gluten-free cereal, is considered one of the most important crops. It is also considered a good source of carbohydrates and has a high protein content, which is a richer source of essential amino acids than wheat (Kalinova & Moudry 2006).

Limited studies on the use of different cereal and legume flours to produce of gluten-free meat products such as rice flour in chicken nugget (Jackson et al 2006),

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sorghum flour in chicken nugget (Devatkal et al 2011), millet flour in kibbeh (Brasil et al 2015), chickpea flour in chicken nugget (Öztürk et al 2018), corn flour in fish patty (Romero et al 2018), soy flour in meatball (Mastanjević et al 2014) and quinoa flour in meatball (Bağdatlı 2018) are available in the literature. However, there is a lack of comprehensive study in which gluten-free meatballs are made from buckwheat, chickpea, corn and millet flour as a substitute for breadcrumbs. Therefore, the aim of this study is to evaluate the physicochemical, textural and sensory characteristics of meatballs containing buckwheat, chickpea, corn or millet flour as a substitute for breadcrumbs in the formulation.

2. Materials and Methods

2.1. Materials

The beef (*Biceps femoris*) and beef fat were obtained from a butcher in Konya. The breadcrumbs, buckwheat flour (Rasayana, Konya, Turkey), chickpea flour (Doğalsan, Ankara, Turkey), corn flour (Bağdat, Ankara, Turkey) and millet flour (Rasayana, Konya, Turkey) were purchased from a market in Konya. The salt (Salina, Ankara, Turkey), onion powder (Bağdat, Ankara, Turkey) and black pepper (Bağdat, Ankara, Turkey) used in the production of meatballs were obtained from a market in Konya.

2.2. Preparation of meatballs

The beef and beef fat were minced twice in a meat grinder with a plate with 3 mm diameter holes (Kitchen Aid, Classic Model, USA) and then the minced meat was divided into five parts. As outlined in Table 1, five different meatball formulations were prepared as follows: C (control group-including breadcrumbs), Gf1 (including buckwheat flour), Gf2 (including chickpea flour), Gf3 (including corn flour) and Gf4 (including millet flour). In the formulation of meatball samples, the breadcrumb was replaced completely by gluten-free flours in the groups of Gf1, Gf2, Gf3 and Gf4. The minced meat and the other ingredients were weighed separately and then mixed for 7 min. This meatball dough was stored at 4 °C for 5 h and formed into meatballs in a petri dish (40 g per meatball) to obtain an average size (about 4 cm in diameter).

Table 1
Formulation of meatball samples

Formulation	Meatball samples				
(%)	C	Gf1	Gf2	Gf3	Gf4
Meat	75.00	75.00	75.00	75.00	75.00
Beef fat	15.00	15.00	15.00	15.00	15.00
Breadcrumb*	5.00	5.00	5.00	5.00	5.00
Water	2.00	2.00	2.00	2.00	2.00
Salt	1.50	1.50	1.50	1.50	1.50
Onion powder	1.00	1.00	1.00	1.00	1.00
Black pepper	0.25	0.25	0.25	0.25	0.25
Cumin	0.25	0.25	0.25	0.25	0.25

*Breadcrumb was substituted completely by gluten-free flours in the groups of Gf1, Gf2, Gf3 and Gf4. C: control sample including breadcrumbs, Gf1: gluten-free sample including buckwheat flour, Gf2: gluten-free sample including chickpea flour, Gf3: gluten-free sample including corn flour, Gf4: gluten-free sample including millet flour.

A total of 150 meatball samples were produced: ten meatballs for each treatment x five treatments (C, Gf1, Gf2, Gf3 and Gf4) x three independent replications. The samples were grilled for 15 minutes and turned over every 2.5 minutes to reach an internal temperature of 72°C. The temperature was measured with a thermometer (Digitale Bratengabel-TCM).

2.3. Proximate composition and pH measurement

Moisture (AOAC method 985.14), total protein (AOAC method 979.09), total fat (AOAC method 991.36), total ash (AOAC method 942.05) and pH (AOAC method 981.12) of the raw meatball samples were determined according to AOAC (2000).

2.4. Cooking yield

The cooking yield was calculated from the weight differences of the meatball samples before and after cooking. The cooked samples were cooled to room temperature for 30 minutes and then weighed (Murphy et al 1975). The cooking yield results were expressed as a percentage (%).

2.5. Reduction in diameter of meatball samples

The reduction in the diameter of the meatballs was determined by calculating the difference in the diameter of the samples before and after cooking (Yildiz Turp et al 2016). Measurements of the meatball samples were made with a digital micrometre (Mitutoyo, Japan). The reduction in diameter of meatballs was given as a percentage (%).

2.6. Determination of reduction in meatball volume

The reduction in volume of the meatballs was determined by calculating the difference in volume of the samples before and after cooking (Yildiz Turp et al 2016). The reduction in volume of the meatballs was expressed as a percentage (%).

2.7. Determination of antioxidant activity

The antioxidant activity of the cooked meatball samples was determined using DPPH (1,1-diphenyl-2-picrylhydrazyl) according to Brand-Williams et al (1995). The absorbance of the solutions was measured at 517 nm. DPPH antioxidant activity results were given as a percentage of free radical scavenging activity (%).

2.8. Colour measurements

The colour measurements of the raw and cooked meatball samples were made with a colourimeter (Konica, Minolta CR 400, Osaka, Japan). The L^* (lightness), a^* (redness) and b^* (yellowing) were determined according to Hunt et al (1991).

2.9. Texture profile analysis

Texture profile analysis (TPA) was carried out using the double compression method with a texture analyser (TA-HD Plus Texture Analyser, UK). A cylindrical plate with a diameter of 35 cm and a 50 kg load cell were used. The sample was compressed twice, with a delay of

0.1 s between the descents, a distance of 5 mm, a pre-test velocity of 1 mm/s, a test velocity of 5 mm/s, a post-test velocity of 5 mm/sec and a compression of 50%. The parameters of hardness, springiness, cohesiveness and chewiness were determined (Crehan et al 2000).

2.10. Sensory evaluation

A sensory panel consisting of 21 panellists conducted the sensory evaluations of the meatballs. Before the panel, the panellists were informed about the study. Samples were coded with three-digit numbers and randomly presented to the panellists. Along with the meatballs, the panellists were given water and bread. A 9-point hedonic scale was used for the sensory panel (9: very high acceptability value, 1: very low level of acceptability). The panellists were asked to rate the appearance, odour, flavour and texture of the meatball samples using the scale given to them.

2.11. Statistical analysis

This study was conducted in three independent replicates with double sampling and a completely randomised design was used. One-way analysis of variance (ANOVA) was performed for all analysis results using the Minitab version 16.0 programme. Tukey multiple comparison tests were performed to determine differences between means at a 5% significance level.

3. Results and Discussion

3.1. Proximate composition and pH

Proximate compositions and pH values of the raw meatball samples are shown in Table 2. As seen, the different flours did not affect the moisture content, total fat content, total ash content and pH values of the samples, while the total protein contents of the C and GF1 were lower than the other groups ($P < 0.05$). The highest total protein content was found in the meatball samples produced with chickpea flour. Buresova et al (2017) pointed out that chickpea flour had a higher protein content than buckwheat, corn and millet flour. Therefore, this is the reason for the higher protein content of the meatball samples containing chickpea flour. These results are consistent with those of Kurt and Kılıççeker (2012), who reported that different cereal and legume flours did not change the pH and moisture content of raw meat patties, and chickpea flour increased the protein content of the samples compared to wheat flour.

Table 2
Proximate compositions and pH values of raw meatball samples

Samples	Moisture (%)	Total protein (%)	Total fat (%)	Total ash (%)	pH
C	61.89 ± 0.08	17.15 ± 0.11^{b}	16.74 ± 0.30	2.29 ± 0.05	6.12 ± 0.01
Gf1	61.86 ± 0.18	17.11 ± 0.04^{b}	16.97 ± 0.30	2.23 ± 0.07	6.19 ± 0.01
Gf2	61.46 ± 0.28	17.93 ± 0.04^{a}	16.61 ± 0.38	2.35 ± 0.03	6.16 ± 0.03
Gf3	61.09 ± 0.09	17.58 ± 0.32^{ab}	16.98 ± 0.16	2.44 ± 0.04	6.12 ± 0.03
Gf4	61.55 ± 0.45	17.62 ± 0.26^{ab}	16.77 ± 0.12	2.19 ± 0.01	6.13 ± 0.04

Values with different lowercase superscript letters show significant differences ($P < 0.05$). C: control sample including breadcrumbs, Gf1: gluten-free sample including buckwheat flour, Gf2: gluten-free sample including chickpea flour, Gf3: gluten-free sample including corn flour, Gf4: gluten-free sample including millet flour.

3.2. Cooking characteristics

The cooking yield, reduction in diameter and in volume of the meatball samples are given in Table 3. Gluten-free flours increased the cooking yield of the meatball samples ($P < 0.05$). The lowest cooking yield was found in the control group ($P < 0.05$). The differences in the cooking yield results of samples with gluten-free flours were not significant ($P > 0.05$). It was reported that cooking characteristics of meat products were generally influenced by the ability to bind water and fat during cooking process (Salcedo-Sandoval et al 2014). The results of the current study indicate that the improvement in cooking yield by adding gluten-free starch-based flour to meatballs is mainly related to water retention. When the flour is heated, the starch gelatinises, and the flour fibres swell. The swollen starch and fibres can interact with the protein of the meatball matrix to prevent the migration of moisture from the product during cooking (Narayana et al 1982). Similarly, Makri and Douvi (2014) indicated that corn flour showed increased cooking yield in gilthead sea bream (*Sparus aurata*) patties. Alakali et al (2010) also stated that Bambara groundnut flour increased the cooking yield values of beef patties.

Table 3
Cooking characteristics of meatballs

Samples	Cooking yield (%)	Reduction in diameter (%)	Reduction in volume (%)
C	80.53 ± 0.44^{b}	16.73 ± 0.28^{a}	20.72 ± 3.99^{a}
Gf1	84.08 ± 0.61^{a}	14.50 ± 0.13^{b}	17.85 ± 4.62^{ab}
Gf2	84.66 ± 0.25^{a}	8.35 ± 0.98^{c}	12.63 ± 3.09^{ab}
Gf3	85.28 ± 1.29^{a}	9.29 ± 0.95^{c}	8.08 ± 0.58^{b}
Gf4	84.31 ± 0.41^{a}	13.37 ± 1.17^{b}	14.26 ± 5.70^{ab}

$^{a-c}$: Values with different lowercase superscript letters show significant differences ($P < 0.05$). C: control sample including breadcrumbs, Gf1: gluten-free sample including buckwheat flour, Gf2: gluten-free sample including chickpea flour, Gf3: gluten-free sample including corn flour, Gf4: gluten-free sample including millet flour

Gluten-free flours decreased the reduction in diameter of meatball samples compared to control group ($P < 0.05$). Chickpea flour (Gf2) and corn flour (Gf3) have been found to be the most effective flours for reducing the diameter of meatballs ($P < 0.05$). It was determined that corn flour was the most effective in volume reduction ($P < 0.05$). This effect of corn flour could be due to its starch, which plays an important role in improving reformed meat products, as well as its protein content and gelling properties (Berry 1997; Alakali et al 2010). Similarly, Kurt and Kılıççeker (2012) reported that corn flour decreased the diameter reduction values of beef patties.

3.3. Antioxidant activity

DPPH antioxidant activity results of the cooked meatball samples are shown in Figure 1. The highest antioxidant activity was determined in meatball samples with buckwheat flour (Gf1) ($P < 0.05$).

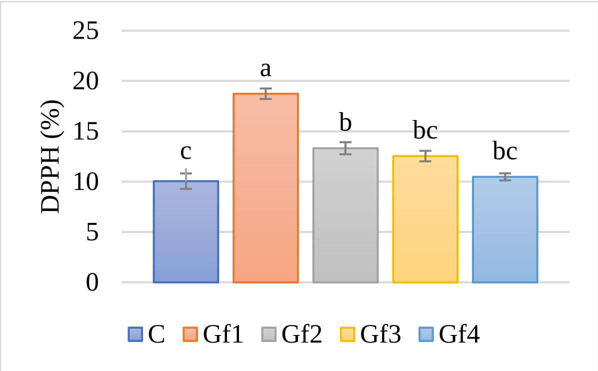

Figure 1
DPPH antioxidant activity of cooked meatball samples. Bar charts with different letters (a-c) indicate significant differences between the sample groups ($P < 0.05$). C: control sample including breadcrumbs, Gf1: gluten free sample including buckwheat flour, Gf2: gluten free sample including chickpea flour, Gf3: gluten free sample including corn flour, Gf4: gluten free sample including millet flour.

This group was followed by meatballs containing chickpea flour (Gf2) ($P < 0.05$). Control group meatballs had the lowest DPPH values. Similar results were obtained by Sedej et al (2010), who reported that buckwheat flour had higher polyphenols content and DPPH antioxidant activity than wheat flour. Beitane et al (2018) also pointed out that the content of phenols and antioxidant activity in buckwheat flour was higher than in wheat flour.

3.4. Colour properties

Colour is one of the most important quality parameters for meat products. The L^*, a^* and b^* values of the raw and cooked meatball samples can be seen in Table 4. Gluten-free flours did not change the colour parameters of either the raw or the cooked meatballs ($P > 0.05$). Similarly, Sanjeewa et al. (2010) found that the L^* and a^* values for the cooked bologna were not affected by the addition of chickpea flour. Also, Makri and Douvi (2014) reported that addition of 2.5% corn flour did not affect the colour properties of the sea bream (*Sparus aurata*) patties.

Table 4
Colour properties of raw and cooked meatball samples

Samples	Raw meatball samples			Cooked meatball samples		
	L^*	a^*	b^*	L^*	a^*	b^*
C	39.38 ± 1.13	12.78 ± 0.83	7.75 ± 0.38	34.40 ± 0.80	6.81 ± 0.31	5.78 ± 0.29
Gf1	44.09 ± 1.18	13.62 ± 0.80	9.65 ± 0.92	35.27 ± 0.65	7.78 ± 0.26	5.91 ± 0.26
Gf2	41.76 ± 1.43	13.42 ± 0.86	10.21 ± 0.88	35.62 ± 0.97	6.42 ± 0.47	6.28 ± 0.29
Gf3	39.22 ± 0.86	14.17 ± 1.17	9.71 ± 1.02	35.44 ± 1.34	7.70 ± 0.53	6.72 ± 0.30
Gf4	41.70 ± 1.64	12.19 ± 0.35	9.14 ± 1.05	34.34 ± 0.83	7.30 ± 0.22	5.77 ± 0.22

Values with different lowercase superscript letters show significant differences ($P < 0.05$). C: control sample including breadcrumbs, Gf1: gluten-free sample including buckwheat flour, Gf2: gluten-free sample including chickpea flour, Gf3: gluten-free sample including corn flour, Gf4: gluten-free sample including millet flour.

3.5. Textural properties

The values for hardness, springiness, cohesiveness and chewiness of the meatball samples are given in Table 5. The addition of gluten-free flours influenced all parameters of the texture analysis ($P < 0.05$). The lowest hardness and chewiness values were determined in the samples with breadcrumbs (C) and chickpea flour (Gf2), while corn, millet and buckwheat flour increased the hardness and chewiness values compared to the control ($P < 0.05$). In terms of springiness and cohesiveness, samples including gluten-free flours were simlar to control group ($P > 0.05$).

The change in textural properties due to the addition of gluten-free flour to meatballs is mainly related to water binding. In this study, improving the textural properties of meatballs with chickpea flour, which has the best cooking properties (Table 3), shows that the results are mutually supportive. Similar observations were reported for gilthead sea bream patties formulated with different concentrations of corn flour (Makri & Douvi 2014). Bahmanyar et al (2021) also reported that buckwheat flour increased the values of textural parameters in fried beef burgers compared to the control group.

Table 4
Textural characteristics of meatball samples

Samples	Hardness (N)	Springiness	Cohesiveness	Chewiness (N x mm)
C	168.30 ± 4.84^{c}	0.85 ± 0.01^{ab}	0.58 ± 0.02^{ab}	98.25 ± 3.57^{c}
Gf1	191.49 ± 4.99^{b}	0.86 ± 0.01^{a}	0.62 ± 0.01^{a}	118.47 ± 3.56^{b}
Gf2	163.15 ± 3.29^{c}	0.83 ± 0.00^{b}	0.54 ± 0.01^{b}	88.17 ± 2.33^{c}
Gf3	223.39 ± 7.36^{a}	0.87 ± 0.01^{a}	0.63 ± 0.01^{a}	140.22 ± 5.60^{a}
Gf4	207.70 ± 4.08^{ab}	0.86 ± 0.00^{a}	0.61 ± 0.01^{a}	127.54 ± 3.84^{ab}

Values with different lowercase superscript letters show significant differences ($P < 0.05$). C: control sample including breadcrumbs, Gf1: gluten-free sample including buckwheat flour, Gf2: gluten-free sample including chickpea flour, Gf3: gluten-free sample including corn flour, Gf4: gluten-free sample including millet flour.

3.6. Sensory scores

The sensory results of the cooked meatball samples are presented in Figure 2. The gluten-free flours had no effect on the appearance, odour and texture of the samples ($P > 0.05$), while the flavour scores of the meatballs were significantly different ($P < 0.05$). The samples including millet flour had the lowest flavour scores. The differences between the other groups were not significant for the flavour scores ($P > 0.05$). Although no difference was detected between the texture scores of the samples in the sensory panel, as seen in Table 5, the textural properties of the samples were different in the texture profile analysis. This inconsistency may be due to different temperatures of the test conditions. In the sensory panel, the samples were served at a temperature of about 40 °C, but texture profile analysis with the Texture Analyser was measured at room temperature (Bahmanyar et. al., 2021). Brasil et. al. (2015) reported that cooked kibbehs with millet flour did not differ in appearance, texture and flavour from the samples with wheat flour. Elhassan et al. (2019) indicated that sensory evaluation (appearance, taste, texture, juiciness and overall acceptability) significantly decreased by increasing the chickpea flour content in beef sausages. These different results between studies may be due to differences in treatments, levels of added flour, other additives, meat products and cooking process.

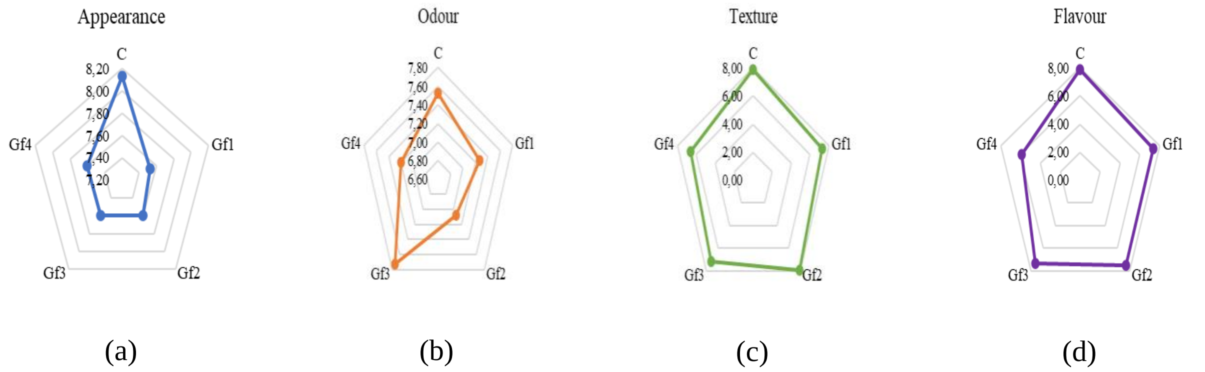

Figure 2
Spider web view of the sensory scores of meatball samples. (a): Appearance scores of the samples, (b): Odour scores of the samples, (c): Texture scores of the samples, (d): Flavour scores of the samples. C: control sample including breadcrumbs. Gf1: gluten free sample including buckwheat flour, Gf2: gluten free sample including chickpea flour, Gf3: gluten free sample including corn flour, Gf4: gluten free sample including millet flour.

4. Conclusion

The results of this study could be helpful in the production of gluten-free meatballs for celiac patients. The replacement of breadcrumb by buckwheat, chickpea, corn and millet flours in samples was found to be effective on characteristics of meatballs. The obtained results showed that the raw meatballs including chickpea flour had a higher protein content. Gluten-free flours increased the cooking yield of the samples and chickpea flour in particular improved the cooking properties of the meatballs. The cooked meatballs with buckwheat flour had the highest antioxidant activity. Gluten-free flours had no significant effect on the colour properties of raw and cooked meatballs. In terms of textural properties, the chickpea flour improved the texture of the meatball samples. Although millet flavour decreased the flavour score of the meatballs, the other gluten-free flours had no effect on the sensory properties of the samples compared to the control. In this respect, especially chickpea, corn and buckwheat flours could be used as substitutes for breadcrumbs in the meatball formulations.

5. Acknowledgements

This study received no external funding. The author would like to thank Rabia Duru, Rümeysa Durmuş and Şenay Can Bilgin for contributions to the analyses in the laboratory

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