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Physicochemical, rheological, and baking properties of composite Brotchen bread made from foxtail millet flour

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ABSTRACT

Effect of adding foxtail millet flour (FMF) (10, 20, and 30% w/w) to refined wheat flour (RWF) on physicochemical and rheological properties of dough was studied. Qualitative properties of Brotchen bread including moisture, ash, crude fibre, specific volume, and colour of the breads were evaluated. Adding FMF to the flour increased crude fibre, fat, ash, and protein contents and reduced falling number, damaged starch and wet gluten contents, and sample lightness. Consistograph test indicated that addition of the FMF decreased water absorption capacity, maximum pressure, and tolerance, however, drops in pressure at 250 and 450 s became greater. Alveograph test revealed that with adding FMF, dough resistance to extension and dough strength decreased but an increase in dough extensibility was obtained at FMF30%. Increasing the amount of FMF resulted in a decrease in the volume of the bread, and the FMB (foxtail millet bread) 30% had the highest browning index and b^*. The FMB20% had the highest resilience and springiness, while higher level of foxtail (30%) increased chewiness.

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KEYWORDS

Brotchen bread, foxtail millet, physicochemical properties, rheological behaviour

1. INTRODUCTION

Nowadays, bakery industry is focusing on low-caloric products with high dietary fibre and protein and low carbohydrate contents. However, some flours with high fibre content substituting wheat flour have brought concerns on textural properties of breads, including specific volume, colour, and taste (Bhol and Bosco, 2014; Pourabedin et al., 2017). Foxtail millet (*Setaria italica*) is the sixth most important grain planted in the world and has been introduced as major species of millet (Saleh et al., 2013). Each 100 g of edible portion of foxtail millet (FM) contains 12.3 g protein, 4.3 g fat, 2.4 g fibre, and 3.3 g minerals (Banerjee and Maitra, 2020). It has higher contents of proteins and lipids than some cereals such as wheat or maize (Sachdev et al., 2020). The composition of FM protein indicates that it is rich in lysine and can be used as a protein supplement with many cereals (Mohamed et al., 2009). The oil obtained from FM is a rich source of linoleic acid and tocopherols (Liang et al., 2010). Thiamine (0.6 mg/100 g) and riboflavin (1.65 mg/100 g) content of FM is higher than wheat and rice (Kumar et al., 2018). FM is a good source of dietary fibre (14 g/100 g) (Ballolli et al., 2014). Foxtail millet seeds can be effectively used in different foodstuffs for diabetic people (Saleh et al., 2013).

Many articles have been published on the nutritional value and bread making from different species of millet, but so far there is little research on the replacement of refined wheat flour (RWF) with foxtail millet flour (FMF) in Brotchen bread (Gavurnikova et al., 2011; Ranasalva and Visvanathan, 2014). Thus, the aim of the current work was to investigate the physico-chemical, rheological, and baking properties of wheat-foxtail millet composite flours.

2. MATERIALS AND METHODS

2.1. Materials

RWF was obtained from Ghoncheh flour Co., Ahwaz, Iran. Foxtail millet grains, Bastan variety, were purchased from Organization of Agriculture, Isfahan. All chemicals used in the experiments were provided by Merck Co. (Germany). Baking ingredients were purchased from a local market of Isfahan, Iran.

2.1.1. Preparation of flours. Bastan foxtail millet grains were cleaned and then milled in an experimental roller mill and FMF was obtained from whole foxtail millet grains. The RWF was replaced by FMF at 10, 20, and 30%, and samples were sieved to determine the particle size of the flour samples (Table 1). RWF was considered the control.

2.2. Physicochemical properties of flours

2.2.1. Proximate composition. The proximate composition of the flour samples, including the moisture, fat, ash, crude fibre, and protein contents, was determined according to AOAC

Table 1. Physicochemical properties of flours

Parameter (unit)	Flours				
	RWF	FMF10%	FMF20%	FMF30%	FMF
Moisture (%)	13.00 ± 0.05[a]	12.52 ± 0.06[b]	11.53 ± 0.04[c]	10.86 ± 0.06[d]	7.22 ± 0.03[e]
Protein (g/100 g dm)	11.03 ± 0.07[e]	11.35 ± 0.05[d]	11.96 ± 0.08[c]	12.65 ± 0.05[b]	13.45 ± 0.17[a]
Fat (g/100 g dm)	1.77 ± 0.03[e]	2.65 ± 0.04[d]	2.94 ± 0.04[c]	3.38 ± 0.05[b]	4.25 ± 0.03[a]
Ash (g/100 g dm)	0.63 ± 0.00[e]	0.85 ± 0.00[d]	1.01 ± 0.00[c]	1.32 ± 0.00[b]	2.77 ± 0.00[a]
Crude fibre (g/100 g dm)	0.37 ± 0.01[e]	0.85 ± 0.03[d]	1.38 ± 0.04[c]	1.86 ± 0.05[b]	5.46 ± 0.05[a]
Falling number (s)	422.50 ± 2.50[a]	372.50 ± 3.50[b]	346.00 ± 4.00[c]	330.50 ± 0.50[d]	260.50 ± 6.50[e]
Wet gluten (%)	25.25 ± 0.25[a]	23.15 ± 0.15[b]	22.55 ± 0.05[c]	21.40 ± 0.10[d]	0.00 ± 0.00[e]
Damaged starch (%)	6.08 ± 0.02[a]	5.88 ± 0.02[b]	5.75 ± 0.01[c]	5.04 ± 0.02[d]	4.19 ± 0.05[e]
Particle size (%): Sieve No.					
475	0[b]	0[b]	0[b]	0[b]	0.11[a]
180	5.05[c]	6.5[c]	8.85[bc]	11[b]	23.8[a]
125	24[b]	25[b]	25.19[b]	27.68[b]	66.6[a]
106	16.7[b]	14.4[b]	15.5[b]	35.12[a]	8.49[c]
Below 106	54.25[a]	53.91[a]	50.65[a]	26.2[b]	1[c]

Values with the same letters in the same column are not significantly different ($P > 0.05$).
dm: dry matter; RWF: refined wheat flour; FMF: foxtail millet flour; (s): second.

standard methods No. 925.10, No.922.06, No.923.03, No. 962.09, and No. 950.36, respectively (AOAC, 2005).

2.2.2. Wet gluten. Wet gluten content was determined using JMC gluten index analyser (China) according to AACC method No. 38-12.02 (AACC, 2000).

2.2.3. α-Amylase activity. α-Amylase activity was measured using Falling-Number instrument SPT Group, Iran, according to AACC method No.56-81.03 (AACC, 2000).

2.2.4. Damaged starch. Damaged starch content was quantified using SDMatic, Chopin Technologies, France, by amperometric method according to AACC method No. 76-33.01 (AACC, 2000).

2.3. Rheological properties of dough

Rheological properties of dough were determined by an alveo-consistograph (AlveoLAB, ChopinTechnologies, Cedex, France). Alveograph and consistograph tests were defined according to AACC methods No. 54-30 and No. 54-50, respectively (AACC, 2000). For evaluation of dough rheology, maximum pressure (PrMax), water absorption capacity (HYD2200), water absorption (WA), TprMax (s) (time to reach maximum pressure), time (s) for the pressure to rise above PrMax minus 20% or tolerance (Tol), the drop in pressure at 250 and 450 s from PrMax minus 20% (D250 and D450) were measured by Consistograph (Callejo et al., 2009).

Moreover, maximum overpressure needed to blow the dough bubble (P index of tenacity or resistance to extension), dough extensibility (L) as the length of the alveograph curve, and W-value that is related to the dough strength, indicates the total deformation energy, and is defined as the area under the curve and represents the energy required to expand the dough were evaluated (Indrani et al., 2007).

2.4. Bread making

Brotchen bread (bread roll, German type) was made from RWF and with different levels of FMF. The other baking ingredients on flour-weight-basis were: light malt powder (0.25%), compressed yeast (2.5%), salt (0.8%), improver powder (0.3%), and emulsifiers (DATEM (0.25%)) and SSL (0.25%). Each treatment was separately mixed in spiral mixer and the ingredients were added and mixed for 5 min at low speed. The dough was let initially rest for 10 min, divided into approximately 50 g pieces, and rolled to dough balls. Afterwards, dough balls were put into the 30 °C fermentation cabin with 80% relative humidity for 60 min to pass the final fermentation step. Finally, the dough balls were transferred into the rotating oven at 200 °C for 20 min. The cooled bread rolls were packed in polypropylene bags and stored at room temperature before further analysis.

2.5. Physicochemical properties of breads

2.5.1. Proximate composition. The breads, without drying, were placed in a porcelain mortar, crushed, and tested. The proximate composition of breads, including moisture, fat, ash, crude fibre, and protein contents was determined according to AOAC standard methods (AOAC, 2005).

2.5.2. Colour measurement. Crumb colour parameters (L^*, a^*, b^*) were measured using TES 135A colorimeter (Hunter Lab). Total colour difference (ΔE) and browning index (BI) was calculated according to Eq. (1 & 2) (Pathak et al., 2016).

$$\Delta E = \sqrt{(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2} \tag{1}$$

where Δa^*, Δb^* and ΔL^* are differences between the colour parameters for standard and sample (Onyango et al., 2020).

$$\mathrm{BI} = \frac{[100\times(\mathrm{X} - 0.31)]}{0.17} \tag{2}$$

where $\mathrm{X} = \frac{(a^*+1.75\times L^*)}{(5.645\times L^*+a^* - 3.012\times b^*)}$

2.5.3. Loaf weight, loaf volume, and loaf specific volume. Loaf weight was measured by an electronic weight balance; loaf volume was measured by rapeseed displacement method according to AACC method No. 10-05.(AACC, 2000), and loaf specific volume was calculated by dividing the loaf volume by loaf weight.

2.5.4. Texture profile analysis (TPA). Texture profile analysis of breads was performed by a CT3- 4500 texture analyser according to AACC method No. 76-33.01 (AACC, 2000). A 20 mm diameter cylindrical probe was used to penetrate to 50% of the sample's depth at a test speed of 5 mm s^{-1} with a 30 s delay between the first and second compressions. The slices were cut from the middle section of the loaf, and the tests were done on the samples (30 × 30 × 20 mm). All textural properties were estimated after 1 day of storage.

2.6. Statistical analysis

All experiments were performed in triplicate. The results were expressed as mean ± SD (SD). Statistical software SPSS v. 17 was used. Analysis of Variance (ANOVA) was performed to identify significant differences and least significant difference (LSD) test was used to compare means at the significance level of 5%.

3. RESULTS AND DISCUSSION

3.1. Physicochemical properties of flour

The physicochemical properties of the RWF, FMF, and the composite flour samples are presented in Table 1. Fibre, fat, ash, and protein contents of the FMF were higher than the RWF, as expected. Therefore, these values were increasing with the increase of the amount of FMF in the composites. In a study, increasing the level of proso millet flour to wheat flour significantly increased its fat and ash contents (Aprodu and Banu, 2015). Also, the fat and protein contents of two varieties of pearl millet flour were found to be significantly higher than the RWF (Suma et al., 2014).

Wet gluten was reduced by 2–5% as FMF level increased in composite flour samples. In fact, increasing FMF causes gluten dilution.

FMF has a higher amylase activity, so the falling number decreased with adding FMF into composite flour.

Damaged starch content of the RWF was higher than that of the FMF. Thus, decrement of damaged starch content was expected as FMF increased. The particle size of the RWF was smaller than the FMF and the composite flours, which resulted in higher damaged starch content.

3.2. Rheological properties of dough

Rheological properties of doughs are shown in Fig. 1. Increase of FMF in the formulation decreased maximum pressure (PrMax), water absorption capacity (HYD2200), and water absorption (WA) of the blend (Fig. 1(1a–d)). HYD2200 decreased from 54.2% to 49.5%, PrMax decreased from 2,876 mb to 1819 mb, and WA decreased from 56.7% to 52% for RWF and FMF30%, respectively. WA reduction could be attributed to lower gluten content and higher lipid content of the composite dough samples (Aprodu and Banu, 2015). The reduction of damaged starch content in the composite flour could also cause decreased water absorption. The FMF30% had the lowest damaged starch, thus it showed the least water absorption among the samples. With increasing FMF proportion in the mixture, pressure drop at 250 and 450 s increased (D250 and D450, respectively), while the tolerance (Tol) of samples decreased (Fig. 1(2a–d)). Similar results were obtained with increasing finger millet flour proportion in the blend (Thorat and Ramachandran, 2016). The alveograms of RWF and composite doughs are

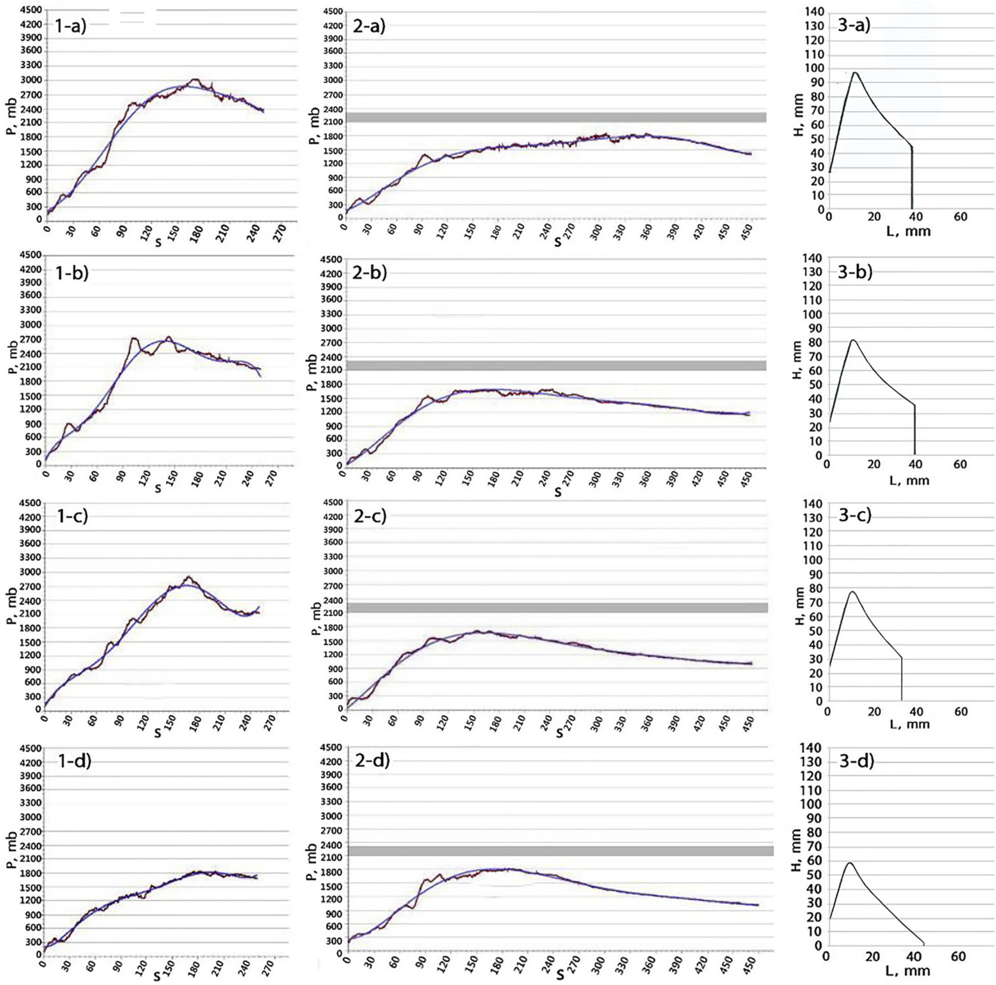

Fig. 1. Consistograph results for constant hydration (1), adapted hydration (2), and alveograph (3): a) RWF, b) FMF10%, c) FMF20%, d) FMF30%
RWF: refined wheat flour; FMF: foxtail millet flour

shown in Fig. 1(3a–d). Dough resistance to extension or tenacity, which is a predictor of the ability of dough to retain gas (Indrani et al., 2007), decreased from 107 mm in RWF to 65 mm in FMF30%. Dough extensibility decreased from 38 mm in RWF and FMF10% to 32 mm in FMF20%, but increased to 43 mm for FMF30%. Curve configuration ratio indicating the ratio of elasticity to extensibility of the dough ranged from 2.82 in RWF to 1.51 in FMF30%. Dough strength decreased from 169×10^{-4} J in RWF to 87×10^{-4} J in FMF30%. Tenacity and dough strength decreased as the FMF percentage increased. Changes in the alveograph properties were due to higher fibre content, lower gluten content, and interactions of gluten and fibre (Wang et al., 2002).

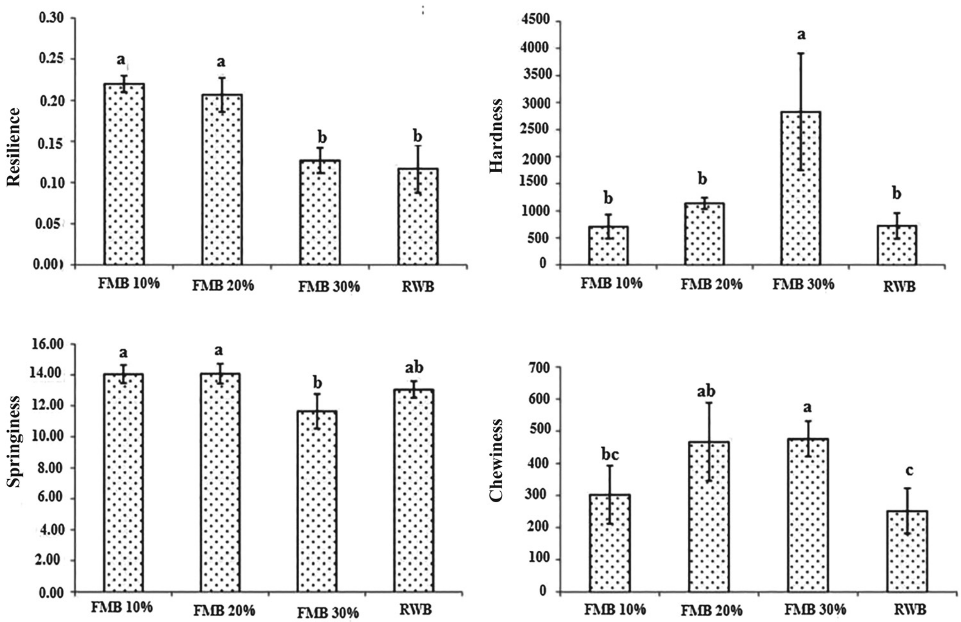

Fig. 2. Textural properties of bread samples after 1 day
RWB: refined wheat bread; FMB: foxtail millet bread

3.3. Physicochemical properties of breads

Proximate composition results (Table 2) showed that as the FMF percentage increased in the bread, a significant increasing trend was observed in protein, fat, ash, and crude fibre contents. Moisture content in refined wheat bread (RWB) was significantly higher than foxtail millet breads (FMB). In composite flour also moisture content decreased significantly with increasing FMF level.

Also there were significant differences between crumb colour parameters of RWB and FMB. FMF reduced crumb L^*, while increased a^*, b^*, and BI, and crumb colour became darker with increased substitution level. However, there were no significant differences among the composite bread samples. The lowest L^* was obtained for FMF30%, which was predictable due to the presence of carotenoid and colour pigments leading to darker colour of FMB. Positive b^* and a^* values of breads indicated red and yellow colour for all bread samples. Therefore, crumb colour was dependent on the flour colour, which influences BI of bread. The browning index indicates the intensity of brown colour and is related to enzymatic and non-enzymatic (Maillard reaction) browning reactions (Salinas and Puppo, 2015). The BI values increased with increasing the substitution of RWF by FMF. It could be due to the Maillard reaction and caramelisation. According to Table 1, the lowest value of falling number was obtained for FMF30% and also FMF30% had the highest α-amylase activity. Amylase activity leads to maltose and glucose formation, which has an important role in Maillard reactions and accelerates the formation of melanoidin as browning pigment, which in turn increases the BI of the breads.

Table 2. Physicochemical properties of breads

Parameter (unit)	Breads			
	RWB	FMB10%	FMB20%	FMB30%
Moisture (%)	27.95 ± 0.05[a]	27.70 ± 0.17[b]	26.39 ± 0.05[c]	26.09 ± 0.010[d]
Protein (g/100 g dm)	11.31 ± 0.08[d]	12.01 ± 0.08[c]	12.96 ± 0.07[b]	13.53 ± 0.11[a]
Fat (g/100 g dm)	2.00 ± 0.03[c]	1.95 ± 0.04[c]	2.38 ± 0.08[b]	2.87 ± 0.07[a]
Ash (g/100 g dm)	1.27 ± 0.04[d]	1.53 ± 0.02[c]	2.06 ± 0.01[b]	2.16 ± 0.02[a]
Crude fibre (g/100 g dm)	0.17 ± 0.02[d]	0.40 ± 0.01[c]	0.72 ± 0.02[b]	1.27 ± 0.04[a]
Loaf weight (g)	28.63 ± 0.51[b]	36.18 ± 1.88[a]	34.35 ± 1.24[a]	36.25 ± 1.25[a]
Loaf volume (cm^3)	180.6 ± 9.75[a]	170.4 ± 4.49[ab]	164.4 ± 7.48[bc]	153.7 ± 9.66[c]
Specific loaf volume (cm^3 g^{-1})	6.30 ± 0.25[a]	4.70 ± 0.01[b]	4.78 ± 0.05[b]	4.24 ± 0.12[b]
Crumb colour (L^*)	70.85 ± 1.29[a]	64.32 ± 8.17[ab]	60.23 ± 4.68[b]	56.82 ± 3.80[b]
(a^*)	0.53 ± 0.39[b]	3.91 ± 1.24[a]	3.77 ± 0.59[a]	6.16 ± 2.45[a]
(b^*)	8.31 ± 1.09[c]	13.48 ± 1.78[b]	17.79 ± 0.25[b]	19.75 ± 0.51[a]
(ΔE^*)	71.34 ± 1.71[a]	65.86 ± 3.04[a]	63.02 ± 4.51[a]	60.46 ± 3.54[a]
(BI)	192.18 ± 1.71[a]	208.50 ± 5.48[b]	219.61 ± 3.68[c]	230.22 ± 5.18[d]

Values with the same letters in the same column are not significantly different ($P > 0.05$).
dm: dry matter; RWB: refined wheat bread; FMB: foxtail millet bread; (L^*): lightness index; (a^*): red-green index; (b^*): yellow-blue index; (ΔE^*): total colour difference; (BI): browning index.

Loaf weight obtained for bread samples with composite flour was significantly higher than RWB, however, they were not different from each other. High loaf weight of composite breads might be due to their low CO_2 retention capacity (Rai et al., 2012). The RWB was shown to have significantly higher loaf volume and loaf specific volume among treatments. Lower loaf volume in composite bread samples could be attributed to lower gluten content of FMF samples (Ragaee and Abdel-Aal, 2006; Devani et al., 2016).

Crumb texture can be used as a criterion for freshness in consumers' point of view, as well (Amini Khoozani et al., 2020). The results of texture profile analysis of crumbs are shown in Fig. 2. Hardness and chewiness in FMB30% was significantly higher than other breads. Addition of FMF led to the increment of crumb hardness compared to RWB. The increased fibre content might have caused thickening of the wall around the air bubbles in the bread crumb and led to increased hardness of samples (Pathak et al., 2016). With increasing FMF in the formula, the texture of bread crumb becomes sandy. Wheat contains gluten, which produces a porous and spongy texture. Replacing wheat flour with gluten-free flours such as FMF, reduces the total gluten content and, as a result, produces firmer bread with a sandy texture (Ballolli et al., 2014). High levels of FMF significantly decreased springiness and resilience. Chewiness value changed directly with firmness. These results are in accordance with those of Frutos et al. (2008), who studied the effect of artichoke fibre on wheat bread texture. Resilience indicates the elasticity of bread crumbs (Fig. 2).

4. CONCLUSIONS

Experiments and results showed that foxtail millet is a good source of fibre, fat, protein, and minerals and, therefore, could be considered as a nutritionally important grain. However, due to gluten deficiency, it has weaker rheological properties and should be used with appropriate formulations for baking bread. Brotchen breads containing FMF had higher amounts of protein and less volume and specific volume compared to the control sample (RWF). Increasing FMF up to 20% did not change the hardness of breads and even improved resilience and springiness. Addition of FMF at more than 20% increased hardness of breads. Finally, FMB20% were determined as acceptable breads based on the obtained results from texture analysis and crude fibre.

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