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# Processing Technology of Shatangju Mandarin Fiber Oatmeal Toast

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**Abstract** [**Objectives**] To optimize the processing technology of Shatangju mandarin fiber oatmeal toast and to develop a nutritious functional baked product. [**Methods**] Using high-gluten flour as the benchmark, the effects of varying addition levels on toast quality were investigated through single-factor experiments, with Shatangju mandarin juice, citrus fiber powder, oats, and butter as the primary variables, and sensory score serving as the evaluation criterion. Subsequently, the formulation was optimized via an orthogonal test. [**Results**] The optimal technical formula consisted of 1% citrus fiber powder, 5% oats, 12% butter, 70% Shatangju mandarin juice, supplemented with 2% yeast, 1% salt, and 10% sugar. The optimal technological conditions were as follows: 60 min for primary fermentation, 30 min for secondary fermentation, baking at 195 ℃ for the upper heat and 185 ℃ for the lower heat, with a total baking time of 28 min. Toast produced under these conditions exhibited high sensory scores, as well as favorable texture and specific volume characteristics. [**Conclusions**] This technical formula enables the production of Shatangju mandarin fiber oatmeal toast of high quality, offering a valuable reference for the development of functional baked goods and the comprehensive utilization of fruit by-products.

**Key words** Shatangju mandarin, Citrus fiber, Oats, Toast bread

## 0 Introduction

Toast, a widely consumed staple both domestically and internationally, is commonly incorporated into all three daily meals due to its convenience and suitability for fast-paced lifestyles. With the enhancement of living standards, consumer preferences have shifted from mere "satiation" to a focus on "healthy nutrition". Nevertheless, most commercially available toast products exhibit limited nutritional ingredients, rendering them insufficient to satisfy the public's demand for high-quality dietary options. Therefore, the development of toast enriched with functional ingredients holds considerable significance. Previous research has demonstrated that Shatangju mandarins from Sihui, Guangdong, are abundant in various macronutrients, trace elements, crude fiber, total sugars, and pectin, thereby exhibiting significant nutritional value. Dietary fiber derived from citrus, an important category of dietary fiber, possesses functions such as intestinal moisturizing, laxative effects, and blood glucose reduction[1-2]. Moreover, citrus fruits serve as high-quality sources of dietary fiber, and their utilization can facilitate the development of fruit by-products[3-4]. Oats are recognized as a functional food due to their nutritional composition, and their incorporation into food products enhances flavor and texture while conferring certain health benefits[5-8]. Currently, relevant research predominantly concentrates on the application of individual functional ingredients, with oats primarily utilized in their minimally processed forms. There is a notable deficiency in studies examining the combined use of Shatangju mandarin, citrus fiber, and oats in toast products. Furthermore, research addressing the synergistic optimization of these three components to enhance both nutritional value and quality remains limited and challenging to accomplish. In this study, high-gluten flour was employed as the benchmark, while Shatangju mandarin juice, citrus fiber, oats, and butter were selected as the primary factors. Initially, the experimental procedure was established through preliminary testing, followed by the determination of the appropriate addition range for each ingredient via single-factor experiments. Subsequently, an $L_9(3^4)$ orthogonal test was utilized to optimize the technical formula. Finally, physicochemical indices, including texture and specific volume, were assessed through validation tests. The objective was to develop a Shatangju mandarin fiber oatmeal toast with enhanced nutritional quality and to provide a reference for the research and development of functional toast products and the further processing of agricultural commodities.

## 1 Materials and methods

**1.1 Materials** The materials utilized in the experiment comprised citrus dietary fiber powder (90% content; Shaanxi Taimei Bioengineering Co., Ltd.), Australian oat bran (Henan Erbanqiao Food Technology Co., Ltd.), Shatangtu mandarin (commercially available), butter (Angel Butter), yeast (Angel Yeast Co., Ltd.), high-gluten flour (Chen Keming Food Co., Ltd.), and toast bread (commercially available; Changdachang Food).

**1.2 Instrument** The instrument utilized in this study included an oven (YXD 50B-24, Foshan Shiwan District Kangwei Electric Appliance Factory), a juicer (X20, Zhongshan Tengju Electric Co., Ltd.), a balance (KFS-X3, Kaifeng Group Co., Ltd.), a dryer (Xinchi ST-00, Shandong Xinchi Photoelectric Technology Group Co., Ltd.), and a texture analyzer (Brookfield CT3, Guangzhou Brookfield Viscometer and Texture Analyzer Technical

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Service Co., Ltd.).

**1.3 Technological process** The technological process was as follows: weighing the raw materials, adding juice and mixing thoroughly, conducting the first fermentation, dividing the dough, shaping the dough into rounds, placing the rounds in toast boxes, performing the second fermentation, and finally baking[8].

**1.4 Operation points**

**1.4.1** Preparation of Shatangju mandarin juice. The Shatangju mandarin was peeled to extract the pulp, which was then squeezed to obtain the juice. The juice was subsequently filtered through gauze or a sieve mesh, and the resulting filtrate was reserved for later use.

**1.4.2** Preparation and fermentation of dough. The weighed high-gluten flour, citrus fiber powder, oats, salt, sugar, and yeast were sequentially combined and mixed. Subsequently, the measured Shatangju mandarin juice was incorporated and stirred until thoroughly blended. Thereafter, butter was added and kneaded until it was fully absorbed, and the dough attained the fully developed stage, characterized by a smooth surface with optimal elasticity and extensibility. The dough was placed in a fermentation chamber maintained at a temperature of 35 – 40 ℃ with controlled humidity, achieved by placing warm water nearby to adjust moisture levels, and allowed to ferment for 60 min.

**1.4.3** Shaping and baking. After the completion of fermentation, the dough was removed to release the trapped air and divided into three portions of equal weight. Each portion was rolled into a rectangular shape and then rolled up. This procedure was repeated once more before placing the dough pieces into the toast box. Following a secondary fermentation period of 30 min under identical temperature and humidity conditions, the dough was baked in a preheated oven with the upper heat set to 195 ℃ and the lower heat to 185 ℃ for a duration of 28 min.

**1.5 Single-factor experimental design** The primary influencing factors considered were the levels of citrus fiber powder, oats, Shatangju mandarin juice, and butter added to the toast. Single-factor experiments were conducted for each of these variables independently.

**1.5.1** Effects of varying addition levels of citrus fiber powder on the sensory score of toast. Using high-gluten flour as the benchmark, the levels of butter, oat bran, and Shatangju mandarin juice were fixed at 8%, 10%, and 70%, respectively, while other variables were held constant. The levels of citrus fiber powder were varied at 0%, 1%, 4%, 7%, and 10% to examine its effect on the quality and texture of toast.

**1.5.2** Effects of varying addition levels of oats on the sensory score of toast. Using high-gluten flour as the benchmark, the levels of added ingredients were fixed as follows: butter at 8%, citrus fiber powder at 4%, and Shatangju mandarin juice at 70%, while all other variables were held constant. Oat bran was incorporated at varying levels of 0%, 5%, 10%, 15%, and 20% to examine its effect on the quality and texture of toast.

**1.5.3** Effects of varying addition levels of butter on the sensory score of toast. Using high-gluten flour as the benchmark, this study examined the effects of varying butter additions (4%, 6%, 8%, 10%, and 12%) on the quality and textural properties of toast, while maintaining fixed addition levels of citrus fiber powder (4%), oat bran (10%), and Shatangju mandarin juice (70%).

**1.5.4** Effects of varying addition levels of Shatangju mandarin juice on the sensory score of toast. Using high-gluten flour as the benchmark, with fixed additions of butter (10%), oat bran (10%), and citrus fiber powder (4%), while keeping other variables constant, Shatangju mandarin juice was incorporated at levels of 60%, 65%, 70%, 75%, and 80%. The effects of varying addition levels of Shatangju mandarin juice on the quality and texture of toast were subsequently examined.

**1.6 Orthogonal experimental design** Based on a single-factor experimental design, four factors were selected: the level of citrus fiber powder added (A), the level of oats added (B), the level of butter added (C), and the level of Shatangju mandarin juice added (D). Each factor was examined at three levels. An $L_9(3^4)$ orthogonal table was employed for experimental optimization (Table 1).

**Table 1 Levels of orthogonal experiment factors for the processing technology of Shatangju mandarin fiber oatmeal toast** %

| Level | Citrus fiber powder added (A) | Oats added (B) | Butter added (C) | Shatangju mandarin juice added (D) |
|---|---|---|---|---|
| 1 | 1 | 5 | 8 | 65 |
| 2 | 4 | 10 | 10 | 70 |
| 3 | 7 | 15 | 12 | 75 |

**1.7 Sensory scoring method** The product was manufactured in accordance with the experimental plan. Subsequently, the toast was cooled and softened prior to sensory evaluation. A sensory evaluation team, consisting of 12 trained evaluators, conducted the assessment of the toast. The highest and lowest scores were excluded, and the mean of the remaining 10 scores was calculated. The sensory evaluation form is presented in Table 2.

**1.8 Determination of texture characteristics** A texture analysis and comparison were performed between high-quality products and those obtained from the market. The product was first cooled and softened, with both ends removed, and subsequently sliced into 1.5 cm thick sections for texture analysis. The texture profile analysis (TPA) mode was employed during the measurement process. The test parameters included the use of a Ta-4 probe, a pre-test speed of 1.00 mm/s, a test speed of 1.00 mm/s, a return speed of 1.00 mm/s, a trigger point load of 7.0 g, and a compression target of 5.0 mm. Each sample underwent two cycles, and the average values were recorded. Texture characteristic parameters such as hardness, elasticity, chewiness, viscosity, and resilience were determined using the TPA method on the texture analyzer[9-11].

**1.9 Determination of specific volume** Volume replacement was performed using small particle fillers (millet)[12]. The specific volume was calculated using the formula: $P = V/m$, where $P$

denotes the specific volume (mL/g), $V$ represents the volume of the toast (mL), and $m$ corresponds to the mass of the toast (g). Each sample was measured in triplicate, and the mean value was reported.

**Table 2 Sensory evaluation criteria for Shatangju mandarin fiber oatmeal toast**

| Item | Evaluation criteria | Score//points |
|---|---|---|
| Form | Intact and complete, exhibiting no defects, cracks, black blisters, or visible scorch marks | 15 – 20 |
| | Relatively intact and complete, exhibiting only minor defects and cracks, with no presence of black blisters or conspicuous scorch marks | 8 – 14 |
| | Neither intact nor complete, exhibiting defects and cracks, as well as black blisters or clearly visible scorched marks | 1 – 8 |
| Surface color | The crust displays a lustrous orange-yellow hue and is uniformly colored, with no indications of charring or whitening. The bread's core is light yellow with a silky sheen, and the oat bran is evenly distributed throughout. | 11 – 15 |
| | The crust exhibits colors ranging from light brown to brownish-yellow or sepia, characterized by a dull luster, uniform coloration, with no evidence of charring or whitening. The bread's core lacks a silky sheen, and the oat bran is distributed relatively evenly throughout. | 6 – 10 |
| | The crust exhibits a grayish-white or burnt gray coloration, while the bread's core is yellowish-gray. The oat bran is distributed unevenly, and there are occurrences of charring or whitening. | 1 – 5 |
| Texture | The toast exhibits a fine and elastic texture characterized by uniformly distributed pores throughout. Its structure is distinct and spongy, without any noticeable holes or firm areas. | 15 – 20 |
| | The toast exhibits a relatively fine and elastic texture, characterized by evenly distributed pores throughout. Its structure is somewhat distinct and spongy, containing a few holes alongside firmer areas. | 8 – 14 |
| | The texture of the toast is coarse and exhibits low elasticity. The internal pores are irregularly distributed. The toast is susceptible to breakage when sliced, lacks a cohesive texture, and contains numerous large holes and firm areas, resulting in a deficiency of smoothness and fineness. | 1 – 8 |
| Taste | The toast possesses a soft texture, initially presenting a sweet flavor that lingers as a pleasant aftertaste. It is highly palatable and maintains its structural integrity without easily breaking or crumbling. | 16 – 25 |
| | The toast possesses a relatively soft texture and a sweet flavor with a lingering aftertaste. It is generally palatable but tends to break or crumble easily. | 8 – 15 |
| | The toast exhibits a relatively hard texture, accompanied by a mildly sweet taste that is subsequently followed by a bitter or sour flavor. It is generally unpalatable and tends to break or crumble easily. | 1 – 7 |
| Flavor | The toast exhibits a rich aroma, characterized by the fresh and smoky flavors of Shatangju mandarin and oats, and a balanced sweet and salty taste, accompanied by a subtle yeast note, without any off-flavors. | 15 – 20 |
| | The toast exhibits a pronounced aroma, whereas the aroma of Shatangju mandarin and oats are comparatively subtle. It presents a burnt fragrance accompanied by a sweet and salty flavor, without any detectable off-flavors. | 8 – 14 |
| | The toast exhibits a weak aroma. The flavor of Shatangju mandarin and oats is either excessively strong or insufficiently pronounced. Additionally, it presents a slightly bitter or sour taste accompanied by other off-flavors. | 1 – 8 |

## 2 Results and analysis

### 2.1 Single-factor experiment results

**2.1.1** Effects of varying addition levels of citrus fiber powder. As illustrated in Fig. 1, the sensory score initially increased and subsequently decreased with the increasing level of citrus fiber powder added, reaching its peak at a 4% addition level. Samples with moderate additions (1% – 4%) received higher scores compared to those with no addition or excessive addition (10%). This phenomenon may be attributed to the fact that an appropriate quantity of dietary fiber facilitates the formation of a stable starch-gluten-fiber network structure, whereas excessive levels significantly increase the dough's stretching resistance and impair its fermentation capacity[13-14].

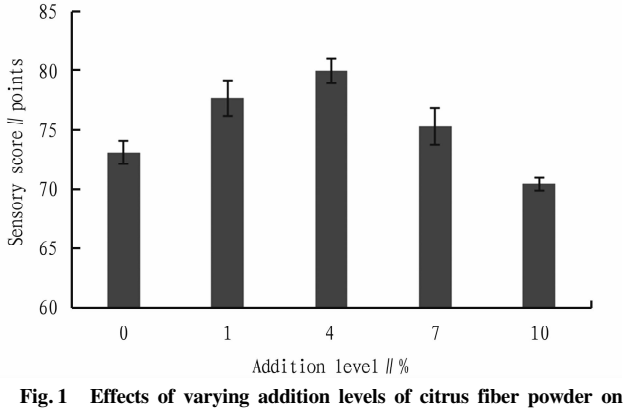


**Fig. 1 Effects of varying addition levels of citrus fiber powder on the sensory score of toast**

**2.1.2** Effects of varying addition levels of oats. As illustrated in Fig. 2, the sensory score initially increased and subsequently decreased with the increasing addition level of oats, reaching its peak at a 10% addition level. Incorporating an appropriate quantity of oats enhanced the taste, but excessive addition (*e.g.*, 20%) adversely affected the dough's gas-holding capacity, resulting in diminished fermentation performance and taste. Consequently, the sensory score at this level may approximate that of the control

group without oat addition[15]. Toast prepared without oats exhibited a relatively thin texture, which corresponded to a lower sensory score.

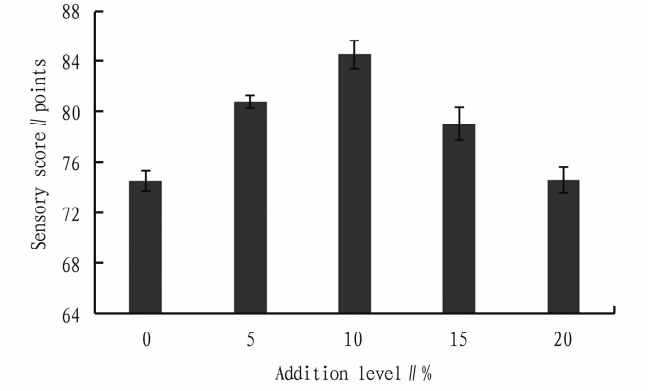


**Fig. 2 Effects of varying addition levels of oats on the sensory score of toast**

**2.1.3** Effects of varying addition levels of butter. As illustrated in Fig. 3, the sensory score initially increased and subsequently decreased with increasing butter level, reaching its peak at an addition level of 10%. Both insufficient (<8%) and excessive (>12%) butter additions resulted in suboptimal taste. An appropriate quantity of butter contributed to the formation of a stable gas film and reduced hardness. When the butter level was too low, the resulting gas film density was insufficient, leading to the evaporation of gases produced during toast fermentation[16]. Conversely, excessive butter content increased oil levels, which accelerated oil evaporation and promoted rancidity.

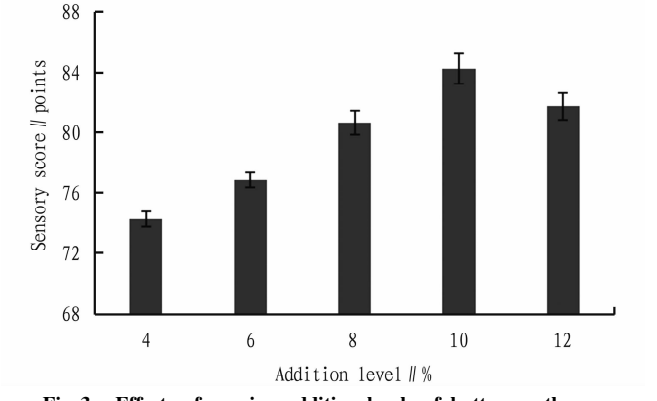


**Fig. 3 Effects of varying addition levels of butter on the sensory score of toast**

**2.1.4** Effects of varying addition levels of Shatangju mandarin juice. As illustrated in Fig. 4, the sensory score initially increased and subsequently decreased with the increasing addition of Shatangju mandarin juice, reaching its peak at a 70% addition level. The sensory scores for 60% and 80% additions were comparable. This phenomenon can be attributed to the composition of Shatangju mandarin juice, which contains fructose and water; water is a critical factor influencing the texture of toast. Excessive water content results in an overly sticky toast, whereas insufficient water leads to a hard crust during baking, thereby adversely affecting the overall taste.

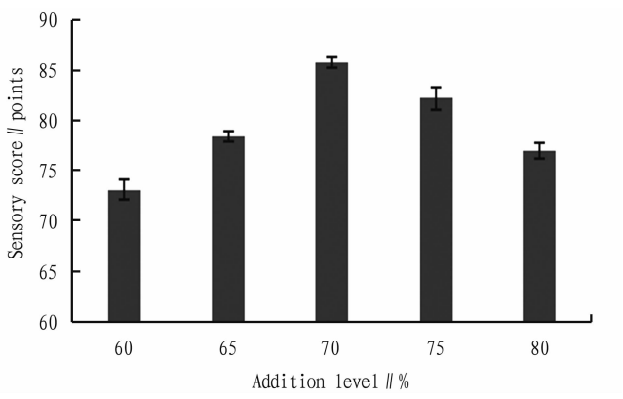


**Fig. 4 Effects of varying addition levels of Shatangju mandarin juice on the sensory score of toast**

**2.2 Optimization results of orthogonal experiments** The range analysis presented in Table 3 indicated that the factors influencing the sensory score of toast were ranked as follows: D (level of Shatangju mandarin juice added) > A (level of citrus fiber powder added) > B (level of oats added) > C (level of butter added). The optimal combination identified through intuitive analysis was $A_1B_1C_3D_2$, corresponding to 1% citrus fiber powder, 5% oats, 12% butter, and 70% Shatangju mandarin juice. As this combination was not included among the nine orthogonal experimental groups, a verification test is necessary.

**Table 3 $L_9$ orthogonal experiment results for the processing technology of Shatangju mandarin fiber oatmeal toast**

| Group No. | Level of citrus fiber powder added (A) | Level of oats added (B) | Level of butter added (C) | Level of Shatang mandarin juice added (D) | Sensory score points |
|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 88.08 |
| 2 | 1 | 2 | 2 | 2 | 89.75 |
| 3 | 1 | 3 | 3 | 3 | 87.67 |
| 4 | 2 | 1 | 2 | 3 | 89.58 |
| 5 | 2 | 2 | 3 | 1 | 82.83 |
| 6 | 2 | 3 | 1 | 2 | 87.42 |
| 7 | 3 | 1 | 3 | 2 | 89.00 |
| 8 | 3 | 2 | 1 | 3 | 82.83 |
| 9 | 3 | 3 | 2 | 1 | 76.25 |
| $K_1$ | 265.50 | 266.66 | 258.33 | 247.16 | |
| $K_2$ | 259.83 | 255.41 | 255.58 | 266.17 | |
| $K_3$ | 248.08 | 251.34 | 259.50 | 260.08 | |
| $k_1$ | 88.50 | 88.89 | 86.11 | 82.39 | |
| $k_2$ | 86.61 | 85.14 | 85.19 | 88.72 | |
| $k_3$ | 82.69 | 83.78 | 86.50 | 86.69 | |
| Range | 5.81 | 5.11 | 1.31 | 6.33 | |
| Primary and secondary factors | | | | DABC | |
| Optimal formula | | | | $A_1B_1C_3D_2$ | |

**2.3 Verification test results** The combination with the highest sensory score identified in the orthogonal experiment ($A_1B_2C_2D_2$: 1%, 10%, 10%, 70%) and the theoretically optimal combination ($A_1B_1C_3D_2$: 1%, 5%, 12%, 70%) were subjected to verification. The results indicated that the average sensory score of the

theoretically optimal combination (92.08 points) was significantly higher than that of the highest-scoring combination (89.75 points). Consequently, $A_1B_1C_3D_2$ was determined to be the optimal formula, comprising 1% citrus fiber powder, 5% oats, 12% butter, and 70% Shatangju mandarin juice.

**2.4 Texture characteristic results** The texture of the product prepared using the optimal formulation was compared to that of a commercially available product (control). The product was cooled and softened, with both ends removed, and then sliced into 1.5 cm thick pieces for texture analysis. The resulting data are presented in Table 4.

**Table 4 Comparison of texture characteristics of Shatangju mandarin oatmeal toast and commercially available toast**

| Item | Hardness g | Elasticity | Viscidity | Chewiness g | Cohesion |
|---|---|---|---|---|---|
| Control | 87.5 | 0.39 | 0.70 | 45 | 0.57 |
| Sample | 369 | 0.67 | 0.30 | 284 | 0.82 |

As presented in Table 4, the hardness, elasticity, chewiness, and cohesion indices of the products formulated under optimal conditions were significantly higher than those of the control. This finding indicates that the texture of the optimized product was firmer, but this did not adversely affect its palatability, suggesting a relatively compact molecular structure with strong internal connectivity. Furthermore, the average elasticity of the samples exceeded that of the control, indicating that the toast exhibited a chewy, resilient texture with favorable sensory qualities.

**2.5 Specific volume results** The specific volume measurement of the toast prepared using the optimal formula is presented in Table 5, revealing an average specific volume of 2.66 mL/g. This value falls within the typical range for bread (generally 1.0 – 5.5 mL/g) and is relatively high, suggesting that the product exhibited favorable expansion and softness.

**Table 5 Specific volume results of Shatangju mandarin toast**

| Sample | Volume mL | Mass g | Specific volume//mL/g | Average specific volume//mL/g |
|---|---|---|---|---|
| 1 | 489.7 | 183.5 | 2.67 | 2.66 |
| 2 | 487.9 | 183.4 | 2.66 | |
| 3 | 488.2 | 183.6 | 2.66 | |

## 3 Conclusions

The experiment investigated four primary factors: the levels of citrus fiber powder, oats, butter, and Shatangju mandarin juice added. Orthogonal experiments, along with related comparative verification tests, were conducted following preliminary single-factor experiments. The results indicated that, with 100 g of flour as a benchmark, the Shatangju mandarin fiber oatmeal toast produced using a technical formula containing 1% citrus fiber powder, 5% oats, 12% butter, and 70% Shatangju mandarin juice, with a first fermentation time of 60 min, a second fermentation time of 30 min, and baking temperatures of 195 ℃ (top heat) and 185 ℃ (bottom heat) for 28 min, exhibited favorable internal quality and appearance. The specific volume was measured at 2.66 mL/g, and texture profile analysis revealed a hardness of 369 g, elasticity of 0.67, viscosity of 0.30, chewiness of 284 g, and cohesion of 0.82. Additionally, the product achieved a sensory score of 92.08 points, indicating excellent overall quality. This study integrates fruit by-products with grains to develop functional baked goods, aligning with current trends in healthy food research and development, and offers novel approaches for the resource utilization of agricultural by-products and the upgrading of baked products.

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