# Dry-roasted Air-classified Edible Bean Protein Flour Use in Cake Doughnuts[1]

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## ABSTRACT

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When 0–30% dry-roasted air-classifed navy, pinto, or black bean protein flour was substituted for all-purpose flour in cake doughnuts, fat absorption decreased as the level of substitution increased. All levels decreased doughnut height relative to the control. The doughnuts with 30% navy or pinto bean protein flour spread less during cooking than did the control. Navy bean protein substituted at the level of 10 and 20% produced a doughnut more tender than the control or doughnuts from other bean types. The doughnuts made from navy and pinto protein flour were brownish, whereas those from the black bean protein flour were gray. A sensory panel also found that doughnuts containing black bean protein had poor color. None of the other sensory characteristics were significantly different. Consumer panels indicated that a 13% substitution of navy or pinto protein for the dry mix produced doughnuts that tasted good and were well liked. These doughnuts also had less fat, were softer, and showed less firming after six days of storage.

The nutritional composition of dry beans is ideal for delivery of protein and minerals if the beans are properly prepared and positioned in the diet. Dry roasting of navy beans with a particle-to-particle heat exchanger effectively destroys antinutritional factors present in the raw bean (Aguilera et al 1982a). Removal of hulls by air aspiration produces products high in fiber, whereas air classification of bean flour produces fractions high in protein and starch. This fiber fraction has been used successfully in cookies and quick breads (DeFouw et al 1982a, 1982b). Whole bean flour has been used previously to increase the protein of white bread and of chemically leavened quick breads (D'Appolonia 1978, Dryer et al 1982). A navy bean protein fraction has been added to bread and cookies (Zabik et al 1983).

Doughnuts are widely consumed in the United States. Lawhon et al (1975) was the first to propose increasing the protein content of doughnuts by using 18–26% protein blends of glandless cottonseed, liquid-cyclone processed cottonseed, peanut, and soy flours. This study discusses the effects on quality characteristics of cake doughnuts when up to 30% of the all-purpose wheat flour is replaced with high-protein flours of navy, pinto, and black bean.

## MATERIALS AND METHODS

Navy, pinto, and black (*Phaseolus vulgaris*) dry beans were dry-roasted in a particle-to-particle heat exchanger with a bead temperature of 240°C for 1 min at the bean-to-bead ratio of 1:5, according to the procedure of Aguilera et al (1982b). The roasted beans were then dehulled by air aspiration, pin-milled, and air-classified to produce high-protein flour fractions. The fractions contained 44–45% protein. The complete proximate analyses of these fractions were reported previously (Uebersax et al 1982) and are summarized in Table I. All other ingredients were obtained as common lots.

### Doughnut Preparation

The first study involved the preparation of cake doughnuts substituted with 0, 10, 20, or 30% navy, pinto, or black bean protein fractions and used the formulation outlined in Table II. To compensate for different water absorptions, milk levels were adjusted as shown in the table. Shortening was creamed with half the sugar for 60 sec at medium speed (144 rpm), using a Kitchen Aid K5-A mixer. Egg and remaining sugar were then added in four portions. After each addition, the formulation was mixed for an additional 30 sec. The remaining dry ingredients were sifted and then added alternately with portions of the milk while mixing for 1 min at low speed (98 rpm). After the dough was conditioned in a warm (40°C) water bath to 23°C, the dough was rolled to 1.0 cm (3/8 in.) and cut into doughnuts.

The doughnuts were fried for 1½ min per side at 190°C in a Sears fryer/cooker containing 1.0 kg of Superfine® all-vegetable liquid frying shortening (PVO International, Inc.). The doughnuts and the oil were weighed to the nearest 0.1 g before and after frying to

TABLE I
Proximate Analyses of Dry-roasted Air-classified Protein Fractions of Navy, Pinto, and Black Beans[a,b]

| Bean Type | Moisture (% wb) | Protein (% db) | Ash (% db) | Fat (% db) | Enzyme-Neutral Detergent Fiber |
|---|---|---|---|---|---|
| Navy | 9.18 | 44.06 | 5.41 | 3.68 | 1.78 |
| Pinto | 6.58 | 44.23 | 6.02 | 1.14 | 4.31 |
| Black | 7.28 | 45.52 | 8.04 | 1.16 | 3.67 |

[a] A mean of three observations.
[b] Data from Uebersax et al (1982).

TABLE II
Cake Doughnut Formulations that Include up to 30% Navy, Pinto, and Black Bean High-Protein Flour Substitution

| Ingredient | Level of Bean Protein Flour Substitution | | | | |
|---|---|---|---|---|---|
| | 0% (g) | Control (%) | 10% (g) | 20% (g) | 30% (g) |
| All-purpose flour | 300 | 100 | 270 | 240 | 210 |
| Bean protein | 0 | ··· | 30 | 60 | 90 |
| Whole milk | 122 | 40.7 | 134–140[a] | 143–146[b] | 145–148[c] |
| Sugar | 100 | 33.3 | 100 | 100 | 100 |
| Hydrogenated shortening | 13.0 | 4.3 | 13.0 | 13.0 | 13.0 |
| Eggs | 48.0 | 16.0 | 48.0 | 48.0 | 48.0 |
| SAS baking powder | 12.0 | 4.0 | 12.0 | 12.0 | 12.0 |
| Salt | 4.0 | 1.3 | 4.0 | 4.0 | 4.0 |
| Nutmeg | 1.0 | 0.3 | 1.0 | 1.0 | 1.0 |
| Cinnamon | 1.0 | 0.3 | 1.0 | 1.0 | 1.0 |
| Mace | 0.5 | 0.2 | 0.5 | 0.5 | 0.5 |

[a] Pinto or black bean substitutions were 140 g, and navy bean substitutions were 134 g.
[b] Navy, pinto, or black bean substitutions were 143, 145, or 146 g, respectively.
[c] Navy, pinto, or black bean substitutions were 145, 146, or 48 g, respectively.

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allow for the calculation of the percentages of fat absorbed and of moisture lost:

$$\% \text{ fat absorbed} = \frac{\text{wt fat absorbed}}{\text{wt cooked doughnuts}} \times 100$$

$$\% \text{ moisture lost} = \frac{\text{wt moisture loss}}{\text{wt raw doughnuts}} \times 100$$

Four replications of each variable were made.

Doughnuts to be used in the consumer evaluation were prepared from commercial doughnut mix, or the doughnut mix was blended with 13% of navy or pinto bean flour at the Michigan State University bakery. This substitution level was based on total solids in the mix and is an approximation of the 20% substitution treatment of flour used in the previous formulation. After preparation, all doughnuts were sealed in polyethylene bags and frozen at −24°C. They were thawed 2 hr before being evaluated.

### Quality Evaluations

AACC methods 30-26 and 44-40 (AACC 1983) were used to analyze doughnuts for fat and moisture, respectively. Height and diameter were measured after the doughnuts had cooled 15 min after frying. Tenderness was determined as the pounds of force per gram required to shear doughnut halves in an Allo-Kramer shear-compression cell. The 3,000-lb transducer, a range of 1/10, and a downstroke time of 30 sec were used. Color was determined objectively using the Hunter Lab Color Difference meter, model D-25, standardized with a yellow tile ($L = 78.5$, $a_L = 3.2$, $b_L = 23.4$).

Shelf life was determined on doughnuts prepared for the consumer panel by measuring the shear force as previously outlined. Doughnuts wrapped in polyethylene bags were held at ambient temperature (21–23°C) and sheared at 24-hr intervals for six days.

A trained taste panel of six members evaluated four doughnuts, each chosen at random during each panel session. Taste paneling was conducted in individual booths equipped with standard daylight fluorescent lighting. Exterior and interior color, exterior and interior resistance to biting and chewing, interior texture, and flavor characteristics were evaluated using a linear line 10 cm long with reference points at the 1- and 9-cm marks. The higher number represents the optimum product.

Two consumer panels evaluated doughnuts prepared with the commercial bean protein substituted mix. The first panel involved 205 participants at a USDA commodity food program in Detroit, MI. Of the consumers, 90% were black, 72% were female, 84% were adult, 11% were children, and 5% were teenagers. Consumer income was low. A seven-point modified hedonic scale (7 = tastes great to 1 = tastes terrible) was used along with "smiley faces" for 7, 4, and 1 for this panel. In addition, a consumer panel of 118 people using the Michigan State University Dairy Store also evaluated these doughnuts using a seven-point hedonic scale (7 = like extremely, 4 = neither like nor dislike, 1 = dislike extremely). Of the members on the panel, 52% were male, 78% students, 7% faculty, 12% staff, and 3% nonstudents. The age range for this panel was as follows: 18–20, 20%; 21–23, 33%; 24–35, 35%; and over 35, 12%.

### Analyses of Data

Four replications of each variable were made. The data were analyzed for variance using the factorial statistical programs developed for the Michigan State University CDC 750 computer. Duncan's new Studentized range test (Duncan 1957) was used to sort out significant differences among bean types and levels of substitution when analyses of variance indicated significant differences. Chi-square tests were used to test for significant differences among consumer taste-panel scores.

## RESULTS AND DISCUSSION

### Doughnut Height and Diameter

Height of the doughnuts (Table III) decreased significantly when 10, 20, and 30% navy or pinto protein flour was incorporated into the dough, but the height of the doughnuts in which bean protein was substituted was not significantly affected by level of substitution. The height of doughnuts, with 10% black bean high-protein flour increased significantly from the control, whereas the height of the variable with the 30% level of substitution decreased. The diameter of the doughnuts with 30% navy, 20 or 30% pinto, and 10% black bean high-protein substitutions was significantly less than that of the control. The high amount of protein present in the dough probably created competition for available water and did not allow as much dough expansion during frying. Even with the water compensation in the dough formulation, the protein could still interfere with hydration and formation of gluten, and thus change the doughnut shape.

The tenderness of the cake doughnuts was significantly affected by the type of bean flour used and by level of substitution for all-purpose flour. Cake doughnuts with navy bean protein blend were significantly more tender on the average ($P < 0.001$) than the cake doughnuts containing either pinto or black bean protein. Lowest shear values were obtained for the cake doughnuts with 10 or 20% navy bean protein. Cake doughnuts with 10% pinto protein were also significantly more tender than the control. Cake doughnuts with 10 or 20% black bean high protein flour were

**TABLE III**
**Objective Size, Texture, and Color Measurements[a] of Cake Doughnuts with 10, 20, and 30% Navy, Pinto, or Black Bean Protein Flour Substituted for All-Purpose Flour**

| Variable | Height (cm) | Diameter (cm) | Shear (lb/g) | Color | | |
|---|---|---|---|---|---|---|
| | | | | L (lightness) | $a_L$ (redness) | $b_L$ (yellowness) |
| Control | 3.4 ± 0.3 | 7.2 ± 0.3 | 4.2 ± 1.7 | 35.0 ± 3.0 | 12.8 ± 3.5 | 9.9 ± 4.1 |
| Navy bean protein | | | | | | |
| 10% Substitution | 2.9 ± 0.4 | 7.4 ± 0.2 | 2.4 ± 0.8 | 37.6 ± 3.2 | 16.1 ± 3.0 | 12.8 ± 2.5 |
| 20% Substitution | 2.8 ± 0.2 | 7.0 ± 0.1 | 3.1 ± 0.4 | 36.4 ± 1.0 | 16.2 ± 1.2 | 11.6 ± 1.1 |
| 30% Substitution | 2.9 ± 0.2 | 6.9 ± 0.1 | 4.5 ± 0.7 | 34.5 ± 0.4 | 15.2 ± 1.2 | 10.2 ± 0.5 |
| Pinto bean protein | | | | | | |
| 10% Substitution | 2.9 ± 0.2 | 7.2 ± 0.1 | 3.5 ± 0.7 | 35.4 ± 0.9 | 15.4 ± 1.3 | 10.3 ± 1.1 |
| 20% Substitution | 3.0 ± 0.3 | 6.8 ± 0.1 | 4.1 ± 0.7 | 31.7 ± 4.9 | 14.0 ± 2.0 | 8.9 ± 2.5 |
| 30% Substitution | 2.9 ± 1.9 | 6.9 ± 0.1 | 4.5 ± 0.7 | 34.5 ± 0.4 | 15.2 ± 1.2 | 10.2 ± 0.5 |
| Black bean protein | | | | | | |
| 10% Substitution | 3.8 ± 0.2 | 6.9 ± 0.1 | 5.1 ± 1.0 | 35.8 ± 6.0 | 8.7 ± 2.4 | 5.3 ± 8.1 |
| 20% Substitution | 3.3 ± 0.3 | 7.0 ± 0.1 | 5.5 ± 0.8 | 27.3 ± 1.4 | 7.1 ± 1.1 | 8.7 ± 0.8 |
| 30% Substitution | 2.6 ± 0.2 | 7.1 ± 0.1 | 3.2 ± 0.6 | 26.8 ± 0.1 | 5.2 ± 0.8 | 8.6 ± 0.4 |
| Studentized range value[b] | | | | | | |
| $P < 0.05$ | 0.3 | 0.2 | 0.3 | 4.0 | 2.3 | 2.2 |

[a] Mean of four replications.
[b] Duncan's new Studentized range test (1957).

significantly less tender than the control. Even though the cake doughnuts with 30% black bean protein had a relatively low shear value (3.2 lb/g of doughnut), they were very compact, as shown by their physical dimensions (Table III). Dilution of the flour gluten with the legume protein would result in a weakened structure in all the substituted doughnuts. Nevertheless, the protein content of all three types of bean protein flours was quite similar, so we had expected all bean protein flours to function similarly. The navy bean high-protein flour had more fat and less ash than the other beans. These differences may account for doughnuts supplemented with navy bean protein flour generally requiring less force to shear, but a fundamental study of the globulin fractions in each of the legume flours is needed for a complete explanation. In another study, yeast-leavened doughnut holes with 25% navy bean protein substitution, and peanut butter cookies with 30% of the flour substituted with navy bean protein were also observed to be more tender than controls. However, yeast breads containing either 5 or 10% navy bean protein were less tender than a control (Zabik et al 1983).

The lightness value (L) of the doughnuts was not affected by navy or pinto bean protein substitution, but these doughnuts tended to be more brown (higher redness and yellowness values). Cake doughnuts with black bean protein were darker when 20 or 30% substitution levels were used and less red at all levels of substitution.

Fat absorption, moisture loss, ether-extractable fat, and percentage of moisture of the cooked doughnuts are presented in Table IV. Slightly more moisture was lost from doughnuts to which additional moisture (milk) was added to obtain similar dough consistency, but these differences were not significant. Moreover, the moisture contents of the cake doughnuts determined by vacuum drying were not significantly affected by bean type or level of protein substitution. Both the calculated fat absorption and the ether-extractable fat showed less fat in the doughnuts as the level of protein increased, especially at the 20 or 30% levels of protein substitution. Decrease in height and diameter of these doughnuts decreased the surface area for fat absorption. Lawhon et al (1975) also reported lower oil contents for some of their oilseed-substituted doughnuts, particularly those substituted with soy, liquid-cyclone processed cottonseed, and higher levels of peanut flours.

Sensory evaluations performed by the trained panel are summarized in Table V. Addition of any of the levels of navy, black, or pinto bean protein to cake doughnuts did not significantly reduce the panel scores for flavor or for exterior or interior resistance to biting and chewing. In fact, doughnuts with protein substitution were scored as more desirable than the control for these attributes.

Doughnuts with 10% bean protein substitution were scored significantly higher ($P < 0.05$) than the control for exterior color. Exterior color was only scored significantly lower for the variable with 30% black bean protein substitution, but interior color of all the doughnuts with black bean protein was scored significantly lower ($P < 0.05$) than the control. Navy bean protein substitution did not affect doughnut color, nor did pinto bean protein up to a 20% level of substitution. Sensory evaluation of yeast-raised doughnut holes with 25% navy bean protein substitution and bread with 5 or 10% substitution did not have significantly different scores (Zabik et al 1983).

To further assess sensory characteristics, consumer panels were held in Detroit, MI, and at Michigan State University. Data from these panels are summarized in Table VI. The two consumer panels provided information on doughnut acceptability by people from diverse socioeconomic backgrounds. Moreover, people who participated in the Detroit panel are from a group who may benefit from protein-supplemented foods, so we were particularly interested in whether these products tasted good to them.

**TABLE IV**
**Fat and Moisture Data[a] for Cake Doughnuts with 10, 20, and 30% Navy, Pinto, or Black Bean Protein Substituted for All-Purpose Flour**

| Variable | Fat Absorption (%) | Moisture Loss (%) | Chemical Analyses[b] Ether-extractable Fat (%) | Water (%) |
|---|---|---|---|---|
| Control | 17.6 ± 1.3 | 6.3 ± 4.6 | 28.9 ± 0.3 | 19.5 ± 0.6 |
| Navy bean protein | | | | |
| 10% Substitution | 18.6 ± 2.5 | 10.6 ± 2.4 | 28.5 ± 0.7 | 22.6 ± 0.1 |
| 20% Substitution | 16.3 ± 2.0 | 10.3 ± 2.8 | 22.8 ± 0.5 | 21.5 ± 0.2 |
| 30% Substitution | 12.7 ± 2.3 | 8.5 ± 2.0 | 21.0 ± 0.5 | 23.8 ± 0.0 |
| Pinto bean protein | | | | |
| 10% Substitution | 13.8 ± 1.9 | 8.4 ± 2.7 | 27.8 ± 0.5 | 22.8 ± 0.1 |
| 20% Substitution | 12.9 ± 1.0 | 7.9 ± 1.5 | 19.4 ± 0.4 | 25.2 ± 0.1 |
| 30% Substitution | 11.7 ± 2.3 | 8.5 ± 2.0 | 21.3 ± 0.4 | 23.5 ± 0.2 |
| Black bean protein | | | | |
| 10% Substitution | 16.0 ± 2.0 | 6.8 ± 4.4 | 27.0 ± 0.1 | 21.7 ± 0.2 |
| 20% Substitution | 15.0 ± 1.2 | 6.8 ± 1.1 | 23.7 ± 0.7 | 23.0 ± 0.1 |
| 30% Substitution | 14.3 ± 2.1 | 7.5 ± 1.7 | 21.8 ± 0.3 | 22.7 ± 0.1 |
| Studentized range value[c] $P < 0.05$ | 2.9 | ns[d] | 0.8 | ns[d] |

[a] Mean of four replications.
[b] Dry-weight basis.
[c] Duncan's new Studentized range test (1957).
[d] ns = not significant.

**TABLE V**
**Sensory Evaluations[a] of Cake Doughnuts with 10, 20, and 30% Navy, Pinto, or Black Bean Protein Flour for All-Purpose Flour**

| Treatment | Trained Taste-Panel Evaluation[a] Exterior Color | Exterior Resistance | Interior Texture | Interior Color | Interior Resistance | Flavor |
|---|---|---|---|---|---|---|
| Control | 5.4 ± 2.7 | 3.5 ± 1.6 | 4.8 ± 1.1 | 8.0 ± 0.7 | 3.2 ± 1.5 | 4.8 ± 1.8 |
| Navy bean protein | | | | | | |
| 10% Substitution | 5.2 ± 2.2 | 5.9 ± 0.3 | 6.7 ± 0.5 | 8.1 ± 0.2 | 6.2 ± 0.8 | 6.1 ± 0.7 |
| 20% Substitution | 6.0 ± 0.4 | 7.0 ± 0.4 | 5.5 ± 1.1 | 7.7 ± 0.9 | 7.7 ± 0.3 | 6.5 ± 0.8 |
| 30% Substitution | 6.2 ± 0.6 | 7.1 ± 0.8 | 3.7 ± 0.8 | 7.4 ± 0.8 | 6.3 ± 0.9 | 5.5 ± 0.9 |
| Pinto bean protein | | | | | | |
| 10% Substitution | 7.0 ± 0.7 | 6.8 ± 1.4 | 6.6 ± 0.6 | 8.4 ± 0.3 | 7.5 ± 0.9 | 7.2 ± 1.4 |
| 20% Substitution | 6.3 ± 1.4 | 6.7 ± 0.8 | 5.8 ± 0.6 | 7.5 ± 0.5 | 7.1 ± 0.2 | 6.6 ± 1.2 |
| 30% Substitution | 5.9 ± 0.5 | 5.5 ± 1.2 | 4.2 ± 1.2 | 6.8 ± 0.5 | 6.9 ± 0.3 | 5.5 ± 0.3 |
| Black bean protein | | | | | | |
| 10% Substitution | 5.8 ± 0.6 | 7.3 ± 0.3 | 7.0 ± 1.0 | 6.8 ± 0.7 | 7.3 ± 1.0 | 6.7 ± 0.7 |
| 20% Substitution | 4.2 ± 1.5 | 6.4 ± 2.2 | 5.6 ± 1.2 | 5.9 ± 0.6 | 7.1 ± 0.6 | 6.1 ± 1.2 |
| 30% Substitution | 2.1 ± 0.7 | 5.8 ± 1.3 | 3.8 ± 0.9 | 2.4 ± 1.1 | 7.6 ± 1.1 | 5.1 ± 1.2 |
| Studentized range value[b] $P < 0.05$ | 1.3 | ns[c] | 1.6 | 1.0 | ns[c] | ns[c] |

[a] Taste-panel evaluation performed using a 10-cm line scale, with 10 representing the optimum. Six-member panel evaluated products from four replications.
[b] Duncan's new Studentized range test (1957).
[c] ns = not significant.

**TABLE VI**
**Consumer Evaluation of Cake Doughnuts with Navy or Pinto Bean Substitution[a] as Compared with Controls**

| Variables | Panel | |
|---|---|---|
| | Focus:HOPE[b] | Michigan State University[c] |
| Control | $6.2 \pm 0.8^a$ | $6.9 \pm 1.0^a$ |
| Navy | $6.0 \pm 0.9^b$ | $5.8 \pm 1.4^b$ |
| Pinto | $5.9 \pm 0.8^b$ | $5.8 \pm 1.4^b$ |

[a]Protein substituted for 13% of mix. Chi-square differences $P < 0.05$.
[b]n = 205. HOPE = USDA food program. Chi-square differences $P < 0.05$.
[c]n = 118.

**TABLE VII**
**Shelf-life Study Shear Values for Consumer Panel Donuts**

| Time (hr) | Control (lb/g) | Navy Bean Protein Doughnuts (lb/g) | Pinto Bean Protein Doughnuts (lb/g) |
|---|---|---|---|
| 0 | 4.06 ± 0.01 | 2.87 ± 0.15 | 2.70 ± 0.81 |
| 24 | 3.97 ± 0.12 | 2.55 ± 0.11 | 3.50 ± 0.18 |
| 48 | 5.66 ± 0.31 | 3.55 ± 0.10 | 3.98 ± 0.61 |
| 72 | 6.94 ± 0.50 | 3.50 ± 0.30 | 4.37 ± 0.62 |
| 96 | 6.87 ± 0.39 | 3.63 ± 0.40 | 4.24 ± 0.54 |
| 120 | 5.92 ± 0.24 | 3.11 ± 0.30 | 3.82 ± 0.23 |
| 144 | 6.44 ± 0.01 | 3.24 ± 0.27 | 3.77 ± 0.24 |

Although chi-square tests showed that variables for both bean-substituted doughnuts were significantly lower ($P < 0.05$) than the control for both panels, the Detroit consumers described the doughnuts as "tasting good." A score of six on the hedonic scale used by the consumer panelists at Michigan State University indicated "liked very much," so the bean-substituted doughnuts were also highly acceptable. In addition, comments about color, size, and softness made by several of the Detroit panelists indicated that many of these panelists were evaluating overall quality, even though the hedonic scale had been modified to a "taste" evaluation to make the terminology meaningful.

Ether-extractable fat analyses showed that fat content of these protein-substituted doughnuts also was considerably less than for the control (ether-extractable fat expressed on a dry-weight basis is as follows: control 37.6 ± .4% navy bean protein-substituted doughnut, 29.4 ± .3% and pinto bean protein-substituted doughnut, 22.5 ± .5%). Soy flour is often incorporated into doughnut mix to control fat absorption. The legume protein flours might function in a similar capacity. The tenderness and change in tenderness over time of doughnuts prepared for the consumer panels showed that doughnuts substituted with either navy or pinto bean protein were more tender (ie, required less force to shear) and the rate of tenderness change was less than for the control (Table VII).

For all three types of doughnuts, the shear values decreased slightly after 96 hr. Additionally, the difference in cutting the surface and the interior of doughnuts after this time was small. This may have also resulted in slightly lower readings of peak force. Thus, substituting bean protein into a commercial doughnut mix produced products that tasted good, were well liked, and had lower fat content and good shelf life.

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