PHYSICAL CHARACTERISTICS AND ACCEPTABILITY OF EXTRUDED AFRICAN BREADFRUIT-BASED SNACKS

TITUS U. NWABUEZE[1], MADUEBIBISI O. IWE and ENOCH N.T. AKOBUNDU

Department of Food Science and Technology
Michael Okpara University of Agriculture
Umudike, P. M. B. 7267, Umuahia, Abia State, Nigeria

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ABSTRACT

Five-level combinations of African breadfruit, corn and soybean, in the ratios 40:5:55; 55:5:40; 70:5:25; 85:5:10 and 100:0:0%, respectively, were hydrated to 15, 18, 21, 24 and 27% and extruded into snacks at screw speeds of 100, 120, 140, 160 and 180 rpm. Physical characteristics of snacks from blends containing 15 and 18% moisture ranged from thin-smooth to thin-fine-smooth pellets. Those containing 21 to 27% moisture were either thin-smooth or thick-smooth, fine-smooth or rough strands. Feed moisture and feed composition were the most significant process variables influencing physical and sensory characteristics. The optimum process variable combination that had maximum influence on physical and sensory characteristics of snacks was the 70:5:25 feed ratio with 21% moisture and extruded at 140 rpm. This resulted in an overall acceptability score of 8.20 on a 9-point hedonic scale.

PRACTICAL APPLICATIONS

African breadfruit is widely grown in the high rainforest parts of Nigeria and other African countries, where the seeds are traditionally consumed as porridge meal when cooked with ingredients or as snacks when roasted. There is therefore a need to adopt more efficient extrusion technologies to rapidly and efficiently transform African breadfruit and its blends with corn and soybean into acceptable snacks. Optimizing process variable conditions using response surface analysis to evaluate product physical characteristics and acceptability was the thrust of this study. It is expected to give direction toward a more scientific approach to scaling up operations in African breadfruit seed processing and utilization.

[1] Corresponding author. TEL: +234 80354 22843; EMAIL: teeubueze@yahoo.co.uk

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INTRODUCTION

African breadfruit (*Treculia africana*) grown in the high rainforest parts of some African countries is strategic in alleviating hunger in these places because it is available during the period when most staples are under cultivation. The seeds are extracted from the pulpy fruit head, roasted, dehulled and eaten alone or with palm kernel, coconut or corn as snacks or sometimes consumed in rural communities as weaning food.

The present study is part of a larger investigation with a major objective of producing and evaluating extruded African breadfruit–corn–soybean mixtures. The proximate and antinutritional composition of the raw and extruded mixtures have been reported (Nwabueze 2007). The extrusion process is a deviation from the traditional methods reported for African breadfruit seeds processing (Ariahu *et al.* 1999; Iwe and Ngoddy 2001).

Sensory evaluation relies on test subjects' capacity to report directly and reliably their feelings of like and dislike using human saliva as the primary wetting agents. Attempts to prepare saliva artificially or use instruments other than natural wetting agents (Crippen *et al.* 1989; Lee and Resurrecion 2002) with successful/unsuccessful correlation with sensory analyses (Muego *et al.* 1990; Gills 1998) have been reported. Evaluation of extruded products by human sense of touch, smell, taste, sight and hearing to measure food properties such as appearance, aroma, taste and overall acceptability remains a major way out (IFT 1981; Giese 1995).

Although physical techniques are being employed in industry as well as in academia to measure various quality attributes in extruded products, comparison of data is difficult. Previously, separate experiments were used to study factors such as screw speed, feed moisture and others, individually, so that the relationship between processing variables could not be obtained without examining a large number of parameter combinations (Richburg and Whittaker 1990). When changing one variable while keeping others constant, no idea will be obtained concerning interactions between process variables unless a large number of combinations are examined.

A response surface analysis is a system for process optimization (using an appropriate experimental design) involving a collection of mathematical and statistical techniques, which may be used to analyze problems where several independent variables (or factors) influence the value of a dependent response, $f(x)$. The intention is to provide a more precise map of the path that has the highest probability of leading to a successful food product (Crapiste 2000). The primary goal is to determine the value of the independent variable that maximizes (or minimizes) that response. The basic principle is to relate process variables to product responses and then describe interrelations between input parameters and product properties (Colonna *et al.* 1989).

Second-order response surface methodology models are used to give information on the direction and magnitude of the influence of process variable(s) and their combined effects on the products' quality parameters.

In this article, the effect of process variable conditions on the physical and sensory characteristics of single-screw extruded snacks from mixtures of African breadfruit, corn and soybean using response surface analysis is described. The study is necessary in giving direction to a more scientific approach to scaling up operations in African breadfruit seed processing and utilization.

MATERIALS AND METHODS

Raw Materials

Raw materials used in this study included the African breadfruit (*Africana* var.), soybean (*Samsoy* var.) and yellow corn. About 100 kg of African breadfruit seeds was purchased from Mbano, while 20 and 4 kg of soybean and yellow corn, respectively, were purchased from Yola, Nigeria.

Raw Materials Preparation

All raw materials were manually sorted to remove stones and other contaminants. African breadfruit seeds were washed in potable water and hot water blanched at 100C for 15 min. The blanched seeds were drained through a plastic basket and allowed to stand for about 15 min. They were then cracked in a commercial attrition mill. The hulls were removed manually. Dehulled seeds were dried in an air convection Chirana-type oven (HS 201 A, Germany) at 60C for 17 h, cooled and stored in an airtight plastic container at room temperature (30 ± 1C) until needed.

Soybean and corn were each dry-cleaned using a Vegvari Ferenc aspirator (OB 125, Budapest, Hungary). Soybeans were soaked for 18 h at room temperature in a stainless trough. The seeds with loose hulls were washed under a tap to dehull and produce clean cotyledons. Dehulled seeds were dried in the oven at 60C for 10 h and stored at room temperature in an airtight plastic container until needed.

Flour Production

The seed materials were milled to 75-μm particle sizes in a Brabender roller mill (Germany). About 8 kg of the milled soybean was defatted to 12.20% fat content by soaking the flour in hexane for 3 h at room temperature, followed by centrifugation at 4,000 rpm for 15 min. Defatted samples were dried in the oven at 60C to desolventize residual hexane in the flour. The flour was further milled in Brook Crompton laboratory hammer mill (DN 15 8QW, Brook Crompton, England) to break the flour clumps and then stored in airtight plastic container until needed.

Blending of Flours

The feed composition (*fc*) of flours from African breadfruit, corn and defatted soybean was obtained at five-level combinations of 40:5:55; 55:5:40; 70:5:25; 85:5:10 and 100:0:0%, respectively. They were packed in polyethylene bags and stored at room temperature until ready for extrusion.

Extrusion Process

The blends were hydrated from 3 to 6% moisture to the desired feed moisture (*fm*) of 15, 18, 21, 24 and 27% and extruded in a single-screw Brabender laboratory extruder (model DCE 330, South Hackensack, NJ). Extruder screw speed was adjusted to the desired values of 100, 120, 140, 160 and 180 rpm. The center point blend of 70 *fc*, 21 *fm* and 140 *ss* was replicated 10 times to generate a total of 25 experimental runs. Emerging snacks were spread on the laboratory table at room temperature for 4 h and later dried in an oven at 60C.

Physical Characteristics of Snacks

The physical characteristics of the snacks subjectively investigated by panel members included the structural shape, textural appearance and surface color. Structural shape was determined with a pair of calipers (Mitutoyo Corp., Japan) accurate to 0.05 mm. Snacks with a diameter range of 3.17–4.27 cm were said to be thin shaped while those that fell within the range of 4.40–5.85 cm were said to be thick shaped. Snack pieces were placed in polyethylene bags and stacked at room temperature until used for sensory analysis.

Product Acceptance

A 30-member consumer acceptance panel drawn from the college and laboratory staff and student population of Michael Okpara University of Agriculture, Umudike, Nigeria, was used to evaluate the sensory characteristics the extruded snacks. This number of panelists is considered adequate for rough product screening and for evaluating acceptance and/or preference in a laboratory environment (Stone and Sidel 1985). The laboratory environment was well lit with artificial fluorescent tubes. A 9-point hedonic scale with 9 = *like* *extremely*, 5 = *neither like nor dislike* and 1 = *dislike extremely* was adopted according to the literature (Lawless and Heymann 1998).

Sensory evaluation was conducted in the Food Processing Laboratory of the Department of Food Science and Technology, in a single session allowing each panelist freedom to observe not more than two 1-min breaks throughout the period irrespective of the number of samples evaluated in a given break. Sensory attributes evaluated by the panelists were product appearance, aroma, texture, taste and overall acceptability. Before the evaluation, each sample was subjected to a short temperature treatment (60C for 2 h) and cooled to room temperature.

Fifteen grams of each sample was presented to each panelist in a flat plate. Water was provided for each panelist for mouth-rinsing after tasting of each sample to avoid the carryover effect of the aftertaste. An atmosphere of relative quietness was provided for the panelists while conducting the evaluation between 11:00 a.m. and 3:00 p.m. Data obtained were processed and the effects of process variables were investigated using response surface analysis.

Experimental Design and Statistical Analysis

A second-order central composite design for a three-variable, five-level combination coded –1, –1.682, 0, +1, +1.682 as modeled by Snedecor and Cochran (1980) (Eq. 1) was used.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i=1}^{k} \sum_{\substack{i=1 \\ i<j}}^{k} \beta_{ij} X_i X_j + \varepsilon \tag{1}$$

Y is the dependent variable, X_i and X_j are the independent variables in the model, k is the number of independent variables, β_0 is the intercept (constants and regression coefficients of the model) and ε is the random error term.

The essential part of the central composite design involving coded and real variables is shown in Table 1. Multivariate regression analysis with the model in Eq. (1) was performed on the data using statgraphic computer software (Statistica, Statsoft, Inc., Tulsa, OK) to yield Eq. (2) for optimizing product responses.

The model developed for each index was examined for lack of fit. Response surface plot was made after removal of the nonsignificant terms with the same software.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \varepsilon \tag{2}$$

TABLE 1.
ESSENTIAL PART OF THE CENTRAL COMPOSITE DESIGN FOR THREE VARIABLES AND FIVE-LEVEL COMBINATIONS

Experimental runs	Coded variables			Real variables		
	X_1	X_2	X_3	*fc*	*fm*	*ss*
1	−1	−1	−1	55	18	120
2	−1	−1	1	55	18	160
3	−1	1	−1	55	24	120
4	−1	1	1	55	24	160
5	1	−1	−1	85	18	120
6	1	−1	1	85	18	160
7	1	1	−1	85	24	120
8	1	1	1	85	24	160
9	1.682	0	0	100	21	140
10	−1.682	0	0	40	21	140
11	0	1.682	0	70	27	140
12	0	−1.682	0	70	15	140
13	0	0	1.682	70	21	180
14	0	0	−1.682	70	21	100
15	0	0	0	70	21	140

fc = %African breadfruit ratio in the blend with 5% corn and varied proportions (0–55%) of defatted soybean to make up to 100% feed composition. The experimental design had upper (+1.682), intermediate (0) and lower (−1.682) values of process variable conditions. The three variables as feed composition (*fc*), feed moisture (*fm*) and screw speed (*ss*) and five experimental levels coded −1.682, −1, 0, +1 and +1.682 gave 15 variable combinations which when replicated 10 times at the center point (0) generated a total of 25 experimental runs. Each row states the adjustment levels of the variables at one run.

Y is the dependent response variable of the snacks, $\beta_0, \beta_1 \ldots \beta_{23}$ are estimated regression coefficients. X_1, X_2, X_3 are independent variables in the model and ε is random error.

RESULTS AND DISCUSSION

The effect of process variables on the physical characteristics of the snacks as they emerged from the die is presented in Table 2. All the snacks that emerged as pellets were thin and either smooth or fine-smooth in shape. However, snacks that emerged as strands were either thin-rough or thick-rough or fine-smooth in shape. Physical characteristics of snacks extruded from blends containing 15 and 18% moisture ranged from thin-smooth to thin-fine-smooth pellets. Those containing 21 to 27% moisture ranged from thin-smooth to thick-smooth, fine-smooth or rough strands.

TABLE 2.
DESCRIPTION OF PHYSICAL CHARACTERISTICS OF EXTRUDED AFRICAN BREADFRUIT BASED SNACKS

Experimental runs	Structural shape	Surface shape	Textural appearance	Surface color
1	Pellet	Thin	Smooth	Brown
2	Pellet	Thin	Smooth	Light brown
3	Pellet	Thin	Smooth	Brown
4	Pellet	Thin	Smooth	Light brown
5	Strand	Thin	Rough	Light brown
6	Strand	Thin	Smooth	Light brown
7	Strand	Thin	Smooth	Light brown
8	Strand	Thin	Smooth	Golden brown
9	Strand	Thin	Smooth	Dark brown
10	Strand	Thin	Smooth	Light brown
11	Pellet	Thin	Smooth	Brown
12	Pellet	Thin	Smooth	Brown
13	Strand	Thick	Fine-smooth	Light brown
14	Strand	Thick	Fine-smooth	Light brown
15	Pellet	Thin	Fine-smooth	Golden brown
16	Strand	Thin	Smooth	Light brown
17	Strand	Thin	Smooth	Brown
18	Strand	Thick	Rough	Dark brown
19	Strand	Thick	Rough	Dark brown
20	Strand	Thick	Rough	Dark brown
21	Pellet	Thin	Smooth	Brown
22	Pellet	Thin	Smooth	Dark brown
23	Strand	Thin	Smooth	Light brown
24	Strand	Thick	Rough	Dark brown
25	Strand	Thin	Rough	Dark brown

Feed moisture (*fm*) was the most significant ($P \leq 0.05$) process variable influencing both structural and surface shapes of the snacks. The moisture content of feed inside the extruder has an effect on frictional resistance of dough being conveyed through the extruder, irrespective of other variables. Low feed moisture results in high frictional resistance, which encouraged pellet formation. On the other hand, high feed moisture results in increased plasticizing and lubricating effect on starch chain and reduces protein coagulation (Tomás *et al.* 1994). This encouraged strand formation.

The optimum process variable combination that had the most influence on physical characteristics of the snacks was obtained at the center point of 70% (*fc)* (70% breadfruit, 5% corn and 25% soybean), 21% (*fm*) and 140 rpm (*ss*). To obtain thin-fine-smooth pellets, the blend should be hydrated to 21% moisture and extruded at a screw speed of 140 rpm. Hydrating the blend beyond 21% moisture (24–27%) and extruding at a higher screw speed (160–180 rpm) produced snacks with thin-smooth/rough or thick-fine-smooth/rough strands.

On exiting the die orifice, the color of the snacks ranged from light to dark brown. Some were also golden brown. Maillard reaction could be responsible for the observed colors. The effect of extrusion processing on snack color has been variously described in the literature (Gujska and Khan 1990; Iwe 2001). Thermal processing of food can increase the potential for interactions between lipids, proteins and carbohydrates and their breakdown products. Addition of soybean to African breadfruit blend in this work could have provided more protein for a Maillard browning reaction involving amino compounds of natural proteins and reducing sugars during thermal processing.

The panelists' scores on sensory characteristics of the snacks are presented in Table 3. The appearance of the snacks was scored from 3.30 to 8.00. The responses showed that the degree of liking increased toward higher defatted soybean addition relative to snacks containing more African breadfruit. As appearance relies on sense of sight, snack color and shape were most outstanding in the decision of panelists. It is a major response variable governing food

TABLE 3.
ACCEPTABILITY OF EXTRUDED AFRICAN BREADFRUIT-BASED SNACKS

Experimental runs	Appearance	Aroma	Texture	Taste	Overall acceptability
1	5.40	5.60	6.30	5.20	5.50
2	6.00	6.00	6.40	6.10	6.20
3	5.10	5.60	6.10	5.70	5.80
4	5.70	6.10	6.70	5.80	6.10
5	6.10	5.60	6.90	5.70	6.30
6	5.50	5.60	6.30	5.60	6.30
7	6.70	6.10	6.50	6.00	6.40
8	7.20	6.20	7.30	6.50	7.20
9	6.10	5.30	6.50	4.80	4.80
10	7.10	5.80	6.90	5.50	6.10
11	4.30	5.50	6.30	5.60	5.60
12	4.00	5.30	6.10	4.80	5.10
13	7.70	5.40	6.90	5.60	6.40
14	7.50	6.60	7.20	6.10	6.60
15	8.00	6.30	7.50	6.30	8.20
16	6.60	5.70	6.40	5.90	6.40
17	5.30	5.30	5.80	5.40	5.70
18	4.30	5.20	5.10	5.60	4.70
19	3.90	5.40	6.00	5.40	4.90
20	3.70	5.00	5.10	4.60	4.70
21	3.90	5.10	5.10	5.20	5.20
21	3.50	4.60	4.20	4.70	4.60
23	6.20	5.50	6.30	5.10	6.10
24	3.40	4.60	4.70	4.50	4.60
25	3.30	4.40	4.20	4.30	3.90

Sensory scale: 1 = *dislike extremely* to 9 = *like extremely*.

TABLE 4.
ESTIMATED REGRESSION COEFFICIENTS AND ANALYSIS OF VARIANCE FOR APPEARANCE OF EXTRUDED AFRICAN BREADFRUIT-BASED SNACKS

Regression coefficients				
Source	Coefficient	Standard error	df	*P* value
Regression on constant	26.0583			
fc	–0.4452	0.3519	1	0.2265
fm	–0.4551	1.5633	1	0.7752
ss	–0.3023	0.1894	1	0.0329
fc * *fc*	–0.0007	0.0008	1	0.0416
fc * *fm*	0.0218	0.0148	1	0.1620
fc * *ss*	0.0049	0.0024	1	0.0464
fm * *fm*	–0.0076	0.0464	1	0.8729
fm * *ss*	0.0089	0.0087	1	0.3265
ss * *ss*	0.0004	0.0006	1	0.5431
R^2	0.7183			
Analysis of variance				
Factor	df	Sum of squares	Sig. of F	
fc	4	23.443	0.031	
fm	4	9.390	0.255	
ss	4	1.890	0.047	

acceptance (Maga and Kim 1989). Gujska and Khan (1990), investigating the effect of temperature on the properties of extrudates from the high starch fraction of navy, pinto and garbanzo beans, observed changes in product characteristics such as appearance, porous structure and fragility and attributed them to modification of the starch and protein components under high temperature and pressure in the extruder barrel.

The estimated regression coefficients and analysis of variance for snacks appearance are shown in Table 4. Snack appearance scores increased with increase in feed moisture up to 21% and decrease in African breadfruit up to 70%. The polynomial after removing nonsignificant terms becomes

$$App = 26.06 - 0.30ss + 0.00fc.ss - 0.00fc^2 \quad (3)$$

The model in Eq. (3) showed significant ($P \leq 0.05$) linear, cross-product and quadratic effects of screw speed on snack appearance. It accounted for about 71.83% of total variation in snack appearance and showed no significant ($P \geq 0.05$) lack of fit. The response surface plot (Fig. 1) confirmed that appearance improved linearly with screw speed and increase or decrease in *fc*. An increase in screw speed resulted in decreased die pressure; thus, the extrudate encountered less resistance at the die, had a higher linear velocity,

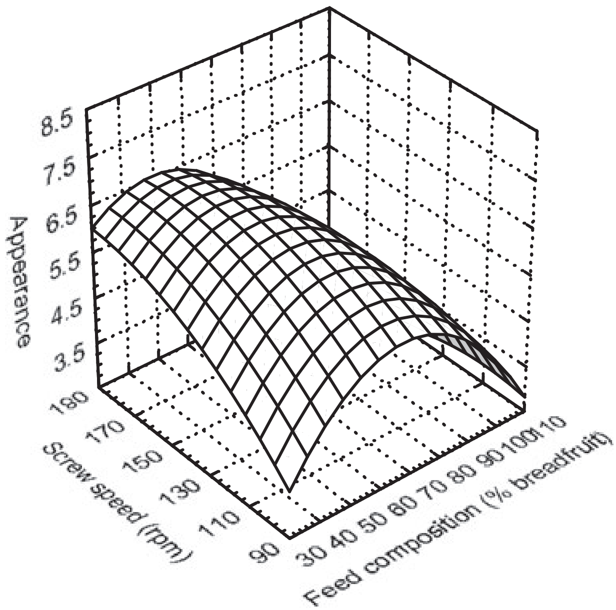

FIG. 1. RESPONSE SURFACE PLOT OF FEED COMPOSITION (% BREADFRUIT) AND SCREW SPEED (RPM) ON APPEARANCE OF EXTRUDED AFRICAN BREADFRUIT-BASED SNACKS

more axial expansion and emerged thick or rough. Hsieh *et al.* (1990) observed that extrudates produced at low screw speeds were darker than those produced at higher screw speeds.

The panelists' mean score on the aroma of the snacks ranged from a minimum of 4.40 to a maximum of 6.60. The 100% breadfruit had the lowest score for aroma, averaging 4.80. It was observed that the experience of the panelists as traditional consumers of African breadfruit products did not give the 100% breadfruit snacks any significant advantage over those from diluted blends. This could probably be due to the effect of extrusion temperature conditions (120–170C), which constitute a major factor in the development of good flavor/aroma of the snack. Protein–starch and protein–lipid (Badrie and Mellowes 1992) interactions during extrusion processing are other factors affecting flavor development of extrudates. Protein and starch can interact because of the attraction of their opposite charges to form ionic bonds, thus preventing loss of exudates from the granules (Badrie and Mellowes 1992). Addition of defatted soybean and corn to African breadfruit is expected to promote both protein–starch and protein–lipid interactions and hence aroma development. The model developed for snacks aroma accounted for 67.08% of the total variation and showed a significant ($P \leq 0.05$) lack of fit.

Texture has been described as one of the most important characteristics affecting consumer acceptance of snack products (Suknark *et al.* 1998). This characteristic makes its scores comparable to those of appearance, ranging from 4.20 to 7.50 (Table 3). In general, increased addition of defatted soybean in the blend increased the scores for liking up to a maximum of 25% before declining. This observation confirms the reports by some workers (Singh *et al.* 1991; Rampersad *et al.* 2003) that addition of protein enhances textural properties of extruded products.

Addition of defatted soybean and corn to breadfruit increased the snack crude fiber from 3.40 to 4.10% (Nwabueze 2007), which may have contributed to the increased mean scores on texture of extruded snacks over those made from 100% breadfruit. This observation agrees with reports that dietary fiber formulations affect extrudate texture, resulting in a compact and noncrisp or less hard product with open texture and better taste (Lue *et al.* 1991; Sotillo and Hettiarachchy 1994).

The estimated regression coefficients and analysis of variance for snack texture did not show significant effect of any process variable on snack texture. The model accounted for 75.42% of the total variation for snack texture and exhibited no significant ($P \geq 0.05$) lack of fit.

The panelists' mean scores for taste (4.30–6.50) showed a relationship with those for aroma (4.40–6.60), indicating that both sensory characteristics are physically and psychologically connected (Iwe 2001). The 100% African breadfruit snacks had the lowest scores, ranging from 4.30 to 5.20. The model accounted for 65.41% of total variation for taste and exhibited no significant ($P \geq 0.05$) lack of fit.

The mean scores on overall acceptability, which ranged from 3.90 to 8.20, gave a general idea of the panelists' total impression toward the snacks. Generally, snacks extruded from blends were more acceptable than those from 100% African breadfruit probably because of the influence of taste and aroma preferences earlier reported. Feed composition was nonsignificantly ($P \geq 0.05$) more quadratic in influencing overall acceptability when it interacted with feed moisture than when it interacted with screw speed.

CONCLUSION

Snacks from blends of African breadfruit, corn and defatted soybean were obtained by single-screw extrusion. The process variable having the most significant ($P \leq 0.05$) influence on physical characteristics of the snacks was the feed moisture (*fm*), while feed composition (*fc*) influenced the sensory characteristics. Optimum process variables for maximum sensory responses were achieved at 70% (*fc*), 21% (*fm*) and 140 rpm (*ss*). This amounted to 25%

defatted soybean substitution for breadfruit and 5% corn inclusion in the blend. This gave an overall acceptability of 8.20 on the 9-point hedonic scale. Depending on the desired snack physical and sensory characteristics, process variables could be manipulated to achieve product objectives.

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