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Development and Evaluation of Potato Chip Bars[a,b]

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ALTHOUGH POTATO CHIPS are well liked by personnel in the Armed Forces, the Quartermaster Corps has been unable to supply them in their usual form as a ration because of the excessive space requirement in packaging and the lack of storage stability. In order to circumvent these obstacles, the Eastern Regional Research Laboratory and the Quartermaster Food and Container Institute for the Armed Forces undertook in 1951 to develop compressed potato chip bars. The purpose of this work was not only to develop bars that might be used as a military ration, but also a product that should be useful as a concentrated foodstuff for stockpiling in protection against disasters and as a civilian snack.

It was found at the outset that chip crumbs could be pressed at ordinary temperature into bars that occupy a volume only about one-twentieth of the original packaging volume of the chips. The bars were self supporting, although it was evident that certain conditions, then undefined, had to be met to prevent excessive crumbling. As it developed, these conditions could be alleviated by selection of the proper type of fat for frying the chips and determination of the order of particle size to which the chips should be reduced before pressing. Details such as the amount of pressure, mode of application, and application time had to be established for obtaining best results in pressing. In addition it was found that a chilling treatment following pressing was of value in firming the bars before wrapping.

It is required by the Quartermaster Corps that ration bars have: 1) acceptable flavor and texture; 2) adequate stability (should remain palatable for at least 6 months during storage at 100° F.); 3) high caloric density, preferably 5 calories or more per gram; and 4) suitable physical characteristics to permit commercial production without undue difficulties. It was immediately recognized that potato chip bars meet the first and third requirements. Chips furnish on the average 5.5 calories per gram. They comprise a concentrated, nutritive foodstuff, containing normally only 2 to 2½% moisture. They contain 35 to 45% fat. The potato solids are made up of 65 to 75% starch, nearly 10% nitrogenous substances, and considerable quantities of inorganic constituents rich in potassium and phosphorus. Tests described in this article proved that chip bars remain palatable and are quite stable in composition during long storage. Limited experience in semi-commercial production of chip bars has indicated that this item should not be difficult to produce in regular commercial operations.

PRELIMINARY EXPERIMENTS

In the initial experiments, the chips were crushed by mild mechanical treatment such as by a wooden roller. Other methods included forcing them through the coarse colander of a Hobart Mixer (Model N-50)[e] by means of the ceramic roller. For most laboratory experiments, though, the chips were crushed by the flat beater attachment of a Hobart Mixer, moving in planetary motion in the bowl at slow speed. The chips were disintegrated to about ⅛ to ¼ inch on a side. Breakage to increasingly smaller particle size eventually leads to material of the consistency of peanut butter. Too large particle size results in poor binding.

Cylindrical molds were used in the laboratory for pressing bars in Carver and in Elmes manually-operated, hydraulic presses. With these presses, the pressure was built up gradually to a maximum, with a total pressing interval of 2 minutes.

Oil loss. The loss of oil during pressing is influenced by several factors: 1) softening point of the fat in which the chips are fried; 2) fat content of the chips; 3) maximum pressure applied in pressing; and 4) manner in which the pressure is applied and time that it is maintained. Since it is desirable to retain the original fat content of chips in the bar, it is important to employ conditions that will minimize fat loss. Table 1 presents laboratory data on the oil loss obtained with 2 samples of chips from the same manufacturer. Crushed chips were compressed in a cylindrical mold 1-5⁄32 inches in diameter to the specified maximum pressures. Chips had been fried in peanut oil. Fat contents of the 2 samples were significantly different, a fact which is reflected by the relative amounts of oil expressed. Loss of fat was nil with one sample and almost negligible with the other at 500 p.s.i. Oil loss increased rather regularly as the maximum pressure was increased to 7,000 p.s.i.

Volume reduction. The volume of a compressed potato chip bar is dependent on the maximum pressure applied during pressing. In the range of 3,000 to 4,000 p.s.i., the volume re-

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[e] Commercial equipment and products referred to in this article are not recommended or endorsed by the U. S. Departments of Agriculture or Defense over similar types of other manufacture.

TABLE 1

Oil loss on pressing 20 g. samples of crushed chips

Maximum pressure	Oil expressed from 37%-fat chips	Oil expressed from 42%-fat chips
p.s.i.	*g.*	*g.*
500	0.7	None
1,000	1.3	2.3
2,000	2.1	3.1
3,000	2.8	3.8
4,000	3.3	4.4
5,000	3.7	5.5
6,000	4.0	5.8
7,000	4.3	6.0

duction is about 20 to 1. This great volume reduction is not primarily due to compression of chip tissue, but arises from the fact that chips in their ordinary form occupy large packaging space. The volume reductions obtained on pressing, in the laboratory, chips containing 35% hydrogenated vegetable shortening are given in Table 2. Part of the volume reduction, of course, is due to the loss of expressed oil, values for which are also given. Direct comparison cannot be made of the oil loss data of Tables 1 and 2, because different lots of chips were used and pressing details were not the same.

TABLE 2

Volume reduction on pressing 20 g. of chips (17.4 cu. in. packaging volume) in cylindrical mold

Pressure	Oil loss	Volume
p.s.i.	*g.*	*cu in.*
500	0.5	1.12
1,000	1.2	1.09
1,500	1.9	1.04
2,000	2.8	0.97
2,500	3.1	0.93
3,000	3.7	0.89
3,500	4.1	0.86
4,000	4.1	0.85
5,000	4.5	0.84
6,000	4.5	0.83

IMPROVEMENT OF BINDING AND FIRMNESS

There are indications that chips fried in hydrogenated vegetable shortening give firmer, better bound bars than those fried in liquid vegetable oils. Some feel, however, that ordinary hydrogenated shortening does not give bars that possess adequate firmness to resist impact and crushing without crumbling. Binders such as dextrin, casein, and dehydrated corn sirup were mixed with crushed chips before pressing. Water had to be added to bring out the adhesive properties of these substances. It was later found in laboratory experiments that increase in moisture content alone without addition of binder apparently helped by utilizing the adhesive properties of the starch and dextrin naturally occurring in chips. Experience proved, though, as discussed below in connection with the first large-scale evaluation of the chip bar, that increased moisture content results in lower storage stability and loss of characteristic crispness.

Coating of the bars with tasteless film formers applied from aqueous solution was tried without much success in improving the binding. Pectin, for example, was unsatisfactory in that the film peeled from the surface as it dried.

Use of hard shortenings in frying chips has been considered as a means for increasing the firmness of bars. Vegetable shortenings hydrogenated to such an extent that they are hard at ordinary temperature provided bars that were deemed too hard. A blend of soft and hard shortenings or use of a shortening of intermediate hardness has given bars of suitable hardness in laboratory tests.

Hard shortenings, however, have not been used to any great extent by industry in frying. Manufacturers thus have little information on their performance in this respect. Hence, the use of hard shortenings in any large-scale trial should come only after thorough testing of small lots of chip bars in the laboratory. These shortenings appear to be exceedingly stable against oxidative deterioration. They reportedly hydrolyze more readily than soft shortenings, but the low moisture content in chip bars should prevent pronounced hydrolysis.

PREPARATION OF CHIP BARS FOR STORAGE TESTS

In order to obtain more data on the processing of chip bars and on the storage stability of the product, a special lot of chips was produced with commercial equipment. Hydrogenated vegetable shortening was used by the processor in the frying. To the shortenings, was added 0.13% of a commercial antioxidant. This preparation consisted of 20% butyl hydroxyanisole, 6% propyl gallate, 4% citric acid, and 70% propylene glycol. Operating conditions in the continuous fryer were typical, with the fat at 375° F. at the front of the oil bath where the slices entered and 300° at the rear, where they were removed 3 to 4 minutes later.

Crushing. Crushing was carried out to the desired particle size by use of an intermediate-size Hobart mixer equipped with a wire loop attachment.

Moisture addition. The moisture content of portions of the special lot of chips was increased to approximately double and triple the original value in order to evaluate further the addition of moisture as an aid to binding. Weighed amounts of water were sprayed in while stirring the material in the 20-gallon bowl of a Hobart mixer with the dough hook attached. After standing overnight in sealed containers, the crushed chips in each lot had uniform moisture distribution.

Pressing. A Denison "Hydroilic Multipress" was used at the Quartermaster Food and Container Institute in pressing bars 3 inches x 1 inch x ⅝ inch. An acceptable bar was produced by applying a single stroke of the punch (entering the die from above) at 3,000 p.s.i. for about 4 seconds. The ejector, on moving from the bottom to the top of the die cavity, removed the bars without damaging them perceptibly. Although the shortening became nearly fluid during the pressing, no oil was expressed as had been the case with laboratory presses. Perhaps the time interval during compression is largely responsible for this difference.

Bars were chilled in a freezer to firm them before wrapping in thin aluminum foil. They were wrapped by hand, although it was later demonstrated that they could be machine-wrapped.

A total of more than 1,000 bars were prepared from crushed chips at approximately 2, 4, and 6% moisture; bars at these 3 moisture levels were coded "A", "B", and "C", respectively. The wrapped bars were canned in nitrogen and in air. The cans were stored at 40°, 70°, and 100° F. Chip bars were also sealed in envelopes (air pack), made of kraft paper laminated with an inner, plastic film. It was later found that this type of packaging did not give the required protection for high-temperature storage.

In addition, a smaller number of bars from regular commercial chips fried in 80% corn oil-20% hydrogenated vegetable shortening with antioxidant, were wrapped, canned (some in air and some in nitrogen), and placed in storage at the three temperatures. Bars prepared from chips fried in the corn oil-shortening mixture were designated "D".

Chemical determinations were made on the bars one month after their preparation. Two cans were selected from each moisture level group. Since the values obtained in these duplicate samples agreed well, they are averaged together in the data given in Table 3. The percentage fat decreased, of course, as more moisture was incorporated. The free-fatty acid and iodine number values were higher for "D", the only lot containing corn oil.

INITIAL TASTE EVALUATION STUDY

Shortly after the bars were prepared, samples of the 4 different formulas (A, B, C, and D of Table 3) were submitted to a panel of 20 trained judges at the

TABLE 3

Analytical and fat characterization data[1] on potato chip bars

	A	B	C	D
Moisture, %	2.3	3.9	5.5	2.2
Ash, %	4.5	4.6	4.6	4.2
Fat, %	37.3	35.8	35.1	37.9
Protein (N x 6.25), %	4.0	4.0	3.9	4.0
Cl, as NaCl, %	2.7	2.8	2.7	2.3
Perox. Val.	3.7	3.3	2.8	3.3
Free fatty acid, %	0.07	0.09	0.10	0.23
Iodine No.	66.1	66.5	66.6	79.1

[1] All determinations by procedures in *Official Methods of Analysis of the Association of Official Agricultural Chemists.* Seventh Ed., (1950), except peroxide value, by method in Jacobs, *Chemical Analysis of Foods and Food Products,* p. 434 (1938).

Quartermaster Food and Container Institute. Judges rated the samples on a 9-point hedonic scale (Table 4). This scale permitted 4 degrees of *dislike,* a neutral position, and 4 degrees of *like* in the following descriptive terms, valued in the order given as 1 to 9: *dislike extremely, dislike very much, dislike moderately, dislike slightly, neither dislike nor like, like slightly, like moderately, like very much,* and *like extremely.* Judges were instructed to reflect their general acceptance of the item for possible use in the Army's "Assault Ration" as well as to rank the different samples in the order of preference.

Some tasters thought that the bars whose scores are given in Table 4 were too salty and that B and C were "rancid." The latter effect is perhaps due to loss of characteristic crispness accompanying the unnaturally high moisture contents. Tasters had a preference for the bars made from commercial chips (lot D) over those from the special chips fried in hydrogenated vegetable shortening, although this preference over lot A was slight. In general, the degree of acceptance for a product of this type was considered as quite satisfactory.

TABLE 4

Taste evaluation of freshly-prepared chip bars

Sample	Score	% Scoring in dislike range
A	6.2	25
B	5.8	35
C	5.8	40
D	6.5	20

THREE MONTHS' STORAGE TESTS

Samples of the 4 different formulas of chip bars were again given to the same panel after the bars had been stored 3 months at 40°, 70°, and 100° F. Results are given in Table 5. Since the difference between the air and nitrogen packs was insignificant during the early phase of the storage, values for the 2 packs are averaged together in this table.

The scores of 40°- and 70°-stored samples were nearly the same at the end of 3 months. At 100° F. some decline was in evidence, particularly with the C and D formulations.

SIX MONTHS' STORAGE EVALUATION

After 6 months' storage, the bars were tested by the 20 tasters who had previously rated them. Formula D was dropped from consideration, since these samples had developed an off-flavor. Even bars of this lot that had been canned in nitrogen exhibited appreciable browning. Scores for the 6 months' test are given in Table 6, with data on the percentage dislike.

TABLE 5

Taste scores and percentage dislike[1] of chip bars after 3 months' storage

Temperature	A	B	C	D
° F.				
40	6.3(20)	6.7(10)	6.1(34)	6.9(50)
70	6.5(15)	6.3(20)	6.0(41)	6.8(17)
100	6.1(20)	6.1(30)	5.0(65)	5.9(30)

[1] Percentage of tasters scoring in dislike range given in parentheses following taste score.

Except for the 100° F. nitrogen pack of formulas A and B, the scores regularly diminished from A to C accompanying higher moisture content. Nitrogen-pack samples received slightly higher scores than air pack. There was little difference between the 40° and 70° samples. The acceptability score of the 40° samples after 6 months was actually above the original. This is probably due to a better attitude of the tasters toward this product as they became accustomed to it. It also indicates little flavor change.

TABLE 6

Taste scores and percentage dislike[1] of chip bars after six months' storage

Temperature	Pack	Score		
		A	B	C
° F.				
40	N_2	7.15(5)	7.0(5)	6.5(15)
40	Air	6.55(25)	6.35(25)	6.3(15)
70	N_2	6.8(20)	6.62(12)	5.8(35)
70	Air	7.05(5)	6.65(20)	5.65(45)
100	N_2	5.95(30)	6.3(25)	4.9(60)
100	Air	5.6(40)	5.35(45)	4.5(75)

[1] Percentage of tasters scoring in dislike range given in parentheses following taste score.

Peroxide value determinations were made on the chip bars and gaseous contents of the containers analyzed after the samples had been stored for 6 months. Results in the main were about the same as in the original analyses. However, as shown in Table 7, considerable oxygen uptake (indicative of oxidative rancidity development in the fat) occurred in the air packs at 100° F. This suggests that nitrogen packing should be used for high temperature storage.

EVALUATION AFTER ONE YEAR'S STORAGE

Sensory evaluation of the chip bars after one year's storage resulted in scores high enough to indicate that the product should be acceptable. Bars that had been canned in nitrogen and stored at 70° F. received about the same rating as at the time they entered storage. The air pack stored at 70° was still palatable, although less so than the nitrogen pack. Storage at 100° F. resulted in definitely lower scores than at 70° F. Table 8 gives the ratings scored by the judges.

TABLE 7

Composition of head space after 6 months' storage of canned chip bars at different temperatures. Air and nitrogen packs

Temperature °F.	40		70		100	
Pack	Air	N_2	Air	N_2	Air	N_2
Formula A						
% CO_2	0.7	0.6	1.2	0.9	3.1	1.5
% O_2	19.2	1.4	17.1	0.9	12.0	0.3
Formula B						
% CO_2	1.2	0.9	2.2	1.3	4.1	1.9
% O_2	17.4	1.5	17.8	1.7	15.5	0.3
Formula C						
% CO_2	1.2	1.3	2.7	0.8	6.9	1.5
% O_2	17.4	1.5	15.2	0.6	8.5	0.3

Only the A group, containing the least moisture, was examined chemically after one year's storage because the others were considered to be beyond the range of normal acceptability. Samples from 100° F. storage were selected for examination, since chemical changes would be expected to be most pronounced at the high temperature. The CO_2 content in the head space of the cans was of the same order as at the six months' sampling period. The O_2 content in the head space, however, had fallen after a year to about 3% in the air pack and to zero in the nitrogen pack. The air-pack cans were under 3½ to 4 inches of vacuum, showing that changes in high-temperature storage involved predominantly absorption rather than evolution of gas.

TABLE 8

Taste evaluation of chip bars (2.3% moisture) after one year's storage

Temperature	Pack	Score	% of tasters scoring 5 and below
°F.			
70	N_2	6.50	15
70	Air	5.75	45
100	N_2	5.15	65
100	Air	4.9	65

The free fatty acid content of the low-moisture chip bars remained essentially unchanged during the year's storage, with no appreciable hydrolysis of fat in evidence. The peroxide value of the bars packed in air, however, increased from about 3 to 20, indicative of oxidative deterioration in the fat.

POSSIBILITIES IN THE CIVILIAN MARKET

Chip bars have also been evaluated by an untrained, consumer-type taste panel of 40 persons at the Chicago Quartermaster Corps Depot. Bars produced from a second lot of chips fried in hydrogenated vegetable shortening containing antioxidant were used in this test. Antioxidant salt (The Griffith Laboratories, Inc., "GS-245" product) was employed in seasoning the chips. Since the first lot of chip bars was considered too salty, the NaCl content was reduced from 2.6 to 1.3% for the second lot. Although some complained of low salt content in this second lot, only 15% of the tasters disliked the bars. The degrees, which corresponded well with the score premean score for taste was 6.2 on a hedonic scale of 9 viously accorded the product by the trained panel of 20 persons. Some tasters objected to greasiness and lack of flavor, both of which could be improved for a civilian-type bar by using vegetable oils, e.g., corn or peanut, for part of the frying-fat requirement and by use of suitable flavor adjunct.

In addition to the evaluation by a consumer-type panel, samples of potato chip bars have been given to a fairly large number of individuals at the Eastern Regional Research Laboratory and elsewhere for tasting. The reaction on the whole has been satisfactory, particularly to bars containing some vegetable oil. Since the civilian-type bar would not have to remain stable over a long period, the use of a blend of vegetable oil and shortening in frying the chips should give a product of satisfactory shelf life.

SUMMARY AND CONCLUSIONS

Potato chips crushed to ⅛ to ¼ inch on a side and compressed at 500 to 3,000 p.s.i. give self supporting bars in which the characteristic crunchy texture of the original chips is preserved. The oil loss is slight or nil if the chips are fried in hydrogenated shortening and compressed in an automatic press under optimum conditions.

Sensory evaluation of the chip bars after one year's storage resulted in scores high enough to indicate acceptability as a ration component for the armed forces. Canned bars stored at 40° and 70° F. for a year were still palatable, while those stored at 100° F. were definitely lower in degree of acceptability. During the year's storage, the free fatty acid content of the bars remained substantially unchanged. The peroxide value of the air-pack product, however, increased appreciably during 100° F. storage. The oxygen content in the head space of the air-filled cans decreased decidedly during high temperature storage, indicating that a nitrogen pack should be used to prevent oxidative deterioration over a long keeping period.

Evaluation by a consumer-type panel indicated that potato chip bars might also have possibilities as a civilian food product. With the less rigorous stability requirements of a civilian product, it should be feasible to fry the chips in a vegetable oil-shortening blend, which appears to make the flavor of the bar more attractive.

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