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PEANUT BUTTER

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INTRODUCTION

The manufacture of peanut butter consumes as large a quantity of peanuts as all other peanut food products combined. In the 1952-53 season more than 560 million pounds of edible grade, raw shelled peanuts were reported (63) as utilized directly by the industry in the manufacture of primary products, and about 287 million pounds, or 51%, were used in the manufacture of peanut butter. While reports (4, 21) are found of the preparation of a paste from peanuts in various parts of the world, peanut butter was probably first used in the United States (75) as a special-diet food about 1890. Despite early use of peanuts for a product of this type in other parts of the world, peanut butter has not reached commercial importance except in the United States (29).

Peanut Composition

The peanut is an annual herbaceous plant belonging to the Papilonaceae, a suborder of the larger order Leguminoseae. The important varieties of peanuts grown in the United States are the Runner, Spanish, and Virginia. After fertilization of the flowers of the plant, a peduncle develops and grows to reach the soil and push the "peg" three to four inches below the surface where the fruit or pods are formed. The pods are about 1/2 to 3 inches in length and roughly cylindrical. The shell of the pod comprises from 20 to 30 percent of the whole "nut" and may easily be separated from the kernels. The kernel consists of two cotyledons (halves) and the germ (heart) enveloped in a thin red-brown, purple or white skin called the testa. Peanut kernels are composed of approximately equal weights of fatty and non-fatty constituents (see Tables 1, 2, 3, and 4), the relative amounts of each depending upon variety and quality of the peanuts. Most of the fatty constituents are contained in the cotyledons, some are found in the germs, and small amounts are generally found in the testa (26). (See Tables 4 and 5).

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Table 1. Composition of Peanut Kernels (27)

Constituent	Range %	Average %
Moisture	3.9 - 13.2	5.0
Protein	21.0 - 36.4	28.5
Lipids	35.8 - 54.2	47.5
Crude fiber	1.2 - 4.3	2.8
Nitrogen-free extract	6.0 - 24.9	13.3
Ash	1.8 - 3.1	2.9
Reducing sugars	0.1 - 0.3	0.2
Disaccharide sugar	1.9 - 5.2	4.5
Starch	1.0 - 5.3	4.0
Pentosans	2.2 - 2.7	2.5

Table 2. Vitamins in Peanut Kernels (27)

Vitamin	Amount present gamma/gram
Vitamin A	26 I.U./100 grams (66)
B Vitamins	
Riboflavin	1.05 - 1.57
Thiamine	8.5 - 14.0
Nicotinic acid	88.0 - 200.0
Pantothenic acid	25.0
Pyridoxin	3.0
Biotin	0.34
Inositol	1800.0
Folic acid	2.8
	mg./100 grams
Vitamin C (ascorbic acid)	5.8
Vitamin E	
α-tocopherol	0.018 - 0.030%
β-tocopherol	0.0 %
ν-tocopherol	0.018 - 0.022%
Δ-tocopherol	About 1/5 of total tocopherol

Table 3. Inorganic Constituents in Peanut Kernels (27)

Constituent	Amount present mg./100 grams
Potassium	680 - 890
Sodium	Trace
Calcium	20 - 80
Magnesium	90 - 340
Phosphorus	250 - 660
Sulfur	190 - 240
Chlorine	Trace
SiO_2	80
Zinc	1.7 - 80
Manganese	0.8 - 50
Iron	1.8 - 100
Cobalt	0.03
Copper	0.7 - 30
Boron	2.6 - 50
Fluorine	0.14
Iodine	0.02
Strontium	0.8 - 5
Barium	8 - 30
Vanadium	10 - 50
Chromium	1 - 30
Aluminum	100
Nickel	3 - 8
Titanium	30 - 80
Molybdenum	0.8 - 3
Tin	0 - 5
Lead	0 - 50

Table 4. Chemical Composition of Peanut Germs (27)
(Dry Basis)

Constituent	Variety	
	Spanish %	Runner %
Oil	42.41	41.23
Nitrogen	4.53	4.08
Ash	3.07	2.94
Calcium	0.07	0.06
Magnesium	0.22	0.23
Chlorine	0.01	0.02
Sulfur	0.18	0.15
Potassium	0.75	0.80
Phosphorus	0.54	0.65
Phytin	-----	0.50
Iron	0.0034	-----
Crude fiber	1.8	-----
Sugar (before inversion)	7.9	-----
Sugar (after inversion)	12.0	-----

Table 5. Composition of Peanut Oil 1/ (27)

Glycerides	Varieties	
	Spanish %	Virginia %
Unsaturated		
Oleic $C_8H_{17}CH{:}CH(CH_2)_7COOH$	52.9	60.0
Linoleic $CH_3(CH_2)_4CH{:}CHCH_2CH{:}CH(CH_2)_7COOH$	24.7	21.6
Saturated		
Palmitic $CH_3(CH_2)_{14}COOH$	8.2	6.3
Stearic $CH_3(CH_2)_{16}COOH$	6.2	4.9
Arachidic $CH_3(CH_2)_{18}COOH$	4.0	3.3
Behenic $CH_3(CH_2)_{20}COOH$	----	----
Lignoceric $CH_3(CH_2)_{22}COOH$	3.1	2.6
Unsaponifiable matter	0.2	0.3
Total	99.3	99.6

1/ Calculated as simple triglycerides

Composition and Properties of Peanut Oil

Peanut oil is composed essentially of a mixture of glycerides of fatty acids of which approximately 80% are unsaturated acids and 20% are saturated acids (27). The proportions of the various fatty acids in peanut oils vary with the type of peanut, and with environment and agronomic practices under which they are grown (30). At ordinary temperatures the component glycerides of peanut oil are mixed homogeneously in the form of a clear liquid. Because peanut oil contains a relatively large proportion of glycerides of saturated fatty acids, it will partially or, for practical purposes, completely solidify (7) if kept in a refrigerator. Peanut oil may be converted to a more or less hard or plastic fat upon direct reaction of hydrogen at the double bonds of the unsaturated fatty acids (5a). Hydrogenated peanut oil is sparingly and slowly soluble in peanut oil at normal room temperatures, but solubility (6d) increases with increase of temperature. Melted hydrogenated peanut oil is miscible with peanut oil in all proportions.

The glycerides comprising peanut oil and hydrogenated peanut oil are capable of existing in more than one crystalline form, each of which has a distinct melting point. The particular form obtained by cooling the liquid or melted fat depends upon the temperature at which the crystallization is allowed to take place (6a). For example, Lutton (48) found that tristearin (the triglyceride of stearic acid) could exist in three forms, the α-form melting at 129° F. (54° C.), the β_1-form melting at 147° F. (64° C.), and the β-form melting at 163° F. (73.1° C.); and that hydrogenated peanut oil (iodine value, 8) could exist in three forms, the α-form melting at 125° F. (51.5° C.), the β_1-form melting at 145° F. (63° C.), and the β-form melting at 154° F. (67.8° C.). The lower melting forms are characterized by more finely divided crystals, and are produced by relatively rapid chilling. Once heated beyond their respective melting points, the lower melting forms cannot be re-established merely by normal cooling, but must be rapidly chilled in the original manner (6a). Transformation to a more stable form may take place subsequently without melting (6a).

The development of rancidity is a phenomenon which is associated with atmospheric oxidation of unsaturated vegetable oils, and is the source of most of the spoilage of edible fats and oils. The initial step in the oxidation of a fat is the addition of oxygen in the form of peroxides or hydroperoxides at or near the double bond of a fatty acid chain to form unstable compounds. Whatever the structure of these compounds, they are transitory, and quickly decompose or combine with one another to yield the compounds actually responsible for rancid flavors and odors (5b). The high percentages of unsaturated fatty acids in peanut oil make it susceptible to atmospheric oxidation and hence to development of rancid flavors and odors.

The Manufacture of Peanut Butter

The essential steps in the preparation of peanut butter in their order are cleaning, shelling, and grading (15); and roasting, blanching, and grinding to a pasty consistency usually with salt for flavoring (11). At first these operations were performed manually, either in the home, in institutions, or in groceries, but as the demand for the product increased, machinery was developed for performing most of them. In this evolution a peanut shelling industry was developed which performs the operations required for cleaning, shelling, and grading peanuts for use in the manufacture of peanut products. Groups within this industry have adopted trading rules (77) which include definitions of commercial grades of peanuts. Most peanut butter manufacturers purchase shelled peanuts, but some operate their own shelling plants.

In the manufacture of peanut butter, to produce the desired flavor and appearance, the shelled peanuts are usually roasted in gas-fired roasters, either by radiant-heat or rapid re-circulation of hot gases over the peanuts. The roasted product is then cooled to room temperature by rapidly drawing air from the room through the hot mass. The testa (red skin) and germs (hearts) are separated by passing the roasted peanuts through a blanching machine, in which they are divided into cotyledons (peanut halves or split-peanuts), germs, and testa. The skins are aspirated away from the mixture, and the relatively small germs are separated from the cotyledons by screening. The objectionable material in the split-peanut portion, including unblanched and/or discolored nuts and foreign matter, is removed manually at a picking table. Specific-gravity separators, or oscillating shaker-screen separators are often used as adjuncts to this operation for removal of trash and damaged peanuts. The roasted peanuts are then ground into a smooth paste along with small amounts of salt, and sometimes sugar, for flavoring, and with peanut oil hydrogenated to various extents, or with mono- or diglycerides for the prevention of oil separation. "Chunky" peanut butters are often made by mixing chopped peanuts with the smooth product. In recent years the hot peanut butter issuing from the grinder has been cooled rapidly in continuous chilling machines in order to dissipate heat before packaging and to set the added hard fats rapidly thereby preventing oil separation and producing a more palatable product. Peanut butter is piped from the grinder or the chilling machine to an automatic filling machine, from which it is dispensed into jars or tins. Containers are usually closed tightly and labeled by automatic machines.

Review of Research on Peanut Butter

Despite the age and size of the industry in the United States, very little information can be found in the literature with reference to the technology of the processes involved in the manufacture of peanut butter, or of the effects of the various processing variables on

the quality of the finished product.

The industry and the consumer have been aware of various shortcomings in the product and various methods have been described, usually in the patent literature, for improvement of the quality of peanut butter. A characteristic of peanut butter has been its tendency to undergo various degrees of separation into an oil phase and a meal phase, even though supposedly adequate amounts of stabilizer had been incorporated during manufacture. Also, peanut butters have been found to vary in flavor because of differences in raw stocks from which they are made, conditions of processing (particularly roasting), rate and type of deterioration (i.e., staling, and rancidification) during storage, and for other reasons.

Several processes of producing peanut butter have been discussed in publications of the United States Department of Agriculture (11, 15). Woodroof, Thompson, and Cecil have reported (95) on the quality of peanut butter and unit operations and processes employed in its manufacture. Equipment and processes for making peanut butter have been described (3).

Some effects of heat treatment of peanuts have been reported by Pickett (65). The effect of moisture on peanuts and peanut products has been investigated (96) by Woodroof, et al. The addition of glycerine has been claimed (20, 45) to reduce the stickiness or tendency of peanut butter to clog in the mouth, as has treatment with a proteolytic enzyme (59). The addition of an aqueous dispersion of a wetting agent, preferably lecithin, has been patented and claimed to produce a peanut butter which is in a more stable emulsion, less sticky, and less apt to become rancid (71). Other methods described in the patent literature as means of delaying rancidity include the addition to peanut butter of ground unroasted peanuts (61) and sesame seed (60). Claims have also been made for reducing stickiness of peanut butter by addition of powdered sugar (38) and by grinding with dry yeast (18). Another method of producing a less "sticky" peanut butter has been to grind coarsely or to leave small pieces of unground peanuts in the butter. Woodroof, Thompson, and Cecil surveyed (94) previous work on improvement of quality of peanut butter, and described methods for preventing oil separation, improving spreadability, and incorporating other foods or flavoring ingredients with peanut butter and for firming the peanut butter so that it could be molded and packaged in brick form suitable for slicing.

Probably the prevention of oil separation in peanut butter (25) has received more consideration than any other aspect of the manufacture of this product. The peanut butter industry in the United States has favored the use of hydrogenated peanut oil for preventing the separation of oil, and the majority of products contain some amount of this material. A growing list of processes for prevention of oil separation includes

special grinding of roasted peanuts (22), subjecting the sealed container of peanut butter to steam under pressure (10), improving processing practice (84), addition of water (92), mixing peanut butter with honey (33), treatment with a proteolytic enzyme (59), addition of hydrogenated peanut oil (36, 52, 53, 74, 79), addition of glycerine (20, 45), addition of glyceryl ester such as the monoglyceride of stearic acid (14), coating the peanuts with hydrogenated oil before grinding (70), and replacement of part of the oil in peanut butter with coconut oil (73).

The contents of thiamine, calcium, phosphorus, and iron in peanut butter have been reported (54) by Miller, et al. Pickett reported (65) that a large amount of the thiamine content of peanut products is lost in roasting. Spies, et al. have presented (78) data relative to the effectiveness of a yeast-peanut butter mixture in treating deficiencies of vitamin-B complex.

Research on Peanut Butter at the Southern Regional Research Laboratory

The Southern Regional Research Laboratory has been conducting research on the production of peanut butter in which processing variables have been systematically investigated in an effort to evaluate their effects on the quality of the finished product.

Processing of Peanut Butter

Roasting. In this investigation batches of No. 1 grade (77), white Spanish peanuts were roasted in a 250-lb. capacity, gas-fired, radiant-ray roaster (Figure 1) within the range of 220 to 340° F. The conditions used in roasting, the types of roasts produced, and the moisture contents of the peanuts before and after roasting are given in Table 6. Variation of the temperature within the mass of roasting peanuts with the time of roasting is shown for three of the products (Figure 2).

Cooling of peanuts. The peanuts were cooled immediately after they were dumped from the roaster into a 44 x 58 inch cooling car, (Figure 1, foreground) provided with a perforated screen, which supported the peanuts above the bottom of the car and permitted the free passage of air. The average depth of the peanuts in the cooling car was about 5 inches. Cooling was accomplished by drawing air from the room at the rate of about 1100 cu. ft. of free air per minute downward through the batch of nuts by means of a heavy-duty exhaust fan.

Blanching and sorting. The testa (red skin) and germs (hearts) were separated by passing the roasted peanuts through a split-nut blanching machine (Figure 3) of the ribbed-roll type (11). In this device the shelled peanuts were divided into cotyledons (peanut halves or split-peanuts), germs, and testa by rubbing between ribbed-rubber

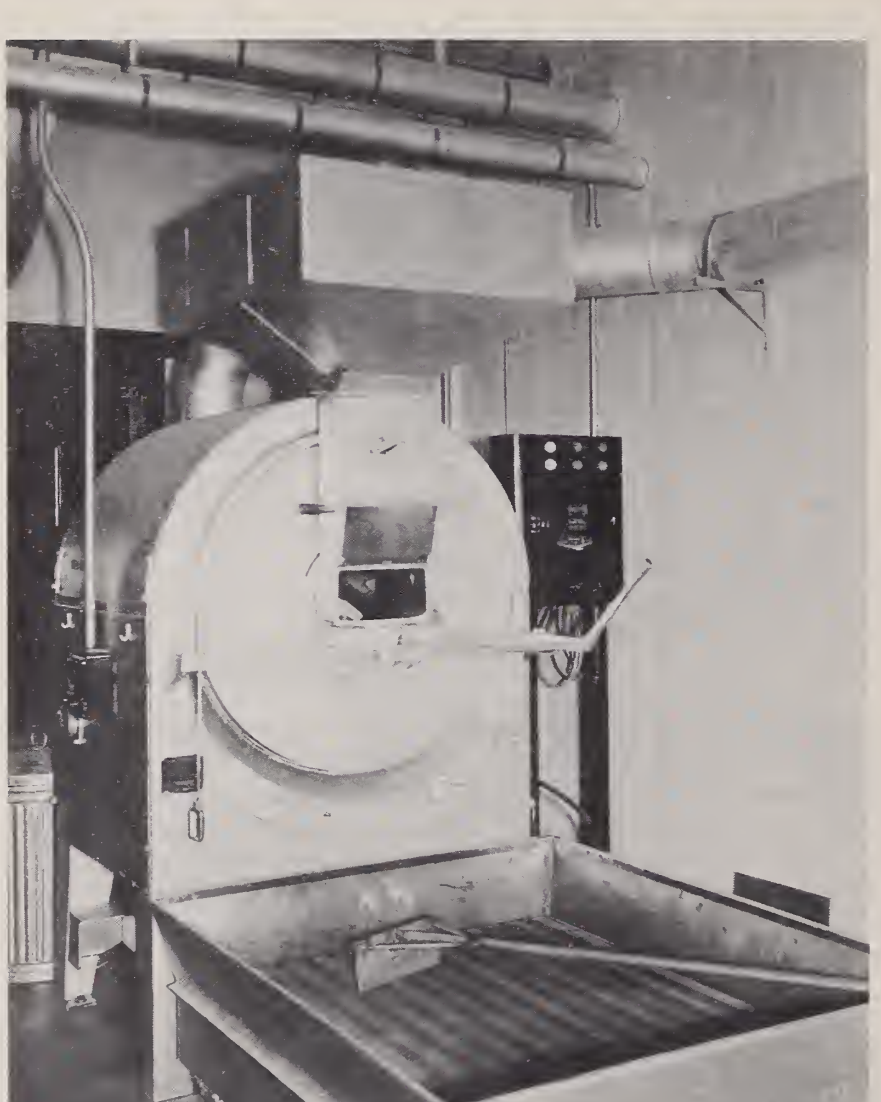

Figure 1. Roaster and cooling car.

Table 6. Results of Peanut Roasting Tests

Batch No.	Raw Peanuts	Roasting time	Roasting Temperature			Peanut Butter Color		Moisture content of peanuts	
			Initial	Minimum	Maximum	Type	Designation 1/	Before roasting	After roasting and cooling
	lbs.	minutes	° F.	° F.	° F.			%	%
1	230	17	275	230	275	very light	11-E3	5.57	2.33
2	230	23	275	205	283	very light	11-J5	6.04	2.03
3	240	21	270	205	285	light	11-G5	5.95	1.71
4	230	22	275	200	285	light	11-G5	6.79	1.92
5	230	21.5	310	205	285	light	11-G5	6.31	1.94
6	230	25	260	200	292	light	11-G6	7.04	1.41
7	234	22.5	280	200	290	medium	11-F6	6.79	1.74
8	246	21	290	210	290	medium	11-F6	6.39	1.50
9	230	26	230	200	298	medium	11-F6	6.37	1.35
10	230	24	250	200	300	medium	11-F6	6.07	1.06
11	230	23	330	215	295	dark	11-J7	6.98	1.80
12	230	26	240	200	308	dark	12-K7	6.45	1.03
13	253	25	340	205	300	dark	12-L7	6.74	1.15
14	230	29	220	200	304	dark	12-J7	6.94	1.30
15	230	24	330	210	300	dark	12-I7	6.91	1.39
16	230	25	300	205	305	dark	12-L8	6.70	1.30
17	230	20	340	240	305	dark	12-L8	6.88	1.05
18	230	21	290	215	315	very dark	13-G9	6.20	1.25
19	200	17.75	300	250	320	very dark	13-F9	6.37	1.17
20	232	22.5	300	210	320	very dark	13-F9	6.27	1.08

1/ Refers to color plates in A. Maerz and M. Rea Paul, A Dictionary of Color. 1930, McGraw-Hill Book Company, Inc., New York.

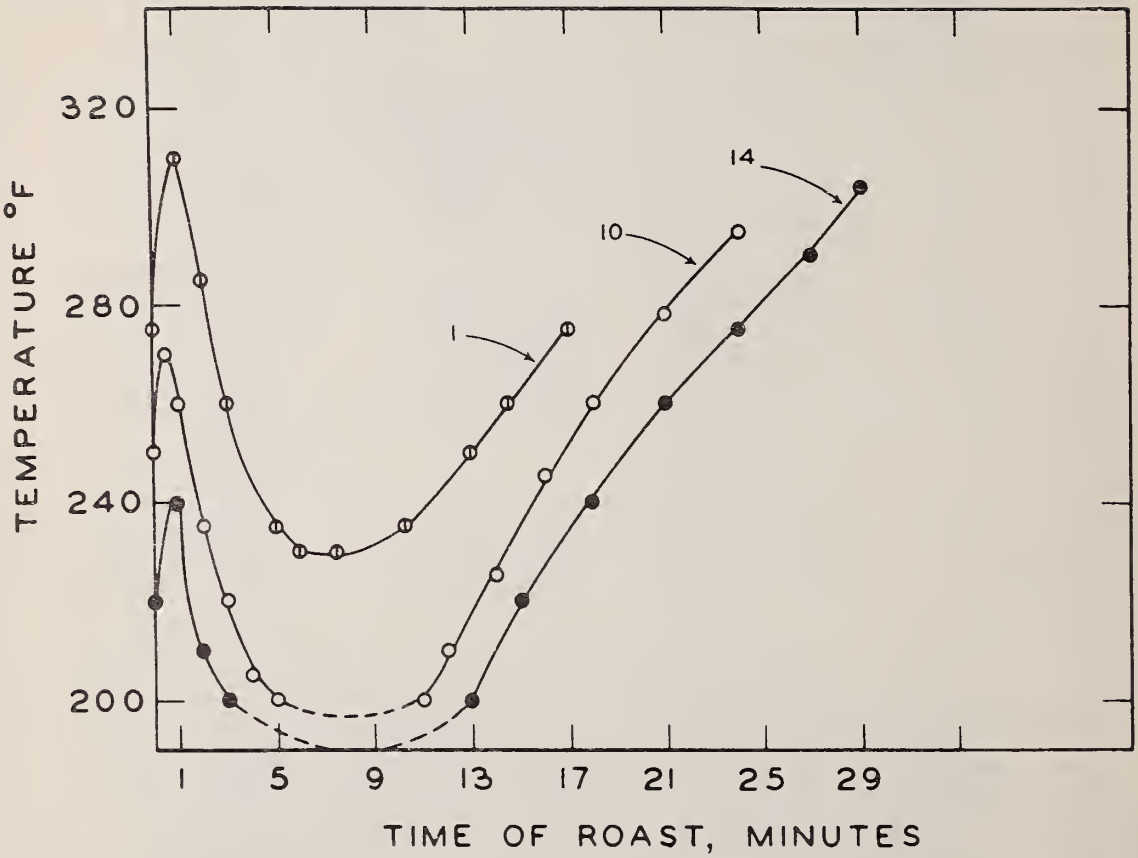

Figure 2. Variation of temperature of peanuts (measured at bottom of mass) with time of roasting. Curves represent light (1), medium (10), and dark (14) roasts.

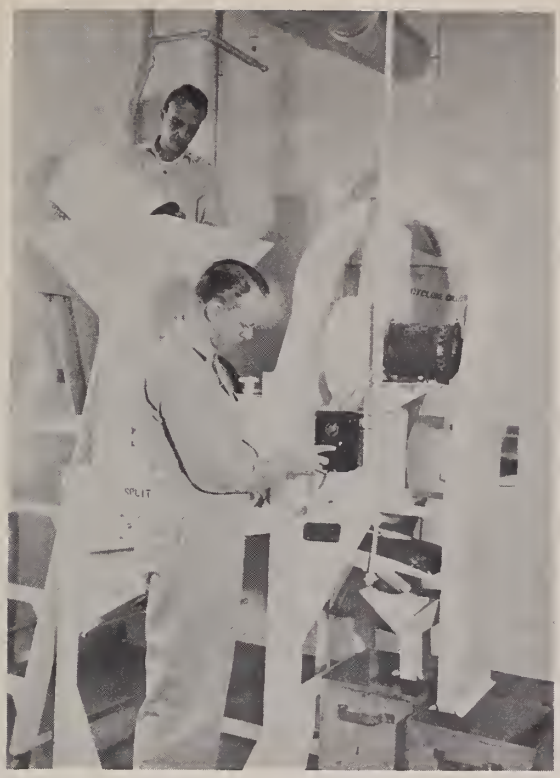

Figure 3. Blanching machine.

Figure 4. Picking table.

surfaces. The testa was aspirated away from the mixture, and the relatively small germs were separated from the cotyledons on an oscillating tray which screened out the germs. The objectionable material in the split-peanut portion, including unblanched and/or discolored nuts and foreign matter, was removed manually at a six-place picking table (Figure 4). The speed of the conveyor belt of the table was controlled by a variable-speed drive, which permitted operation at slower rates as needed and hence efficient removal of objectionable material. Results obtained from these operations are shown in Table 7.

Peanut butters. Each of these batches of blanched, sorted peanuts was ground into peanut butter at the rate of 240 pounds of peanuts per hour in an 8-inch vertical attrition mill. The temperatures of the peanut butters issuing from the mill varied from about 150° to 165° F. (65 to 74° C.). Three types of peanut butter were made from each batch; Type A, containing only ground peanuts; Type B, containing added salt; and Type C, containing added salt, and hydrogenated peanut oil added to prevent oil separation. The resulting peanut butters ranged in color from very light to very dark. The peanut butters were packaged in 8-oz. glass jars provided with lined screw caps leaving an air head-space of about 45 ml. The jars were packed in cartons and stored on shelves in a room maintained at approximately 80° F. (26.7° C.).

Roasting, Cooling, Blanching and Picking of Peanuts

Data obtained during roasting of peanuts indicated in general that the rate of heating for the equipment used was constant, and that all other conditions being equal the time of roasting for a given weight of peanuts was the most important variable affecting the character of the end product. Also, it was noted that the moisture contents of the peanuts after roasting and cooling were proportionately lower as the darkness of the color of the roasted product increased.

Information ascertained during the cooling, blanching, and manual sorting operations indicated that for practical purposes uniformly efficient blanching was obtained for all batches whatever the degree of roasting. It was also observed that a small but appreciable percentage (1-3%) of unblanched and/or discolored and foreign material remained with the peanuts after the blanching operation and should be removed by a supplemental sorting operation prior to grinding into peanut butter (88).

Properties of Peanut Butter

Thiamine. Raw peanuts are a good source of thiamine (vitamin B_1) (12, 31), but roasted peanuts have been grouped with those foods which generally contain only a moderate amount (12) of this substance. Because of the known thermal instability (72) of thiamine and the high temperature and protracted time of heating peanuts to produce the desired

Table 7. Results of blanching and manual sorting of peanuts.

No.	Materials separated during blanching			Materials from manual sorting of the cotyledons	
	Germs	Skins	Cotyledons	Accepted 1/	Rejected
	lbs. per 100 lbs.	lbs. per 100 lbs.	lbs. per 100 lbs.	lbs.	lbs.
1	2.1	4.1	93.8	91.6	2.2
2	2.1	4.0	93.9	90.9	3.0
3	2.5	4.3	93.2	91.3	1.9
4	1.9	3.5	94.6	92.8	1.8
5	1.9	4.1	94.0	92.1	1.9
6	1.6	3.9	94.5	92.8	1.7
7	2.4	4.2	93.4	91.3	2.1
8	2.1	3.7	94.2	91.1	3.1
9	2.1	3.9	94.0	91.4	2.6
10	2.2	4.0	93.8	92.4	1.4
11	1.6	4.1	94.3	91.6	2.7
12	2.1	4.2	93.7	91.6	2.1
13	2.8	4.0	93.2	92.0	1.2
14	2.1	4.0	93.9	91.6	2.3
15	1.5	4.1	94.4	91.9	2.5
16	2.0	4.3	93.7	92.1	1.6
17	2.7	4.4	92.9	90.7	2.2
18	2.0	4.0	94.0	91.4	2.6
19	2.8	3.6	93.6	92.8	0.8
20	2.3	4.0	93.7	92.1	1.6

1/ Used for production of peanut butter.

color, flavor, and aroma in peanut butter, it might be expected that there would be some decrease in the content of this vitamin in the finished product.

Raw, shelled peanuts; raw, shelled peanuts from which the testa had been removed manually; and the peanut butter made from the roasted peanuts were analyzed for thiamine content by a modification (91) of the Conner and Stroub (17) fluorescence method.

Results of analyses for thiamine content showed that from 74 to 97% of the total thiamine is concentrated in the kernel of the raw shelled peanut; and that the thiamine content of the peanut butters diminished with increase of extent of roasting while the peanuts became darker. In general, butters made from light-roasted peanuts retained about 20% of the original thiamine content; those from medium-roasted peanuts less than 14%; those from dark-roasted peanuts less than 10%; and those from very dark-roasted peanuts less than 3% (91).

Oil content and free fatty acids. In view of the conditions and operations required in preparation of peanuts for the manufacture of peanut butter, it might be expected that the oil content of the components would be affected. The relative proportions of oil and meal in roasted peanuts are important in the manufacture of peanut butter, particularly from the standpoint of the amount of stabilizer that should be added to prevent oil separation. The free fatty acids content of the oil of peanuts is an important factor in the quality of peanut butter. Hence, the contents of oil and free fatty acids of peanuts were determined during the manufacture of peanut butter. The oil contents of peanut butters without additives, with only added salt, and with added salt and stabilizer are shown in Table 8.

Raw shelled peanuts, roasted shelled peanuts, germs, testa, sorted cotyledons, and the three types of peanut butters (referred to previously) made from the sorted cotyledons were analyzed for moisture and oil contents. The oils extracted from these samples were analyzed for free fatty acids content (58).

Results indicated (Figure 5) that the roasted peanut kernels have a higher percentage of oil than the corresponding raw kernels, the difference presumably being occasioned by loss of volatile matter in addition to moisture during roasting or by some effect on the non-oil portion of the peanut. Also, the data show that the sorted cotyledons have a higher percentage of oil than the roasted kernels, the difference undoubtedly being occasioned by the separation of components of lower oil content, i.e., the testa and heart. The oil content of the testa removed from the peanuts after roasting was found to be quite high (28%). Because the skin of raw peanuts has been found (26, 27) generally to contain a very low percentage of oil, it was concluded that the skin absorbed oil exuded from the peanut during roasting and blanching.

Table 8. Oil in Peanut Butter

Batch No.	(A) containing no additives Oil content Oven-dry basis	(B) Containing added salt			(C) Containing added salt and stabilizer					Difference, fat content oven-dry, additive-free basis (Type C-Type B)
		Salt content oven-dry basis	Oil content		Content of additives oven dry basis			Oil content		
			oven-dry basis	Dry, salt-free basis	salt	oil	stabilizer	oven-dry basis	oven-dry additive-free basis	
	%	%	%	%	%	%	%	%	%	%
1	50.9	1.53	49.93	50.71	1.53	--	1.5 1/	50.68	52.27	1.56
2	48.6	1.53	47.70	48.44	1.53	--	0.9 1/	48.18	49.40	0.96
3	50.7	1.42	49.9	50.59	1.39	--	0.9 1/	50.4	51.54	0.95
4	50.7	1.42	50.6	51.37	1.42 2/	-- 2/	0.8 2/	51.0	52.17	0.80
5	50.7	1.42	50.21	50.93	0.93	0.93	0.93	51.35	52.81	1.88
6	50.6	1.41	50.15	50.87	1.39 2/	-- 2/	1.2 1/	50.76	52.12	1.25
7	48.5	1.52	47.9	48.68	1.3 2/	1.3 2/	1.30 2/	49.4	51.33	2.65
8	48.3	1.52	47.76	48.50	1.3 2/	1.3 2/	1.3 2/	49.48	51.69	3.19
9	49.4	1.44	48.93	49.64	1.25	--	1.7 1/	49.88	51.40	1.76
10	50.6	1.26	50.07	50.71	1.23	--	0.8 1/	50.47	51.51	0.80
11	49.8	1.42	49.5	50.23	1.4 2/	1.4 2/	1.4 2/	51.0	53.26	3.03
12	50.7	1.39	49.97	50.67	1.3	--	0.3 1/	50.1	50.93	0.26
13	50.7	1.41	50.36	51.08	1.4	--	0.8 1/	50.77	51.94	0.86
14	48.8	1.50	48.3	49.06	1.5	--	0.9 1/	48.8	50.02	0.96
15	50.3	1.41	49.6	50.31	1.5 2/	1.5 2/	1.5 2/	51.2	53.73	3.42
16	50.7	1.41	50.3	50.97	1.38 2/	--- 2/	0.97 1/	50.7	51.96	0.99
17	50.8	1.41	50.5	51.24	1.5 2/	1.5 2/	1.5 2/	51.8	54.06	2.82
18	48.6	1.51	48.1	48.83	1.2 2/	1.2 2/	1.2 2/	49.6	51.43	2.60
19	50.4	1.41	50.13	50.85	1.41 2/	-- 2/	1.5 1/	50.89	52.41	1.56
20	51.0	1.51	50.5	51.26	1.4 2/	1.4 2/	1.4 2/	51.8	53.92	2.66

1/ A commercial grade of hydrogenated peanut oil [ca. mp. 64.5° C. (148° F.) and iodine value of ca. 8].

2/ A commercial grade of peanut butter stabilizer composed of an equal weight mixture of salt, peanut oil, and hydrogenated peanut oil.

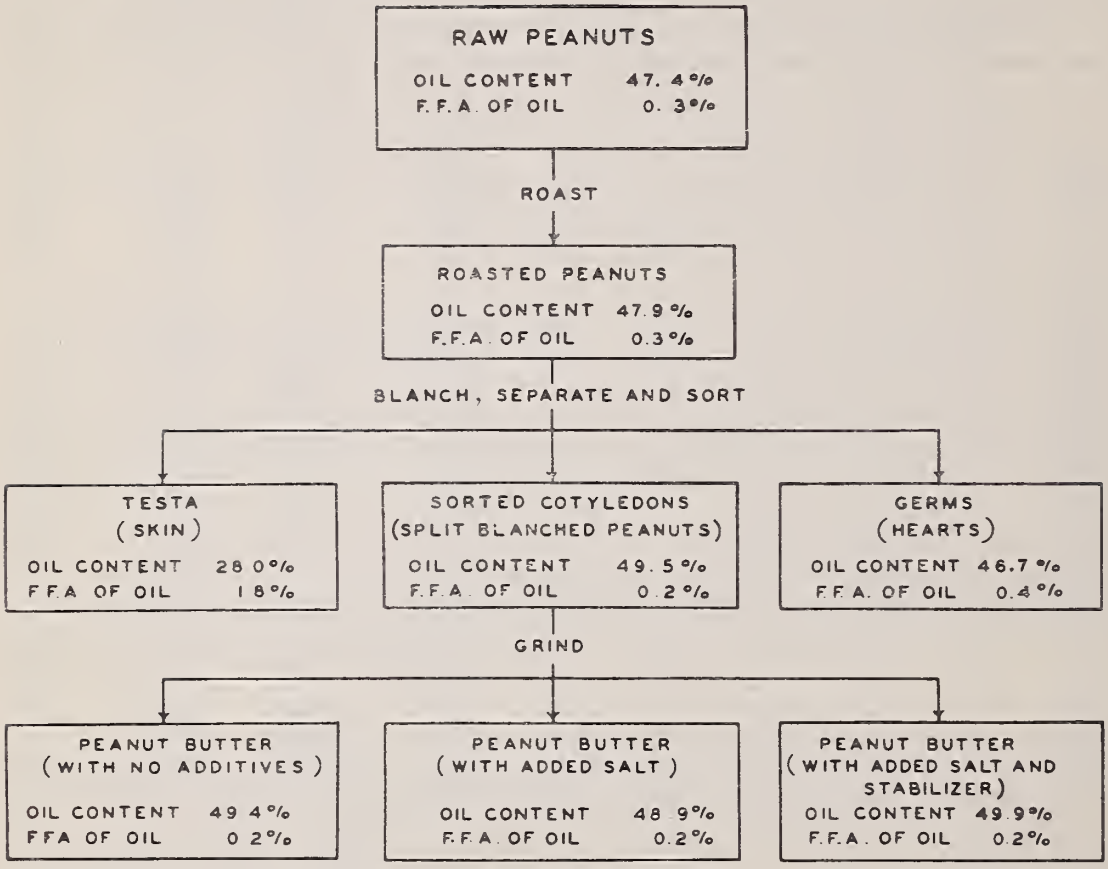

Figure 5. Oil and free fatty acids in the manufacture of peanut butter (Batch No. 9).

Furthermore, data obtained in this work reveal that the free fatty acid contents of the oils extracted from raw and roasted peanuts, sorted cotyledons, and the three types of peanut butter were uniformly low. The free fatty acids of the oils extracted from raw peanuts varied from 0.1 to 0.6%, the average value (20 batches) being 0.33%. The values for the oils from roasted peanuts varied from 0.2 to 0.7%, the average being 0.3%. The sorted, roasted cotyledons yielded oils varying in free fatty acids contents from 0.2 to 0.4%, the average value being 0.25%. Slight decreases in contents of free fatty acids were generally noted as a result of roasting, blanching, and sorting, the average decrease being about 0.1%. This effect probably resulted in part from the slight loss of volatile matter which occurs during roasting, but to a greater extent from the removal of germs, testa, and other material during blanching and sorting. The average values for the content of free fatty acids of oils extracted from the germs and testa were 0.38% (range 0.2 to 0.6%) and 1.6% (range 0.8 to 3.1%) respectively. Also, Figure 5 shows that the testa and the germs, the materials eliminated during blanching and separating, are relatively high in free fatty acids. The results of removing these materials are that the finished product is lower in free fatty acids than the roasted peanuts.

The effect of increase in oil content is to produce a smoother and less sticky product. Data from previous work (88) furnished information for calculation of a materials balance during the manufacture of peanut butter. In the manufacture of Batch No. 9, 100 pounds of raw peanuts yielded 94.9 pounds of roasted peanuts, which on blanching, separating, and sorting furnished 3.7 pounds of testa, 2.0 pounds of germs, 2.5 pounds of objectionable or extraneous material and 86.7 pounds of sorted cotyledons for grinding into peanut butter. By removal of the 3.7 pounds of testa and the 2.0 pounds of germs the free fatty acids content of the finished product was reduced by 30%, while the oil content was increased approximately 2%. These byproducts are a rich source of oil since the 5.7 pounds of testa and germs contain 2 pounds of oil (37%).

Chemical evaluation for stability of oils to rancidity. In vegetable oils, rancidity refers to the development of undesirable odors and flavors from chemical change or deterioration. This deterioration is usually caused by autoxidation (oxidation by the oxygen of the air). Stability of oils (1, 44, 86) of peanuts and peanut products may be used to indicate the relative susceptibility or resistance of the products toward autoxidative rancidity. Stability is expressed arbitrarily as the time elapsing before the onset of rancidity during which the oil is subjected to specified conditions.

Varieties. As a result of observations that products made from different types of peanuts vary in their resistance to oxidative deterioration, an investigation was made to determine whether these differences could be attributed to fatty acid composition, or other characteristics, particularly content of tocopherols, the natural antioxidants (see Table 2)

in crude oils. In this work the oils of 16 varieties of raw shelled peanuts, including Spanish, Virginias, and Runners, were analyzed for initial peroxide value and stability, tocopherol content, and saturated, linoleic, and oleic glyceride contents in order to determine factors that might affect the stability of crude peanut oil.

In general, data (24) (see Tables 9 and 10) indicated that the stability of the crude oil was greatest for the oils containing the smallest amounts of linoleic acid. A wide variation was found in the linoleic acid content of the oils from the different types of peanuts, ranging from 20 to 37%. Oils from peanuts of the so called "prostrate" types, particularly "runners" and some "Virginias" contained the least linoleic acid and were the most stable to autoxidation. Oils from the "erect" or bunch types, particularly the "Spanish" contained larger amounts of linoleic acid and were less stable. The tocopherol compositions of the oils were not found to vary significantly, either in the nature and distribution of individual tocopherols, or in total tocopherol contents, although the tocopherol contents of the oils of runner peanuts were generally higher than those of the other oils.

It may be concluded from these results that products made from peanuts containing oils of relatively low linolein content and of high stability would have an increased shelf-life.

Peanut butters. The stabilities of the oils of the various peanut butters produced from Spanish peanuts in the laboratory pilot plant were determined at the time of manufacture and periodically over two years as the products were stored at 80° F. At the time of examination of each sample the entire contents of an 8-oz. jar of peanut butter were removed and mixed thoroughly to insure uniformity of the sample. The oil was extracted from the sample, and the stability of the oil was determined by the active oxygen method at 97.8° C. Procedures for extraction of the oil, and determination of peroxide values and the stability were those described by Morris and Freeman (55).

It was ascertained (89) in general that the stabilities of the oils of the freshly prepared products were high (see Figures 6 and 7), and that no troublesome decrease in stability of the oils occurred, even when the peanut butters were stored as long as two years.

The average stability of the oils extracted from the freshly prepared peanut butters was about 35 AOM hours. Examinations throughout the period of storage indicated that a reduction in stability of about 12 AOM hours occurred during the first three months of storage. No significant change in stability occurred over the balance of the two year storage period. Neither the addition of salt, or salt and various stabilizers, nor the extent of roasting accorded the peanuts produced any reduction in the stability of the oils of the products.

Table 9. Analysis of Peanuts.

Sample No.	Variety 1/	Moisture	Oil	
			As is basis	Oven-dry basis
		%	%	%
1	Spanish 146 2/	6.75	47.72	51.17
2	Spanish 205 2/	6.03	49.96	53.17
3	Spanish P. I. 121070 2/	6.20	49.74	53.03
4	Spanish 18-38 2/	6.13	50.06	53.33
5	Spanish 13-10 2/	6.08	50.26	53.89
6	Improved Spanish 2B 2/	6.17	49.72	52.99
7	Virginia-Ga. Hybrid 119-24 3/	7.10	43.22	46.52
8	Virginia-Holland Station Runner 3/	6.99	44.00	47.31
9	Virginia Bunch, Large 2/	6.79	46.76	50.17
10	Virginia Jumbo J-11-L 3/	7.14	43.69	47.05
11	Virginia P. I. 124681 3/	7.00	45.71	49.15
12	Virginia-Holland Station Jumbo 3/	6.89	43.94	47.17
13	Dixie Runner 3/	5.88	49.46	52.55
14	Runner 230-118 3/	5.86	51.09	54.27
15	N. C. Runner 56-15 3/	6.10	49.04	52.23
16	Runner-Ga. Hybrid 199-22-A-2 3/	5.81	49.95	53.03

1/ Field and handling procedures were in conformity with practices generally followed.
2/ Bunch type.
3/ Runner type.

Table 10. Analysis, Composition, and Stability of Peanut Oils

Sample No.	Initial peroxide value 1/	Stability - AOM hours		Thiocyanogen value	Iodine value	Fatty acid composition			Tocopherol content		
		Test 2/	Extrapolated 3/			Linolein	Olein	Saturated glycerides	Total 4/	α	γ 5/
						%	%	%	%	%	%
1S	5	26.5	29	71.5	101.6	37.0	43.5	19.5	0.039	0.021	0.018
2S	2	30.0	32	71.3	98.2	33.1	47.6	19.3	0.041	0.024	0.019
3S	7	28.0	32	70.7	98.5	34.1	45.7	20.2	0.038	0.023	0.015
4S	4	26.0	29	70.7	98.9	34.6	45.2	20.2	0.043	0.026	0.017
5S	2	30.0	32	70.3	98.4	34.5	44.9	20.6	0.041	0.025	0.016
6S	4	30.5	34	72.0	98.0	31.9	49.7	18.4	0.039	0.024	0.015
7V	5	28.5	32	74.9	101.3	32.4	52.5	15.1	0.046	0.026	0.020
8V	3	32.5	36	75.5	99.1	28.9	57.0	14.1	0.044	0.025	0.019
9V	7	30.0	36	73.8	95.4	26.4	57.7	15.9	0.043	0.023	0.020
10V	5	30.5	35	73.8	98.3	30.0	53.8	16.2	0.041	0.025	0.016
11V	2	41.0	44	73.4	97.6	29.6	53.7	16.7	0.041	0.025	0.016
12V	3	31.0	36	73.3	98.1	30.4	52.9	16.7	0.041	0.026	0.015
13R	2	48.0	49	73.8	90.2	19.9	64.7	15.4	0.048	0.030	0.018
14R	3	36.5	44	74.4	91.8	21.2	64.2	14.6	0.048	0.029	0.019
15R	4	32.5	38	74.5	94.1	23.9	61.3	14.8	0.052	0.029	0.023
16R	4	36.5	41	73.9	92.8	23.0	61.5	15.5	0.053	0.030	0.023

1/ Milliequivalents of peroxide per kilogram of oil.
2/ Time required by oil to attain a peroxide content of 100 milliequivalents per kilogram of oil during aeration at 97.8° C. with an air flow of 2.33 ml./sec.
3/ Obtained by extrapolation of peroxide accumulation curves to a peroxide value of zero.
4/ Determined by the Parker and McFarlane modification of the Emmerie and Engel method using a 2-1/2-min. reaction time.
5/ Determined by Fisher method using Parker and McFarlane treatment.

R - Runner peanuts.
S - Spanish peanuts.
V - Virginia peanuts.

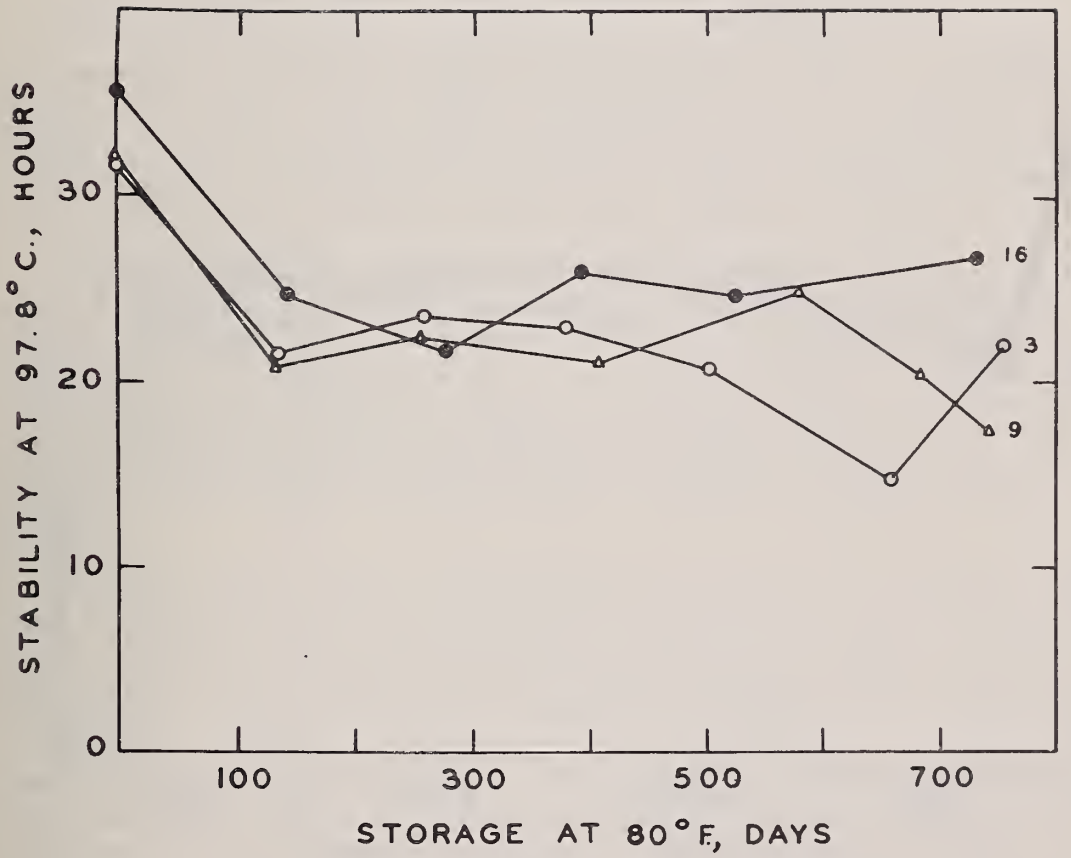

Figure 6. Effect of storage on the stability of oils in light, medium, and dark roasted peanut butters. Curve 3 represents Type A peanut butter (control- no additives) from light roasted peanuts. Curve 9 represents Type A peanut butter from medium roasted peanuts. Curve 16 represents Type A peanut butter from dark roasted peanuts.

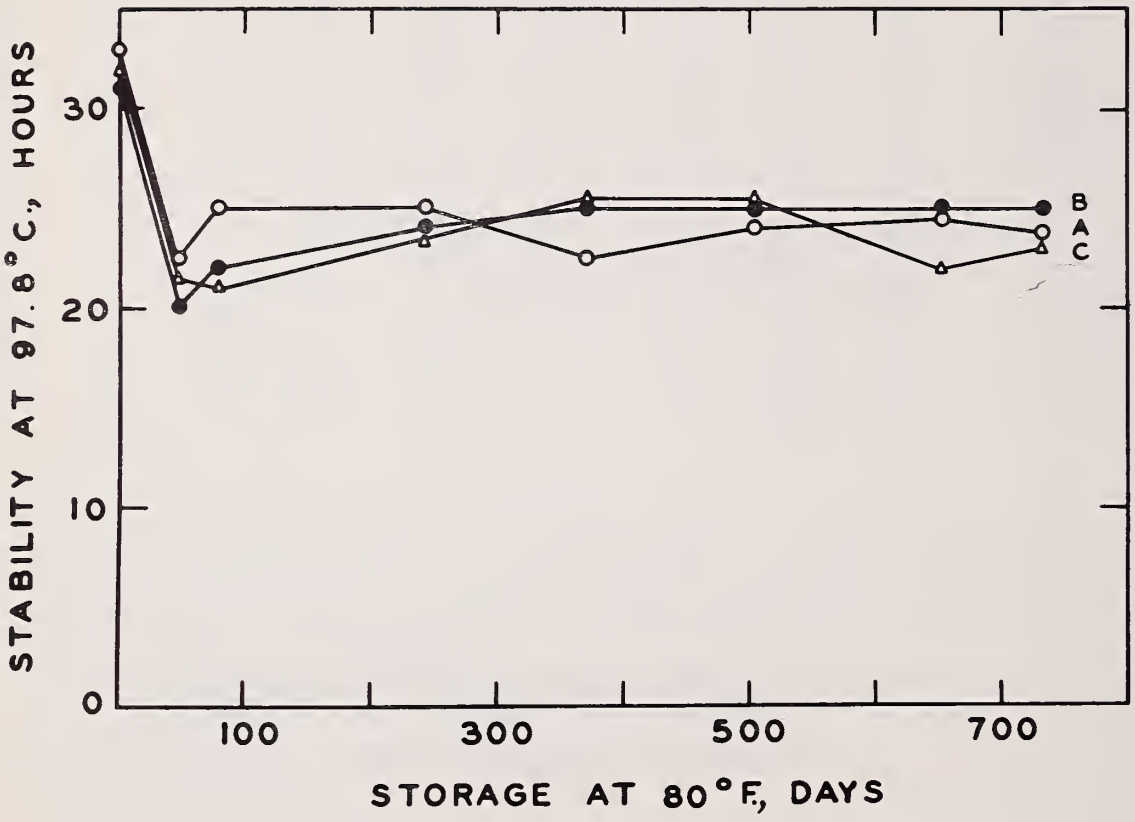

Figure 7. Effect of storage on the stability of oils in peanut butters (Batch 13), containing various additives: (A) Control - no additives. (B) Containing salt. (C) Containing salt and hydrogenated peanut oil.

These observations seem to indicate that autoxidation of the oils of the peanut butters proceeded until the available supply of oxygen in each jar had been depleted, and that thereafter no significant change in stability occurred. It was noteworthy that these results were obtained on peanut butters prepared from Spanish peanuts, the oil from which has been found generally to have the lowest stability of the varieties tested. (24).

Objective determination of the color of peanut butter. Color is a dominant characteristic of peanut butter, and its importance as an index of quality is illustrated by the fact that in the U. S. Standards for Grades of Peanut Butter (81), 20 of the 100 points of evaluation are allocated to color. Color plays an important part in the sale of food products, and the customer often bases his selection on an association of generally appetizing characteristics with color, in the case of peanut butter particularly the flavor and aroma developed by roasting.

Visual comparison methods for color designation have been the ones used most widely, in which color plates or the disc colorimeter have been used to provide close color matches. All these methods involving visual comparison are subjective methods, and results obtained by them are influenced by the observer's judgment and limitations. Objective methods are more desirable because they produce results which are in no way related to the ability of the observer to remember or match colors, and therefore permit closer quality control leading to greater uniformity of products.

Research (57) aimed at development of a method for designation of color of peanut butter establishes that the colors of peanut butter can be measured objectively by reflectance spectrophotometry. For comparative purposes the series of peanut butters produced in the pilot plant from peanuts roasted to various extents was evaluated. The method used consisted of recording the spectral reflectance properties (Figure 8) of peanut butter directly by use of an automatic recording spectrophotometer equipped with a diffuse reflectance attachment, and expressing the spectral data numerically in terms of the C.I.E. system of color notation. C.I.E. designations (Table 11) were converted into Munsell renotations and Hunter values for convenience of those accustomed to using these color systems.

In general, the x-trichromatic coordinate, the redness factor, was found to increase with increase of extent of roasting. The medium and dark peanut butters had x-coordinates of not less than 0.40 nor greater than 0.42. In the Munsell renotations the magnitude of the expression for hue was considered the best criterion of color. The magnitude of hue increased rapidly for the under-roasted products, and decreased rapidly for the over-roasted products. The range for the eleven medium and dark peanut butters measured from 7.1 YR to 9.8 YR. In Hunter color and color difference terms the a-coordinate is most analogous to the C.I.E.

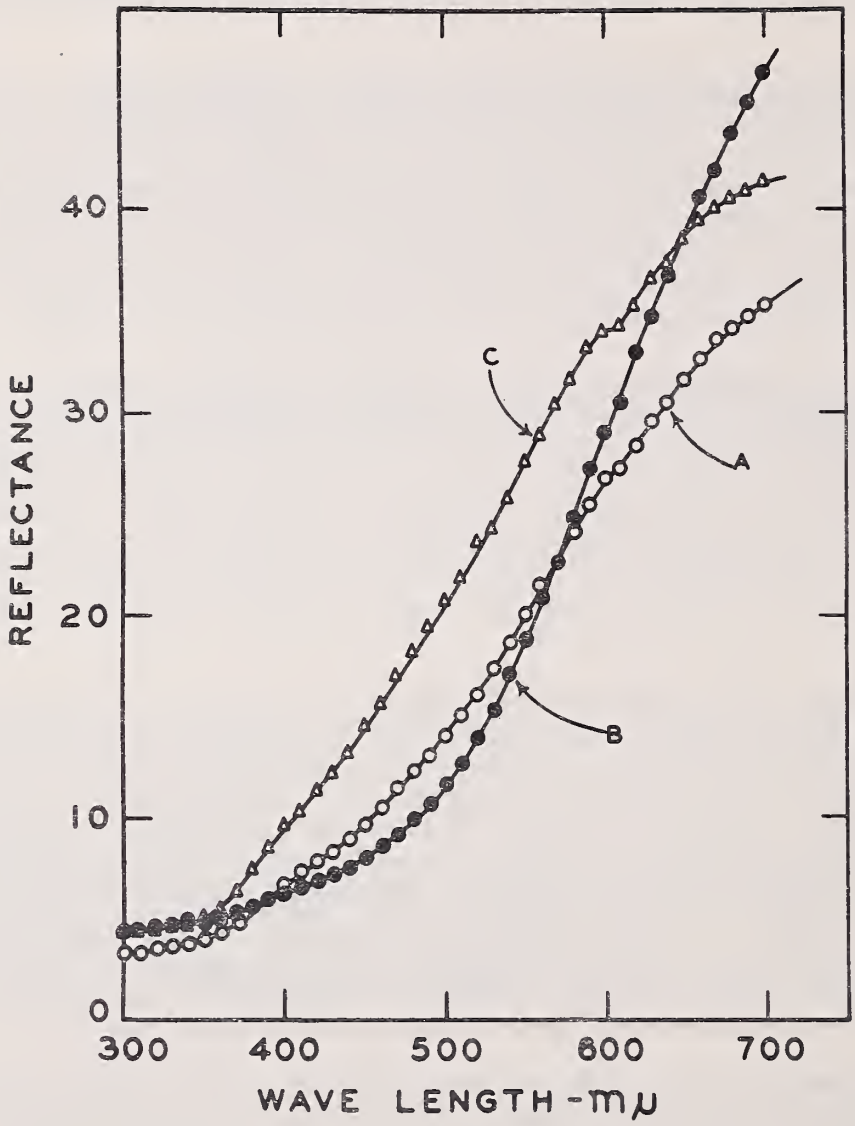

Figure 8. Color changes due to extent of roasting.
A. Peanut butter No. 9.
B. Peanut butter No. 18.
C. Peanut butter No. 3.

TABLE 11

Variations in color of peanut butter with variation in extent of roasting

(Data obtained from reflectance spectrophotometric curves)

No.	Peanut butter color		I.C.I. designation			Psycho-physical attributes			Munsell renotations		Hunter scale numbers		
	Type	Designation 1/	Tristimulus value Y	Trichromatic coordinates x	Trichromatic coordinates y	Reflectance	Dominant wave length	Excitation purity	Hue	Value/chroma	Luminous reflectance Rd	a	b
						%	mμ	%			%		
1	very light	11-E3	0.38197	0.3634	0.3704	38.2	577	28.9	12.9YR	6.65/3.1	38.2	0.08	17.70
2	very light	11-J5	0.50647	0.3914	0.3862	50.6	580	40.5	10.7YR	7.50/5.2	50.6	4.26	25.91
3	light	11-G5	0.28154	0.3824	0.3777	28.2	580	35.8	10.9YR	5.83/3.7	28.2	3.28	18.66
4	light	11-G5	0.40930	0.3916	0.3838	40.9	580	40.0	10.5YR	6.67/4.7	40.9	4.71	23.42
5	light	11-G5	0.38869	0.3958	0.3852	38.9	581	41.3	10.0YR	6.70/4.9	38.9	5.46	23.60
6	light	11-G6	0.30442	0.3873	0.3812	30.4	580	38.1	10.8YR	6.03/4.1	30.4	3.76	20.68
7	medium	11-F6	0.42995	0.4051	0.3880	43.0	582	44.7	9.3YR	6.81/5.5	43.0	7.69	25.96
8	medium	11-F6	0.39713	0.4168	0.3898	39.7	583	48.4	8.3YR	6.76/6.2	39.7	10.39	26.60
9	medium	11-F6	0.21002	0.3987	0.3824	21.0	582	41.5	9.8YR	5.13/4.1	21.0	5.77	18.72
10	medium	11-F6	0.36028	0.4162	0.3902	36.0	583	48.3	8.5YR	6.49/5.9	36.0	9.73	25.64
11	dark	11-J7	0.29900	0.4052	0.3864	29.9	582	44.3	9.3YR	5.99/5.0	29.9	7.19	22.40
12	dark	12-K7	0.22522	0.4149	0.3886	22.5	583	47.5	8.8YR	5.29/4.9	22.5	8.29	21.30
13	dark	12-L7	0.21748	0.4164	0.3892	21.7	583	48.1	8.8YR	5.21/4.9	21.7	8.38	21.22
14	dark	12-J7	0.18877	0.4135	0.3870	18.9	583	46.7	8.9YR	4.90/4.5	18.9	7.85	19.70
15	dark	12-I7	0.24685	0.4154	0.3865	24.7	583	47.0	8.4YR	5.51/5.1	24.7	9.26	21.79
16	dark	12-L8	0.21610	0.4215	0.3901	21.6	583	49.7	8.4YR	5.20/5.2	21.6	9.37	21.69
17	dark	12-L8	0.22058	0.4257	0.3841	22.1	585	49.3	7.1YR	5.11/5.3	22.1	12.07	21.47
18	very dark	13-G9	0.20948	0.4299	0.3868	20.9	585	51.1	7.2YR	5.13/5.5	20.9	12.14	21.73
19	very dark	13-F9	0.18485	0.4374	0.3829	18.5	587	52.0	5.9YR	4.73/5.5	18.5	14.34	20.91
20	very dark	13-F9	0.12497	0.4255	0.3756	12.5	587	46.8	6.0YR	4.08/4.3	12.5	11.64	16.52

1/ Refers to color plates in A. Maerz and M. Rea Paul, A Dictionary of Color, 1930, McGraw-Hill Book Company.

x-coordinate, the redness factor. A medium or dark peanut butter was found with a single exception to have an a-coordinate between 5.77 and 12.07.

Information obtained in this work provides the basis for measurement of the color of peanut butter with less complicated and less expensive equipment.

Prevention of oil separation. The gravitational separation of peanut butter (94) into an oil phase and a meal phase occurs because of the difference in specific gravity of the solid particles and the oil comprising the product, and gives rise to the practice of incorporating hydrogenated peanut oil for the purpose of overcoming this separation.

The earliest reference to use of hydrogenated peanut oil for preventing oil separation appeared in a patent (79) issued to Stockton in 1921. Stockton mixed 85 parts of "natural" peanut oil with 15 parts of "fully" hydrogenated peanut oil (m.p. ca. 58-60° C.), and ground 5 parts by weight of this mixture with 95 parts of "roasted, blanched peanut kernels," so that the finished product contained about 0.75% of the hydrogenated peanut oil. He stated that the effective ingredient of the mixture was the hard fat, and that a smaller amount would be required, i.e., from 0.50 to 0.25%, if the hydrogenated peanut oil were added alone. Before 1948 the majority of manufacturers producing "stabilized" peanut butters preferred to add hydrogenated peanut oil [m.p. ca. 64.5° C. (148° F.), iodine value ca. 5] alone, either in granular or melted form. A unique process patented by Rosenfield (73, 74) involved the mechanical expression of an average of 18% of the oil content of the comminuted peanuts, hydrogenation of this oil "to a point where it has a melting point of approximately 98° F.", followed by "re-incorporation" of the hydrogenated peanut oil with the comminuted peanut cake or mass. The mixture could be chilled by passage through chilling rolls or packaged without chilling. Recently, several suspensions of hydrogenated peanut oil and salt in peanut oil (36, 52) have been developed, and used in the production of peanut butter. The principal advantage of the hard fat-salt-oil mixtures is the fact that they are pumpable, and hence distribution and the amount of stabilizer and salt being incorporated can be controlled more precisely.

The total content of oil in peanut kernels may range from 44-56% (27) according to the type and quality, but only part of the oil is liberated from the peanuts (93) during the manufacture of peanut butter. The specific amount liberated depends upon the grinding procedure employed which determines the quantity of hydrogenated peanut oil that needs to be added (22).

Various devices used by the industry for grinding peanuts into peanut butter have been referred to as comminuters, attrition mills, homogenizers, disintegrators, hydraulic presses, expeller presses, hammer mills, or colloid mills (22, 33, 43, 70, 73, 74, 79, 85). Milling equipment including these general types has been described by Bailey (5d) and Kanowitz (39). Most of these devices are constructed so that they can be adjusted over a wide range, thereby permitting considerable variation in the quantity of peanuts ground per hour, the fineness of the product, and the proportion of oil freed from the peanuts. General experience has been that coarse to medium ground peanut butter issues from the grinder at approximately 130 - 170° F. (54 - 77° C.), and the more finely ground products issue at temperatures from 170 - 200° F. (77 - 93° C.) or higher.

Since crystals of fat are not present in the natural oil of peanut butter at ordinary temperatures, hydrogenated peanut oil, which is crystalline at these temperatures, is mixed uniformly with the product to provide such crystals. Generally, the incorporation is accomplished above the melting point of the hydrogenated peanut oil to insure more complete dispersion of the hard fat with the natural oil and the entire mass comprising peanut butter. In a satisfactorily stabilized peanut butter, crystallization of the added fat (hydrogenated peanut oil) takes place generally throughout the product before the oil-meal mixture can separate. Only enough hard fat need be incorporated in the product to insure the presence of sufficient crystals at room temperature to entrap the natural oil.

It was stated previously that fats can solidify in different crystal forms, the type being dependent upon the rate of cooling. Within limits, fats have the property of retaining nuclei of original crystal forms for a short time and over restricted temperature ranges after they are melted, and upon cooling these nuclei influence the re-establishment of the crystal form that existed before melting. However, if the fat is heated considerably above its melting point, these nuclei are destroyed, and the fat may crystallize into any one or a mixture of the possible forms depending on the rate of cooling (6a, b, c).

The lower melting crystal-forms of hydrogenated peanut oil have the maximum ability to stabilize peanut butter. Rapid chilling, which produces the lower melting forms, results in greater quantities of solids and hence more effective prevention of oil separation. In addition, crystals of these forms are finely divided, a condition which contributes toward a smoother product. Also, the lower melting forms are considered desirable because they melt nearer to body temperature thereby minimizing the tallowy or unctuous sensations attributed to hard fats (5g).

Dilatometric Measurements on Peanut Butter

In consideration of reports that oil separation had been experienced in peanut butters manufactured to contain supposedly adequate amounts of hydrogenated peanut oil, aspects of this subject were investigated. From dilatometric data on peanut butters it was concluded (76) that the effectiveness of hard fat incorporated in peanut butter was dependent upon the amount dissolved and its distribution throughout the oil in the product. In this work Singleton and Freeman examined the properties and behavior of (1) unstabilized peanut butter, (2) a peanut butter stabilized with 3.6% of a pumpable fatty suspension (36, 52) composed of equal parts of peanut oil, hydrogenated peanut oil and salt, and (3) a peanut butter stabilized by the incorporation of about 0.7% of hydrogenated peanut oil as the hard fat. These products were ground in a 8-inch peanut butter mill of the vertical attrition type, and issued from the grinder at 140-145° F. (60-63° C.). It was found that only about 8 parts of hydrogenated peanut oil were dissolved in each 92 parts of the free oil of the peanut butter. It was concluded that the stabilized character resulted from the amount of dissolved hard fat and the general distribution of most of the hard fat in the original crystal form throughout the products. It was also found on heating these stabilized butters to about 176° F. (80° C.) that the stabilizer melted and mixed uniformly with the free oil present, thereby destroying the crystalline condition obtaining after production of these butters. The original condition of the stabilizer was not re-established by rapid cooling to -40° F. (-40° C.), or by slow cooling to the same point over a 24-hour period. The characteristics of such peanut butters treated in this fashion were found to resemble those of an "unstabilized" peanut butter. These results indicate that the content of hard fat in peanut butter must be increased in cases of relatively high processing temperatures.

They also support at least one current industrial practice of adding stabilizer, so that the hydrogenated peanut oil constitutes at least 5% of the total fat content and about 2.5% of the total mass of peanut butter. In such a process, peanuts are finely ground at the rate of about one ton per hour with from 6 to 7% of a pumpable suspension composed approximately of 41.5% hydrogenated peanut oil, 41.5% peanut oil, and 17% salt. The mass may issue from the grinder between 165-200° F. (74-93° C.), and is cooled rapidly to about 80-100° F. (26-38° C.) in a continuous chilling machine (37) immediately before packaging. The relatively high proportion of hydrogenated peanut oil mixed with the peanut oil results in relatively rapid crystallization under such conditions, so that separation of oil does not occur.

Ward, Singleton and Freeman reported the heat capacity of stabilized peanut butter (83) over the range of temperature from 32° to 176° F. (0-80° C.) and found that about 0.7 B.t.u. of heat must be removed from each pound of the product in order to lower the temperature one degree

Fahrenheit, or expressed in metric units about 0.4 calorie per gram per degree Centigrade.

Solubility of Hydrogenated Peanut Oil in Peanut Oil

In work on stabilized and unstabilized peanut butter Singleton and Freeman concluded (76) that the effectiveness of the added hard fat in preventing separation of oil was dependent upon the amount of hard fat dissolved and its distribution throughout the oil in the product. However, data available on the solubility of hydrogenated peanut oil in peanut oil (34) did not cover the range of concentrations pertinent to the problem of prevention of oil separation in peanut butter. Since the amount of solid crystals present in the oil is important in "stabilizing" peanut butter, Magne, et al., measured (50) the solubility of a commercial peanut fat in peanut oil by the static method (49) with the purpose of providing basic information applicable to processes for the prevention of oil separation. In these measurements two temperatures were observed, one at which the last crystals of the hard fat just disappeared in the peanut oil, and the other at which a few crystals remained undissolved after prolonged agitation. The solubility temperature was taken as the mean of these two temperatures corrected for both thermometer calibration and emergent stem (see Table 12).

Results show that the hard fat is completely melted at 67.8° C., and that a temperature of about 57° C. is required to dissolve 9% of it in the peanut oil. Below this concentration the solubility temperature drops off rapidly with decreasing hard fat content. The solubility temperatures were unchanged by melting the mixtures and allowing them to cool gradually to room temperature. However, if cooled rapidly by immersion in an ice bath, they exhibited lower solubility temperatures, which could not be accurately determined because an unstable crystal modification is involved.

While low-melting, finely divided crystals, produced by rapid cooling of mixtures of hard peanut fat and peanut oil, are considered desirable in certain respects, such as palatability (5g) and greater liquid-retentive ability (5e), they nevertheless have the disadvantage of a low melting or solubility temperature -- about 37° C. when the hard fat concentration is 5%, and lower at lower concentrations. Some oil separation, at least temporarily, could result from this condition until the transformation to the higher-melting modification took place. This behavior is illustrated by the data presented in Table 13 for mixtures containing 5.28% hard fat which were shock-chilled from a molten condition to 0° C. (32° F.) prior to immersion in a constant temperature bath at each temperature given. Shock chilling to -40° C. (-40° F.) gave the same results.

Table 12. Solubility of Hydrogenated Peanut Oil in Refined Peanut Oil and Nature of Tempered Mixtures

Hard fat 1/	Solubility temperature	Physical nature of mixture at room temperature after shock chilling of melt and tempering at 33.6° C.
%	° C.	
0.63	42.8	Translucent liquid
1.20	45.6	Translucent liquid
2.03	49.5	Viscous, translucent fluid
5.28	52.9	Translucent, either non-fluid or, with agitation, fluid
9.09	55.5	Opaque solid
17.76	58.4	Opaque solid
25.69	60.8	Opaque solid
50.71	64.5	Opaque solid
75.37	66.2	Opaque solid
100.00	67.8	Opaque solid

1/ An almost completely hydrogenated peanut oil used widely in the manufacture of peanut butter (36).

Table 13. Phase Behavior on Tempering Mixture Containing 5.28% Hard Peanut Fat After Shock Chilling From Molten Condition.

Tempering temperature	Behavior
° C.	
50.6	Melts to clear liquid
48.0	Melts to clear liquid
44.6	Melts to clear liquid subsequently becoming turbid 1/
37.5	Melts to clear liquid subsequently becoming turbid 1/
36.0	Transforms to higher-melting form without visible melting
34.2	Transforms to higher-melting form without visible melting

1/ Turbidity caused by formation of crystals of the higher-melting form.

Transformation to high-melting form. Based on the information contained in Table 13, a temperature [33.6° C. (93° F.)] was chosen, which would permit the transformation of the finely divided, low-melting form without any visible signs of melting, even in the 2.03% mixture. Tempering the shock-chilled 2.03% or 5.28% mixtures at 33.6° C. for 30 minutes was sufficient to permit extensive transformation of the crystals to the high-melting form, as evidenced by the lack of any perceptible melting at 44.6° C. in the 5.28% mixture, whereas prior to this treatment the shock-chilled sample melted completely at this temperature. After tempering, complete melting did not occur until a temperature of 52-53° C. (125.6-127.4° F.) was reached. The shock-chilled 2.03% mixture tempered in the same manner was capable of withstanding 38° C. (100.4° F.) without any oil separation from the mixture.

As shown in Table 12 the tempered mixtures range from translucent liquids to opaque rigid plastic substances depending upon the hard fat content and the temperature. The 5.28% mixture, nevertheless, may resemble a rigid, translucent, plastic fat or a partially melted plastic fat. Agitation during or after tempering produces the latter condition, which however is unstable, requiring an undetermined period of time to reset. If the material is not worked, the former condition results. Evidently there is a range of concentrations in the neighborhood of 5% where this behavior (5f) is possible. Those mixtures containing less than 2% hard fat were always semi-plastic or viscous liquids, depending on the hard fat content, and never set up as rigid plastic fats. In none of the tempered mixtures above 2% was separation of clear oil observed at room temperature (25-30° C.), even when the mixture was centrifuged for 20 minutes at 400 times gravity.

This information indicates that it should be possible to stabilize such a mixture by tempering in this manner, possibly due to the predominance of the higher-melting modification in the tempered product. The product would be expected to retain satisfactory crystal fineness (6e) essential for improved palatability and yet would withstand ordinary storage without separation of the oil.

Slowly cooled mixtures. All the mixtures given in Table 12 when melted and gradually cooled show grainy characteristics in the solidified hard fat. This was especially apparent in those hard fat concentrations of 10% or less where the granules of fat crystals tended to settle, especially with centrifugation, to give a clear supernatant oil. At concentrations above 10% the quantity of hard fat separating is large enough to mask any liquid oil, even under centrifugation. Agitation during the cooling period caused no perceptible difference in this behavior.

Palatability of Peanut Butter

The palatability of peanut butter, as of any food, is the ultimate basis of acceptance. While objective measurements of quality characteristics may strongly indicate quality in a product, in the final analysis flavor largely determines the acceptability. The correlation of palatability of peanut butters with conditions of processing provides information as to the effects of processing on product quality, and hence affords a means of establishing methods of processing leading to improved products. The differences in peanut butters which may be correlated with conditions of processing are differences in appearance and palatability.

Peanut butters prepared in the pilot plant from No. 1 grade, white Spanish peanuts, roasted to various extents, were evaluated (56) periodically by an organoleptic panel throughout a period of storage of two years at 80° F. The peanut butters evaluated contained salt and hydrogenated peanut oil. The wide range of extent of roasting accorded the peanuts is shown by the range of x-trichromatic coordinates (the redness factors) (Table 14) which increase with increase in roasting.

For presentation to the panel, the entire contents of an 8-ounce jar of peanut butter were removed, mixed thoroughly to insure uniformity, and placed in small individual milk-glass jars with screw caps. Four coded samples per session were served to judges who rated them for color, texture, freedom from rancidity, and for palatability.

In general (Table 14) the panel considered the colors of peanut butters from "light" roasted peanuts to be fair whereas it considered the colors of peanut butters from "heavy" roasted peanuts to be good.

The panel found little difference in stickiness (Table 14) of peanut butters in the mouth, regardless of the extent of roasting accorded the peanuts, and described all samples as moderately sticky. The judgment of the panel regarding spreadability of the samples was good or excellent, the tendency being for the peanut butters made from the lighter roasted peanuts to receive the excellent ratings.

The ratings assigned by the panel for the presence or absence of rancidity in peanut butters at the time of preparation and throughout a period of storage of two years at 80° F. indicated that rancidity was not detected organoleptically throughout the two years the investigation was in progress. This finding is supported by chemical determination of the stabilities of the oils of these peanut butters. The stability of these oils toward autoxidative rancidity was found (89) to be quite high at the time of manufacture, and to remain satisfactorily high (although somewhat reduced) even after storage of the peanut butters at 80° F. in the absence of light for two years (5c). Furthermore, the free fatty acid contents of the oils of the experimental peanut butters, for which organoleptic data are given, were uniformly low (ca. 0.2%) at the time of manufacture (58). It has also been found that the free fatty acid

Table 14. Properties of Peanut Butters Made from Variously Roasted Peanuts.

Batch 1/	Processing Information: Roasting Time	Processing Information: Roasting Temp. Minimum	Processing Information: Roasting Temp. Maximum	Color of Peanut Butter: Extent of 2/ Roast	Color of Peanut Butter: x-Trichromatic Coordinates 1/	Panel Evaluation: Texture: Stickiness	Panel Evaluation: Texture: Spreadability	Panel Evaluation: Color
	min.	°F.	°F.					
1	17	230	275	light	0.3634	--	--	--
3	21	205	285	"	0.3824	moderate	excellent	fair
6	25	200	292	"	0.3873	"	"	"
2	23	205	283	heavy	0.3914	"	"	"
4	22	200	285	"	0.3916	"	"	"
5	21 1/2	205	285	"	0.3958	"	"	good
9	26	200	298	"	0.3987	"	good	"
7	22 1/2	200	290	"	0.4051	"	"	"
11	23	215	295	"	0.4052	"	"	"
14	29	200	304	"	0.4135	"	"	"
12	26	200	308	"	0.4149	"	"	"
15	24	210	300	"	0.4154	"	"	"
10	24	200	300	"	0.4162	"	"	"
13	25	205	300	"	0.4164	"	"	"
8	21	210	290	"	0.4168	"	excellent	"
16	25	205	305	"	0.4215	"	good	"
17	20	240	305	"	0.4257	"	excellent	"
18	21	215	315	"	0.4299	"	good	"
19	17 3/4	250	320	"	0.4374	"	good	"
3/								
S-1	--	--	--	--	--	moderate	good	fair
S-2	--	--	--	--	--	moderate	excellent	fair
S-3	32	195	302	heavy	--	moderate	good	good

1/ Batches are arranged in ascending order according to extent of roast from the lightest to the heaviest as indicated by their x-trichromatic coordinates.

2/ "Light" means that the color was not darker than Plate 11, G-6 of Maers and Paul's "Dictionary of Color" and "heavy" means that the color was darker than Plate 11, G-6.

3/ Standard samples S-1 and S-2 were fresh commercial peanut butters and standard S-3 was an experimental peanut butter less than 6 months old.

contents of the oils did not change appreciably during the storage of the peanut butters throughout the period of storage of two years, whereas some reduction in stability of the oils was observed.

There was high acceptance of the peanut butters near the middle of the list of batches (Table 15), even after storage for more than a year. This seemed to indicate that these samples retained desirable flavor longer than the samples made from peanuts of lighter or heavier roasts.

Results obtained upon further evaluation of samples from 10 batches of the peanut butters are shown in Table 16. The balanced incomplete block design (16) was used in each of the three experiments. The statistical analysis was that outlined for the particular design used.

The three peanut butters (Batches 10, 12, and 14) which consistently received the highest scores (Tables 15 and 16), when evaluated throughout the 24 months of storage, were very close together in their x-trichromatic coordinates. The x-trichromatic coordinates, which constitute objective indices of the extent of roasting, were (Table 14) 0.4162, 0.4149, and 0.4135 for Batches 10, 12, and 14, respectively.

It may be concluded from organoleptic data obtained on stored peanut butters prepared from variously roasted peanuts that the peanut butters from medium roasted peanuts were considered by the panel to embody the most desirable flavor throughout the period of 24 months the organoleptic evaluation was in progress. It does not necessarily follow that large consumer panels would prefer exactly the same roast. These data indicate that careful control of roasting of peanuts is necessary for the production of peanut butter of the most desirable flavor and good flavor retention.

Incorporation of Vitamin A in Peanut Butter

The incorporation of vitamin A in peanut butter would be desirable from a nutritional standpoint, because peanut butter as a spread supplements butter or margarine, both of which contain substantial quantities of vitamin A. Although vitamin A deficiency is considered uncommon in this country, Krehl has pointed out (44a) that a considerable proportion of the population, according to dietary surveys, does not receive the recommended amounts of vitamin A. The recommended daily amount of vitamin A in the United States is 5000 international units 2/ for an adult. Vitamin A is not added to peanut butter as a nutritional supplement as is the case with other foods, such as margarine, although peanuts, the principal ingredient of peanut butter, contain practically no vitamin

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2/ Numerically the same as U.S.P. units.

Table 15. Palatability Ratings 1/ for Peanut Butters.

Batch	Extent of roast	Appraisal after storage at 80° F., months				
		0	1-6	7-12	13-18	19-24
3	light	-	-	good-	unsatisfactory	-
6	light	good+	good+	good-	unsatisfactory	unsatisfactory
4	heavy	-	-	good-	unsatisfactory	-
5	heavy	-	-	-	good-	unsatisfactory
9	heavy	excellent-	good	good+	unsatisfactory	fair
11	heavy	-	-	-	good-	good-
14	heavy	good+	-	good	good-	good-
12	heavy	excellent-	excellent-	good+	good-	good-
15	heavy	-	-	good	fair+	good-
10	heavy	good+	excellent-	good+	good-	good-
13	heavy	-	good	-	good-	good-
16	heavy	-	good-	good+	fair+	fair+
17	heavy	-	-	good-	fair+	unsatisfactory
18	heavy	-	-	-	good-	unsatisfactory
19	heavy	-	-	-	-	unsatisfactory

1/ These appraisals are the means of several replicates rated adjectively by a panel of 11 persons, except for the ratings before storage which are the means of two replicates by 6 persons. These adjectives had been assigned numerical values: A rating of perfect denoted a score of 10; excellent, 9; good, 8; fair, 7; and less than fair, 3. In the above table, e.g., good+ denotes that the mean lay between 8.1 and 8.4, and good- denotes that the mean lay between 7.5 and 7.9.

Table 16. Mean Palatability Scores 1/ for Peanut Butters.

Batch	Extent of Roast	Experiment 1 Storage at 80° F., 14-24 months	Experiment 2 Storage at 80° F., 18-24 months	Experiment 3 Storage at 80° F., 21-26 months
6	light	6.4	6.8	6.7
9	heavy	6.8	7.2	6.9
11	heavy	7.7	-	-
14	heavy	8.0	7.9	7.3
12	heavy	7.8	8.0	7.5
15	heavy	7.8	-	-
10	heavy	7.8	7.6	7.8
13	heavy	7.9	7.3	-
16	heavy	7.5	7.4	7.5
17	heavy	6.9	-	-
S-1 2/	-	-	7.0	7.4
S-2 2/	-	-	7.3	-
S-3 2/	-	-	7.1	-
L.S.D. 3/ at 5% level		0.6	0.8	0.8
L.S.D. at 1% level		0.8	1.0	1.1

1/ For experiments 1 and 2 the scores are the means of six replicates scored by eleven judges; for experiment 3 the scores are the mean of ten replicates scored by eleven judges. A score of 10 denotes perfect; 9, excellent; 8, good; 7, fair; 3, unsatisfactory.

2/ Standards S-1 and S-2 were fresh, commercial peanut butters which the panel rated of "fair" color; standard S-3 was an experimental peanut butter (less than six months old) which the panel rated of "good" color.

3/ L.S.D. indicates the least difference between scores which is significant at the stated level of probability.

A (66). Inasmuch as vitamin A is essential for normal growth and maintenance of high visual acuity, resistance to fatigue and proper healing of wounds and fractures, the Armed Forces desire a stable field ration which has been fortified with vitamin A. Peanut butter was considered suitable for this purpose because of its popularity and its general properties (58) and excellent resistance to oxidative deterioration (89).

While some information about the properties of experimental batches of peanut butter fortified with vitamin A has appeared in the literature, no information has been published about the technology of incorporating vitamin A in peanut butter.

Review of Literature. Vitamin A is 3,7-dimethyl-9-(2,6,6-trimethyl-1-cyclohexen-1-yl)-2,4,6,8-nonatetraen-1-ol. The structure was established (40, 41, 42) by Karrer and associates and later confirmed (28) by Heilbron, Norton and Webster. It is destroyed by ultra-violet light and is sensitive to atmospheric oxygen, although the naturally occurring vitamin is stable to heat in an inert atmosphere (51).

Recently, synthetic vitamin A has been made available in commercial quantities. The synthetic product has been found to have the same biological equivalent (46) and stability (9) as the natural vitamin A, but has none of the taste or smell of fish oil (46).

Vitamin A from natural sources dissolved in fats has been found (69) to have a very high percentage of survival (80-100%) when incorporated in bread, biscuits and cake baked at temperatures of from 360-425° F. for 20 to 40 minutes, but substantial losses in vitamin A content have been encountered in baked pie crust of relatively high oil content. The losses were directly proportional to the baking time at 425° F.

The results of early work on the retention of vitamin A in stored foods were somewhat contradictory, but in general seemed to be dependent upon the nature of the material in which vitamin A was present. It has been reported (67) that fatty peroxides in rancid fats destroy vitamin A, and that destruction of vitamin A (32) (added as halibut liver-oil) in margarine during storage at room temperature was accompanied by increase in peroxide value of the oil. Bailey concluded (8) that oxidation is the most significant factor in the destruction of vitamin A in stored samples of fish and halibut liver oils, and that oxidation of the oils is best retarded by the use of completely filled, tightly closed containers, stored in a dark cool place. More recently it has been shown (13) that 90-100% of the vitamin A content could remain in canned samples of Army spread, dried milk, and evaporated milk stored for eighteen months at temperatures of 70, 90, and 100° F.

Because of the vulnerability of vitamin A to active oxygen (hydroperoxides, etc.), early interest was shown in the use of antioxidants to inhibit formation of peroxides and hence destruction of the vitamin. Although it was found (35) that many antioxidants prevented destruction of vitamin A, their effectiveness was appreciably increased by the presence of a synergist.

Using an accelerated storage technique, Dassow and Stansby studied (19) the effects of various temperatures (98, 80, and 25° C.) and aeration on the vitamin A content of halibut-liver oils. These workers were able to correlate increases in fatty peroxide formation at 98° C. with destruction of vitamin A. Their results showed that a combination of nordihydroguaiaretic acid (NDGA) as an antioxidant and citric acid as a synergist was more efficient in protecting vitamin A at 25° C. than at higher temperatures. For this reason concentrations of less than 0.1% NDGA together with the same amount of synergist were effective in protecting the vitamin at 25° C. It had been previously reported (47) that NDGA could not be detected by taste or odor when dissolved in vegetable oils in concentrations up to 0.1%. NDGA was found to be soluble in most vegetable oils, provided it was first dissolved in ethanol, which subsequently could be removed from the vegetable oil. The use of NDGA and citric acid in fats and oils has been approved (68) by the Meat Inspection Division of the United States Department of Agriculture in concentrations up to 0.01% and 0.005%, respectively.

Investigations (9) of Bauernfeind, Rokosny, and Siemers on margarine fortified with synthetic vitamin A ester 3/ incorporated in standard type cakes and cookies indicated no substantial reduction in synthetic vitamin A ester content on baking at 375-400° F. Furthermore, their work showed no substantial change in content of synthetic vitamin A palmitate occasioned by heat when the vitamin was added to freshly prepared peanut butter at a temperature of 140° F. Also they found no change in vitamin A content of the fortified peanut butter upon storage of the product for 1000 hours at 113° F.

Feeding equipment. In the continuous manufacture of peanut butter careful control of feeding mechanisms which govern the ultimate composition of the finished product is essential from the standpoints of uniformity of composition and quality of the product.

No suitable device for the incorporation of vitamin A in peanut butter was included with the conventional equipment comprising the laboratory pilot plant. Also, variation in rates of delivery of peanuts and essential additives was observed when the usual feeding mechanisms were used. Accordingly, it was necessary to replace

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3/ Vitamin A acetate or vitamin A palmitate was used in all of the experiments, but the specific ester used in the experiment was not given.

existing equipment in order to obtain a product of reasonably definite and uniform composition. Hence, four mechanical feeders were installed as adjuncts to a conventional peanut butter grinder. Three of the feeders used for delivering the peanuts, salt, and granulated hydrogenated peanut oil to the grinder were designed at the Southern Regional Research Laboratory and were constructed locally. These feeders were mounted (Figure 9) on a platform erected over the peanut butter grinder. The fourth feeder was a standard item and was used to deliver to the grinder synthetic vitamin A palmitate dissolved in peanut oil. Each of the four feeders was linked to a variable speed drive so that the delivery rate of each material could be adjusted. The materials supplied to each of the feeders were contained in hoppers of appropriate size (87) mounted (Figures 10 and 11) directly over the intakes of the feeders. All of the materials were discharged simultaneously from the feeders directly onto the screw feeder of the peanut butter grinder, thus providing some mixing of the materials before they were ground into peanut butter.

The two small feeders were identical with each other in size and design, and were used to deliver salt and granulated hard fat. By discharging the salt or the granulated hard fat from the top side (Figure 10) of the feeder, variations observed during low rates of delivery when discharging the material from the bottom of the feeder were eliminated.

A Zenith 4/ gear-type pump (Figure 11), consisting simply of a center plate and two counter-rotating gears which displace liquids at a rate proportional to the speed of the gears, was used to deliver vitamin A palmitate dissolved in peanut oil. A reservoir to hold the solution was used to supply the pump. A small stirring motor was mounted directly over the reservoir for the purpose of keeping citric acid in suspension. The discharge of the pump was connected by tubing to a nozzle directed downward toward the screw feeder of the peanut butter grinder.

Materials. Since the uniformity of delivery by volumetric displacement is dependent upon uniformity of particle size, it was necessary in the cases of salt and hydrogenated peanut oil to prepare these materials so that their particle sizes would be nearly uniform. Accordingly, commercial "flour" ground salt was sieved using U. S. Standard sieves. The commercial, flaked hydrogenated peanut oil was first chilled, and then passed through a No. 1 Wiley 4/ mill equipped with a 2 mm. screen. To prevent clogging of the screen after prolonged use small quantities of dry ice were ground along with the hard fat. The

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4/ The mention of trade names does not imply endorsement of products by the U. S. Department of Agriculture and is only for the purpose of identification.

Figure 9. Feeders.

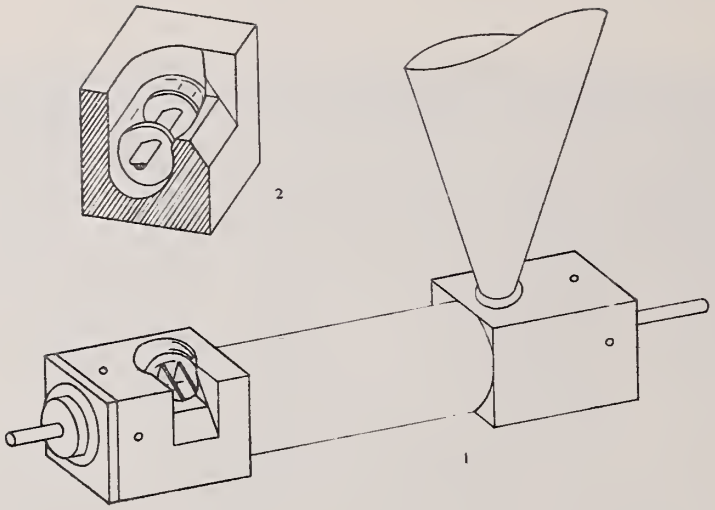

Figure 10. Feeder for salt or granulated hard fat.
1. Feeder.
2. Cross section of discharge end of feeder.

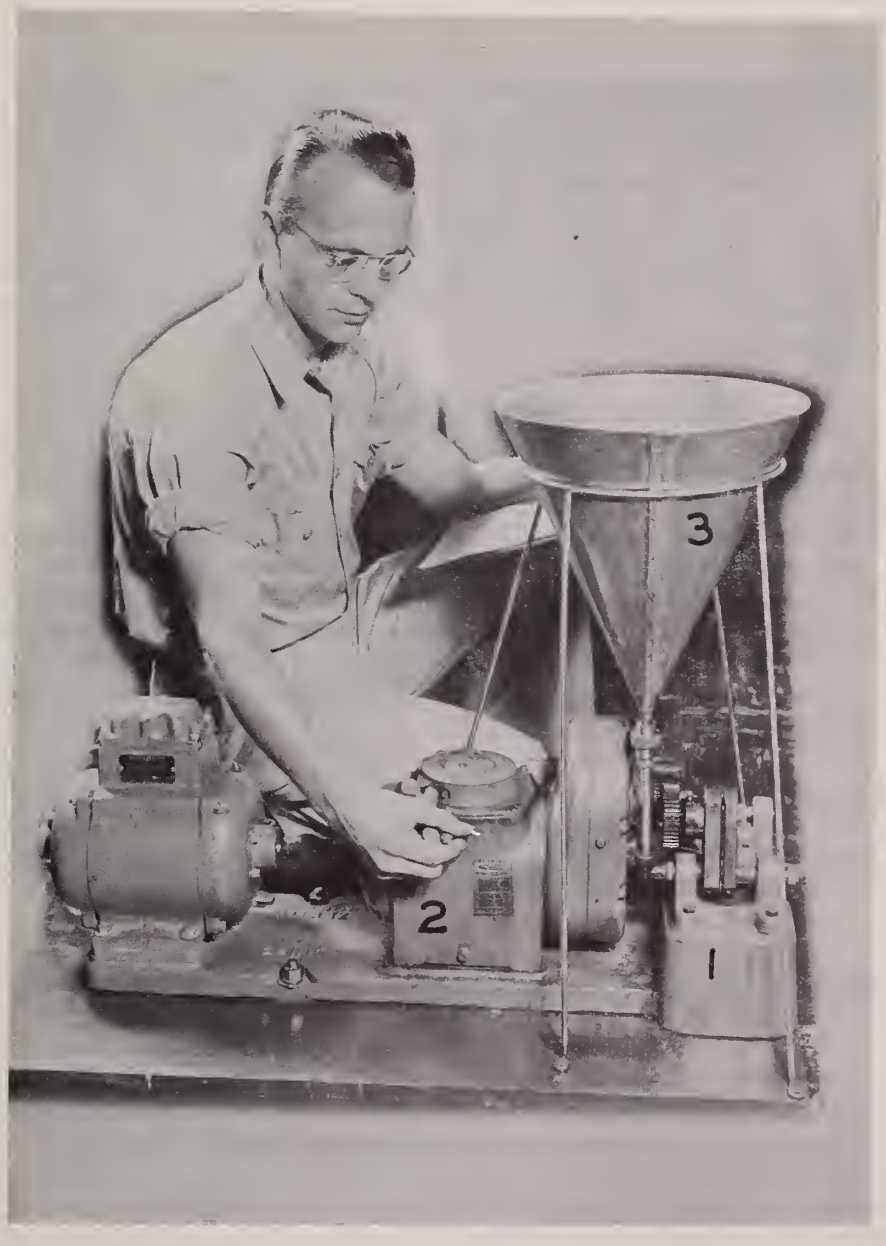

Figure 11. Equipment for delivery of peanut oil as a carrier for vitamin A. (1) Gear-type pump. (2) Variable speed drive. (3) Oil reservoir.

granulated material was sieved, using U. S. Standard sieves. Delivery of roasted peanuts was determined with split-blanched peanuts as customarily prepared for the manufacture of peanut butter (87).

Uniformity of feeding. Delivery measurements which were determined (87) independently on each feeder, indicated a high degree in uniformity of delivery. Furthermore, no significant change in rate of delivery was found upon reduction of the "head" or supply of material contained in the hoppers. Measurements of rate of delivery were obtained on each material under conditions of delivery calculated to produce about 4.1 pounds per minute of a peanut butter composed of 95.5% roasted peanuts, 2% hard fat, 1.5% salt, and 1% peanut oil as a carrier for vitamin A.

Preparation of Peanut Butter

Three batches of peanut butter containing vitamin A, salt and hard fat were prepared from runner peanuts by a process similar to that generally used in industry. Synthetic vitamin A palmitate dissolved in peanut oil was delivered with the other ingredients at the rate of 84 U.S.P. units per gram (computed) of the fortified product, taking into account all ingredients. Nordihydroguaiaretic acid (NDGA) and citric acid, added for the protection of the vitamin A, were incorporated during the preparation of a portion of the batch of fortified peanut butter intended for storage.

Methods of analysis. The vitamin A contents of the fortified peanut butters were determined by a modification of the U.S.P. Spectrophotometric method (51). Stabilities of oils extracted from the fortified peanut butters were determined by the active oxygen method (1, 44, 55, 86) at 97.8° C.

Uniformity of addition of vitamin A. Vitamin A contents were determined on a series of fortified peanut butter samples taken at regular intervals after constant operating conditions had been reached. The temperature of the peanut butter issuing from the grinder was recorded continuously (Figure 12). The temperature recorded after grinding had been in progress for 10 minutes was 138° F. and after grinding had been in progress for 40 minutes was 144° F. Data obtained in preliminary work showed that within the first 10-15 minutes of grinding considerable variation in vitamin A content occurred coincident with the usual rapid rise in the temperature of the issuing peanut butter. Data (Figure 12) indicate that the vitamin A contents of the fortified peanut butter ranged from 74 to 83 U.S.P. units per gram. The average of the vitamin A contents for the series of samples (78 U.S.P. units per gram) was found to be 7% less than the amount computed to have been incorporated during manufacture.

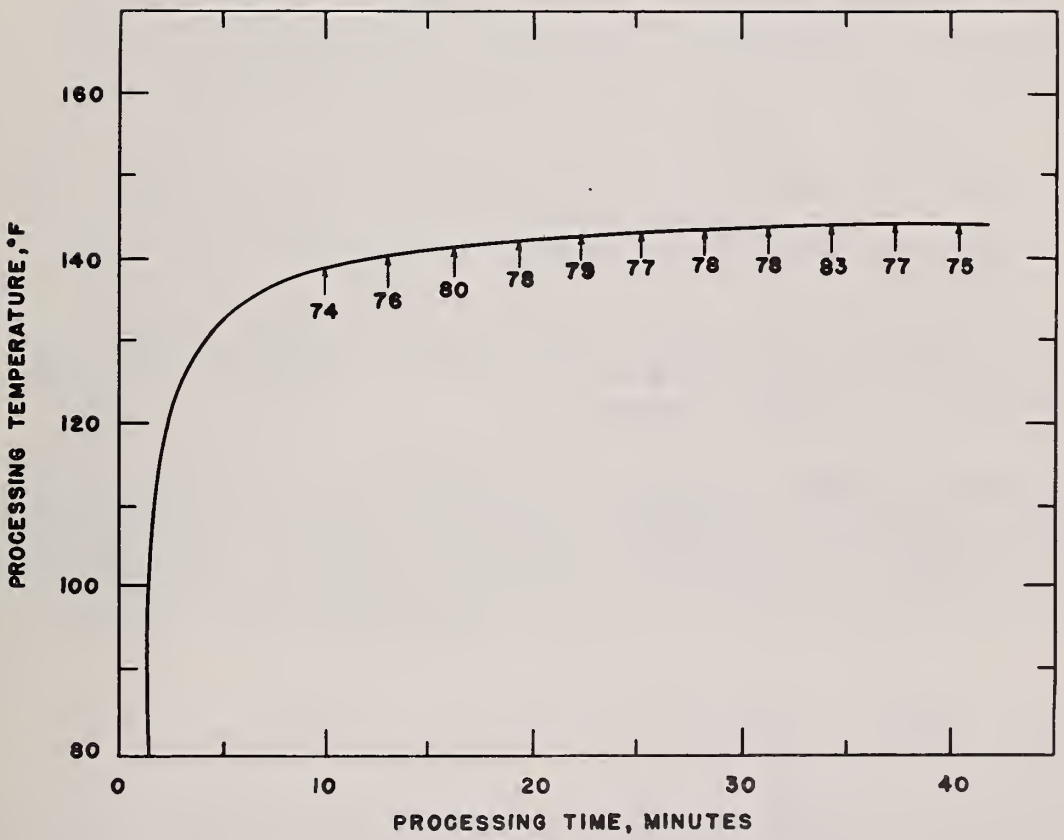

Figure 12. Range of vitamin A content after establishment of constant operating conditions. Figures under arrows refer to U.S.P. units of vitamin A per gram of peanut butter.

Effect of processing temperatures. For determining the effect of processing temperature, the fortified peanut butter issuing from the grinder was mixed in a "Case Homogenizer" 4/ equipped with a heat exchanger in order to simulate the range of processing temperatures generally resulting in industrial practice and to produce peanut butters having temperatures of approximately 140°, 160°, and 180° F., respectively.

Analyses of samples of these fortified peanut butters indicated (90) that the loss in vitamin A content occasioned by processing at 180° F. was only slightly greater than that occasioned by processing at 160° F., or 140° F. The content of vitamin A in the peanut butters processed at 160° F. and 140° F. was found to be 80 U.S.P. units per gram, a decrease of 4 U.S.P. units per gram or 5% on the basis of the amount of vitamin A computed to have been incorporated. Correspondingly, the content of vitamin A in the peanut butter processed at 180° F. was found to be 78 U.S.P. units per gram, a decrease of 6 U.S.P. units per gram or 7% on the basis of the vitamin A incorporated in the product.

These findings and general knowledge concerning the properties of vitamin A support the conclusion that losses in vitamin A content may be ascribed to frictional heat and inclusion of atmospheric oxygen in the peanut butter during grinding.

Effect of storage. Peanut butter fortified with vitamin A was packaged in glass jars (completely filled and closed with lined screw caps) and stored in the absence of light at 80° and 100° F. to determine the effect of storage on the content of vitamin A. Some of the samples contained 0.005% NDGA as an antioxidant and 0.0025% citric acid as a synergist for the protection of the vitamin A.

The fortified peanut butter was found to retain most of its original vitamin A content after storage for six months at both 80° and 100° F.

Analyses of samples made every two months over the period of storage showed (Table 17) generally that the vitamin A contents were still within the range resulting after manufacture (74 - 83 U.S.P. units per gram). In all cases, regardless of temperatures or periods of storage investigated, the vitamin A content per 1-1/2 oz. of peanut butter was found to be more than sufficient to supply one-half the daily recommended amount for an adult (2500 U.S.P. units).

4/ The mention of trade names does not imply endorsement of products by the U. S. Department of Agriculture and is only for the purpose of identification.

Table 17. Vitamin A [1/] Content of Fortified Peanut Butters During Storage.

Days	Time and Temperature of Storage			
	80° F.		100° F.	
	without antioxidants	with antioxidants [2/]	without antioxidants	with antioxidants [2/]
	U.S.P. units/gram			
0 [3/]	76	79	76	79
65	68-1/2	74	75	75-1/2
123	72	74	74	77-1/2
180	67	73-1/2	72	75-1/2

1/ Synthetic vitamin A palmitate; values expressed are averages of duplicate analyses of duplicate samples.
2/ Contains 0.005% nordihydroguaiaretic acid, and 0.0025% citric acid (anhydrous basis).
3/ Freshly prepared peanut butter.

While the results indicate that the vitamin A contents were slightly higher in those samples containing antioxidant and synergist than in the control samples, no strong evidence was obtained of any appreciable benefit from use of these substances.

The further observation, that there was little difference between the AOM stabilities (Table 18) of the oils of these peanut butters determined at the same times as the vitamin A contents, supports the conclusion that little advantage was obtained from adding the antioxidant and synergist.

Table 18. AOM Stabilities of Oils Extracted From Stored, Vitamin Fortified Peanut Butters.

Storage period	Storage at 80° F.				Storage at 100° F.			
	without antioxidant and synergist		with NDGA and citric acid 1/		without antioxidant and synergist		with NDGA and citric acid 1/	
	I.P.V. 2/	stability 3/	I.P.V.	stability	I.P.V.	stability	I.P.V.	stability
months	meq./kg.	AOM hrs.	meq./kg.	AOM hrs.	meq./kg.	AOM hrs.	meq./kg.	AOM hrs.
0	0	59	0	58	0	59	0	58
	-	--	0	54	-	--	0	54
2-1/2	2	49	1	54	2	48	1	49
	2	49	1	55	2	48	1	49
4	3	35-1/2	0	43-1/2	0	42	0	46
	0	37	0	43-1/2	0	42	-	--
6	2	37	2	40	3	38	5	35
	2	38	3	37-1/2	1	39	7	33-1/2

1/ Contains 0.005% NDGA, and 0.0025% citric acid.
2/ I.P.V. refers to the initial peroxide value of the oil before heating and aeration expressed as the milliequivalents of peroxides per kg. of oil.
3/ AOM (hours) refers to the stability of the oil expressed as the number of hours required by the oil to accumulate 100 milliequivalents of peroxides per kilogram during aeration at 97.8° C. with an air flow of 2.33 ml./sec.

Methods for Determination of Properties of Peanut Butter

Only a few methods for determination of properties of peanut butter appear in the literature (62). While analyses of peanuts and peanut butter have been reported (27), official methods of analysis generally do not include techniques that apply specifically to peanut butter. Vincent and Szabo have described (82) methods for ascertaining spreadability, particle size distribution and hydrogenated oil, air, sucrose, and salt contents of peanut butter. In work at the Southern Regional Research Laboratory, methods for analysis of peanut butter have been described which are useful to peanut butter manufacturers in controlling the quality of peanut butter and gaging the efficiency of specific operations.

Peanut Butter Methods

Vitamins. Methods for determination of vitamin B_1 (thiamine) and vitamin A in peanut butter have been described (90, 91) by Willich, et al.

Moisture. A toluene distillation method, using apparatus described by Tryon (80), has been described (64) by Pepper and Freeman and found suitable for determining the relatively small amounts of moisture (1 - 2.5%) present in peanut butter.

Content of hydrogenated peanut oil. Morris, et al. determined, among other things, the oil contents (58) of sorted roasted peanut cotyledons and the peanut butters made from these peanuts containing hydrogenated peanut oil, and pointed out that such analyses (see Table 8) afford peanut butter manufacturers an approximate means of determining the uniformity of incorporation of the hardened peanut oil added to the product for the prevention of oil separation. The content of added fat would be the difference between the oil content (moisture and salt free basis) of the peanut butter and the oil content (moisture free basis) of the roasted peanuts. In the instances where pumpable stabilizers are used, the hydrogenated fat content would be computed as half of this difference.

Stability of oil in peanut butter. Willich, et al. used (89) the active oxygen method (1, 44) to determine the stability of oil extracted from stored peanut butter, in order to show any deterioration during storage of the product occasioned by autoxidation. Morris and Freeman showed (55) that stabilities of crude peanut oils could be determined at 110° C. in 40% of the time required at 97.8° C. by use of Mehlenbacher's modification of the active oxygen method. Fisher and Morris described (23) a stability tube with foam breaker for use with the active oxygen method which controlled excessive foaming of crude peanut oils extracted from peanut butters made from Spanish peanuts.

Color of peanut butter. Morris, et al. described (57) an objective method for determination of the color of peanut butter. The method consists of recording the spectral reflectance properties of peanut butter directly by use of an automatic recording spectrophotometer equipped with a diffuse reflectance attachment, and expressing the spectral data numerically in terms of the C.I.E. (previously I.C.I.) system of color notation. C.I.E. designations can also be expressed as Munsell renotations and Hunter values. In general, the x-trichromatic coordinate, the redness factor, was considered to be the best single expression of the color of peanut butter, since it could be related to the extent of roast accorded the peanuts from which the peanut butter was made. This factor can also be expressed in other terms, the Hunter a-coordinate, or the Munsell hue being most analogous.

Effect of grinding on particle size of peanut butter. Because the extent of grinding affects the amount of oil freed from the peanut and hence the consistency and the separation of oil of peanut butter, efforts were made to determine the particle size distribution of the oil-free meal of peanut butters ground variously. Dry sieving of the oil-free meal from the product was unsuccessful because of the appreciable electrostatic charge produced on the particles during sieving. However, it was found possible to sieve the product satisfactorily by pouring a slurry of peanut butter and commercial hexane (b.p. ca. 60° C.) on the sieve. In this procedure a slurry of 5 grams of the peanut butter and 100 ml. of the solvent was prepared for each sieve in the U. S. Standard series from No. 20 to No. 400. The slurry was poured on the sieve, and the percentage of oil-free meal (dry-weight basis) remaining on the sieve was determined. Results of sieve analyses of variously ground peanut butters are shown in Table 19 and have been plotted in Figure 13.

Only about 5-13% of the meal (dry weight, oil-free basis) was retained in the No. 400 sieve, from which it follows that while the majority of the solid material comprising peanut butter is exceedingly fine, considerable variation in texture results from the amounts of relatively coarse particles produced by the different grinders. Particles retained on the sieves were nearly ovoid in shape with small, jagged protuberances, the general shape or contour being similar regardless of particle size.

Table 19. Particle Size of Meal of Peanut Butter Prepared in Vertical Attrition Mills

	Peanut butter samples					
	1	2	3	4	5	6
FIRST GRINDING						
Diameter plates, in.	8	8	8	8	8	18
Motor horse power	5	5	8.3	8.3	8.3	30
R.p.m., grinding plate shaft	350	350	500	500	500	1800
Production, peanut butter, lbs./hr.	240 1/	240 1/	1000	1000	1000	2000
Grinding plate clearance, in.	0.01	0.005	--	--	--	--
SECOND GRINDING	none	none	none			none
Diameter plates, in.				8	8	
Motor horse power				20	20	
R.p.m., grinding plate shaft				3600	3450	
Production, peanut butter, lbs./hr.				2500	2500	
SIEVE ANALYSIS 2/ Percent by weight, dry basis, on Sieve No.						
20	none	none	none	none	none	none
40	3.0	0.4	0.6	0.2	negligible	negligible
60	6.3	3.7	2.9	1.6	0.5	0.1
80	7.7	5.7	5.3	3.5	1.6	0.6
100	7.9	6.3	6.2	4.6	2.1	1.0
120	8.3	6.8	7.2	5.2	3.0	1.6
140	9.4	7.7	8.0	6.1	3.4	2.1
170	9.3	8.1	9.0	6.7	4.1	3.0
200	10.0	8.8	9.4	7.4	4.5	3.0
230	10.6	9.6	10.5	8.1	5.6	3.8
270	10.4	10.0	10.9	8.5	5.8	3.9
325	11.5	10.9	11.7	9.4	6.9	4.7
400	13.1	12.1	13.2	10.4	7.6	5.4
Totals	108	90	95	72	45	29

1/ About 1/4 maximum rated capacity.
2/ Percent of meal retained on U.S. Std. sieves, 3" diameter. Calculated to a dry basis.

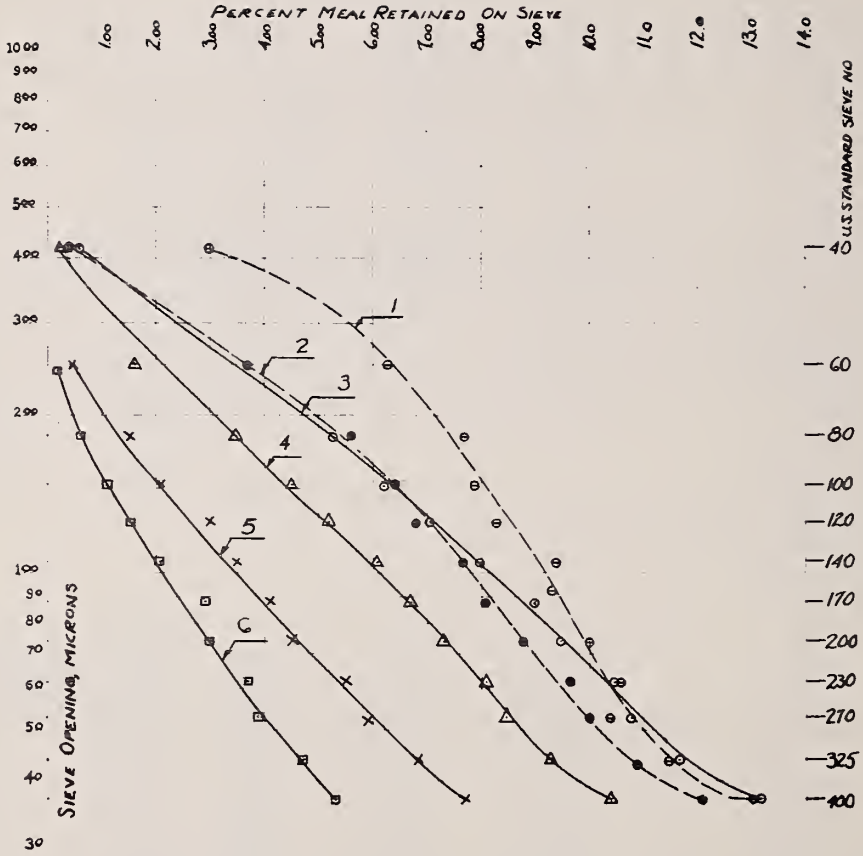

Figure 13. Logarithmic diagram of sieve analyses of six samples of peanut butter.

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