Lipid-Derived Flavors of Legume Protein Products[1]

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ABSTRACT AND SUMMARY

Legumes contain unsaturated lipids that are susceptible to oxidative deterioration. Enzymic and nonenzymic deterioration of these lipids results in the development of off-flavors. The primary objective of this review is to summarize what is currently known about lipid-derived flavors of soybeans and underblanched pea seeds (*Pisum sativum*). Identifying the numerous volatile compounds arising from breakdown of lipid hydroperoxides coupled with organoleptic evaluation defines the flavor problem. Major contributors to the green-beaniness of soybeans were found to be 3-*cis*-hexenal, 2-pentyl furan, and ethyl vinyl ketone. Oxidized phosphatidylcholines cause some of the bitter taste. The interaction of lipid breakdown products with proteins, carbohydrates, and other constituents can affect flavor characteristics and also increase the problems of their removal from soy protein products. To prepare bland products, it will be necessary to develop processes that effectively remove bound flavor components and prevent formation of derived flavors. Solvent systems based on alcohol have been used to extract flavor principles from soybeans; aqueous alcohol treatment of the intact seed or blanching with hot water or steam inhibits formation of off-flavors in peas and soybeans. A new approach involving infusion of antioxidants into the intact seed to control lipid deterioration during processing and storage is proposed to minimize flavor formation without subsequent undesirable changes in protein which occur with alcohol treatments.

INTRODUCTION

The flavor sensation is a composite of taste, odor, and mouthfeel. Volatile substances such as low-molecular-weight acids, alcohols, aldehydes, amines, esters, and ketones and also certain pyrazines, sulfur compounds, and terpene hydrocarbons undoubtedly contribute to the odor of vegetables. Taste as perceived by the mouth is limited to one or more of the four sensations described as sweet, acid, salty, or bitter. Substances contributing to taste are generally nonvolatile and possess some degree of water solubility.

Volatile and nonvolatile compounds giving rise to the flavor sensation can be formed from three basic food ingredients: lipids, proteins, and carbohydrates. These substances can produce either the characteristic flavors that are associated with normal metabolism of a growing plant or the derived flavors which occur after harvesting and during subsequent processing and storage.

Johnson et al. (1), who reviewed vegetable volatiles and their contribution to flavor, listed numerous nitrogen, sulfur, and carbonyl compounds. Yet no single compound was found to be totally responsible for the characteristic flavor of a particular vegetable. Rackis et al. (2) reported that the green-beaniness of soybeans appears at an early stage and does not change in intensity during seed development, whereas bitter taste is more apparent as the seed matures and its intensity values increase fivefold during the maturation. These flavors can be considered characteristic of the soybean and presumably are either released from the protein-carbohydrate matrix or generated enzymically during the chewing of the raw bean.

Maga (3) and Cowan et al. (4) reviewed the literature on flavor problems associated with soybeans and soybean products. Derived flavors formed under certain processing conditions used to produce soy flours, concentrates, and isolates are described as cardboard, astringent, toasted, and mealy (5). Other flavors described as hydrocarbon, painty, and rancid are often noted in full-fat soy products that have been subjected to aerobic blending with water. Rancid flavors in underblanched frozen raw vegetables, notably the pea, arise from lipid precursors (6-8). These findings led Tappel (9,10) to suggest that hydroperoxides formed by the action of lipoxygenase with unsaturated fatty acids decompose to carbonyl compounds which can cause rancidity. Several investigations have been made on volatile compounds of peas and their relationship to flavor (11-14).

Even though the end usage of soybeans and pea seeds (*Pisum sativum*) differs, some of the flavor problems resulting from lipid deterioration are similar. The primary objectives of this review are to summarize what is currently known about their lipid-derived flavors and to critically assess the flavor significance of specific components that have been identified. Preservation methods to control the development of flavor will be discussed.

Pea and Bean Lipids

During maturation of peas and soybeans fatty acid compositions change, and an increase in lipid content was noted in both legumes (15,16). Bengtsson and Bosund (15) found that oleic acid content did not vary significantly with pea maturation, whereas linoleic acid increased and palmitic and linolenic acid decreased. With soybeans (17,18), both oleic and linoleic acid increased while palmitic and linolenic acid decreased.

However, in spite of these changes in polyunsaturation, the characteristic green-beany flavor did not vary in intensity during maturation (2). This would indicate minimal oxidation of the highly unsaturated lipids by low levels of lipoxygenase in green soybeans may be enough to initiate formation of this characteristic flavor. On the other hand, bitter taste developed at the latter stages of maturity. Analysis of the data showed significant correlation at the 1% level between lipoxygenase activity and increase in bitterness intensity. If the green-beany and bitter flavors of mature soybeans are presumed to arise entirely from degradation of unsaturated fatty acids, elimination of these flavors by plant breeding does not appear to be very promising, since it would require development of seeds with much less unsaturation. A great reduction in unsaturated fatty acid content would be required because the green-beany and bitter flavor detection thresholds are at very low levels. For example, our trained taste panel can detect these flavors in raw defatted soy flour at levels of 0.03 and 0.04% in water (5).

Lipid content and unsaturated fatty acid composition of peas and various mature beans are summarized in Table I. Since the values for unsaturated fatty composition can vary (15,19-21) depending on crop year, state of maturity and variety, the reported amounts will be used solely to develop our theme on their potential to oxidize. The lipid content for all the legumes except soybeans listed in Table I varies from 2.6-3.6% depending on species; soybeans have about seven times that amount. Soybean lipids contain mostly

[1]Presented at the AOCS Meeting, New Orleans, April 1976.

TABLE I

Lipid Content and Unsaturated Fatty Acid Composition of Triglycerides and Phospholipids from Legumes

Legume species (common name)	% Crude lipid	Triglycerides[a]				Phospholipids[a]			
		18:1	18:2	18:3	Total	18:1	18:2	18:3	Total
Vicia faba[b] (Broad bean)	3.56	31	41	5	77	14	17	18	49
Pisum sativum[b] (Alaska pea)	2.57	33	24	4	61	10	22	17	49
Phaseolus vulgaris[b] (Great Northern bean)	3.00	3	32	45	80	10	27		37
Glycine max[c] (Soybean)	23.3	25	54	7	86	9	60	7	76

[a]Mole % of fatty acid by gas liquid chromatography (GLC).
[b]See Ref. 19.
[c]Sessa, unpublished.

triglyceride with only about 2.5-2.8% phospholipid, based on phosphorous analysis, while the other legumes contain equal amounts of these two. With Alaska peas and soybeans, polyunsaturated fatty acid content of the phospholipids is higher than that in the triglycerides. All the legumes listed possess a high degree of lipid unsaturation.

LIPID DETERIORATION AND FLAVOR DEVELOPMENT

Hydrolytic vs. Oxidative Deterioration

Lipases directly attack the fatty acid ester bonds of triglycerides and phospholipids producing free fatty acids. The flavors developed by lipase action depend on the composition of fat. Release of short chain fatty acids such as butyric, caproic, and capric causes particularly disagreeable odors and flavors (22), whereas the long chain fatty acids (C_{12} and above) produce candlelike or, at alkaline pH, soapy flavors.

Oxidative deterioration of free and esterified unsaturated fatty acids is primarily responsible for the formation of objectionable flavors in legumes. Enzymes, heat, light, and a variety of metal catalysts including metallo-proteins degrade these fatty acids, initially producing hydroperoxides. Soybean lipoxygenases catalyze formation of mostly 13-*cis-trans*-hydroperoxides and small amounts of the 9-*cis-trans* isomer from fatty acids with *cis-cis*-1,4-pentadiene systems. Autoxidation involves the spontaneous uptake of oxygen by unsaturated fatty acids to form equal amounts of 13- and 9-hydroperoxides such as 13-hydroperoxy-*cis*-9,*trans*-11- and 9-hydroperoxy-*cis*-12,*trans*-10-octadecadienoic acids from linoleic acid through a free radical mechanism (23). Hydroperoxides then decompose by complex series of reactions (24) into a large number of volatile and nonvolatile constituents. Oxygenated fatty acids with epoxy, oxo, and hydroxyl functional groups from homolytic decomposition of linoleic acid hydroperoxides have been identified (25).

Lipid Oxidizing Potential in Legumes

Practically all of the Leguminosae as well as potato, egg plant, artichoke, and cauliflower have high lipid oxidizing activity (26,27). Lipoxygenase activities of various legumes are give in Table II. According to Ericksson (28) lipoxygenases as well as free and bound unsaturated fatty acids are present in all parts of the pea. The potential for an enzyme-catalyzed oxidation is great in this instance since enzyme, unsaturated fatty acid, and molecular oxygen which can diffuse into the pea seed are in close proximity. An analogous study has not been made with soybeans. Haydar et al. (29) found that purified pea seed lipoxygenase devoid of lipase activity can oxidize both triglycerides and free fatty acids but not the polar phospholipids. In soybeans, lipoxygenases specific for either free fatty acids or for triglycerides have been isolated (30,31). Sessa et al. (32) postulated that lipoxygenases can also oxidize phospholipids. However, this aspect has yet to be proven.

TABLE II

Lipid Oxidizing Activity of Legumes

Genus	Common name	Oxygen consumption[a]
Vicia	Bean	840
Pisum	Pea	1769
Glycine	Soybean	4150
Phaseolus	Yellow bean	6480

[a]μl per 10 g fresh tissue per min determined by polarography; see Ref. 26.

TABLE III

Thiobarbituric Acid (TBA) Reactive Substances in Soybean[a] and Pea[b] Samples

Sample	TBA no.[c] for homogenizing medium	
	Water	Acid
Green pea	9.3	0.9
Mature soybean	12.0	1.1
Full-fat chips		2.0
Full-fat flakes—raw	83.8	11.1
Full-fat flakes—toasted	7.7	3.3
Defatted flakes—raw	11.6	9.7

[a]See Refs. 33 and 34.
[b]See Ref. 27.
[c]Milligrams of malonaldehyde per kilogram of sample.

Based on an analysis of thiobarbituric acid (TBA)-reactive substances, Sessa et al. (33) and Rackis et al. (34) demonstrated that processing whole soybeans into oil and meal increased the oxidative deterioration of unsaturated lipids. Results are summarized in Table III. All the samples except toasted full-fat flakes contained active lipoxygenase. When samples are aerobically homogenized in water, the resultant TBA numbers are higher than those of samples blended in water containing acid, presumably because of the lipoxygenase activity in the nonacid medium. Toasting inactivates the enzymes and results in lowered TBA numbers and diminished differences between water and acid media. Defatting has similar effect. These studies showed that lipid oxidizing potential indeed changed with processing. Sessa et al. (33,35) and Maga and Johnson (36) reported residual lipids in raw, hexane-defatted flakes are

TABLE IV

Flavors Derived From Purified Linoleic (LOHP) and Linolenic (LNHP) Acid Hydroperoxides[a]

Flavor description	% Taster's response	
	LOHP, 50 ppm	LNHP, 10 ppm
Grassy/beany	80	90
Bitter	16	19
Astringent	19	19
Raw vegetable	20	16
Musty/stale	35	
Rancid oil	44	5

[a]See Ref. 37.

TABLE V

Major Volatile Compounds Generated from Linoleic Acid Hydroperoxides (LOHP) by Pea and Soybean Lipoxygenases[a]

Compound	Quantity in headspace, GLC peak height[b]	
	Pea	Soybean
n-Butanal	+	+++
n-Pentanal	+++	+++
n-Hexanal	+++	+++
n-Heptanal	++	+
n-Hept-*trans*-2-enal	+++	+++
2-n-Pentyl furan	+	+++

[a]See Ref. 39.

[b]+ = 5-10 mm; ++ = 11-50 mm; +++ = >50 mm. GLC = gas liquid chromatography.

prone to further deterioration during processing and storage.

Hydroperoxides as Flavor Precursors

Taste panel evidence that either hydroperoxides arising from lipoxygenase action on linoleic and linolenic acids or their respective degradation products lead to soybean-like flavors has been reported by Kalbrener et al. (37). Flavors derived from purified fatty acid hydroperoxides are summarized in Table IV. Additional painty, fishy flavors were evident in crude hydroperoxide mixtures. Partially oxidized soybean oils possess similar flavor notes (38). Whether all the volatile compounds reported in the literature that contribute to flavor arise directly from hydroperoxide decomposition has yet to be proven.

KEY FLAVOR COMPOUNDS FROM OXIDIZED LIPIDS

Volatile Falvor Compounds

In comparing action of pea and soybean lipoxygenases on linoleic acid substrates Leu (39) found that the volatile compounds generated were very similar in spite of differences in the ratio of 9- and 13-hydroperoxides for peas (1:1) vs. soybeans (1:4). The volatiles from the deterioration of 9- and 13-hydroperoxides must form by a similar mechanism (Table V). In addition, Heimann et al. (40) and Grosch and Schwencke (41) reported formation of oct-2-enal, nona-2,4-dienal, deca-2,4-dienal and pentanol with soybean lipoxygenase-linoleic acid model systems. Grosch (42) showed that pea oxygenases can degrade lipids extracted from freeze-dried ground peas. Several alk-2-enals and alk-2,4-dienals were identified, many of which are similar to those found in the model systems. Also, some alk-2-enals including hex-2-enal and the above-mentioned alk-2,4-enals were isolated from unblanched frozen peas stored at -17.8 C for 2 yr (12). Therefore, similar volatile compounds form not only when soybean and pea lipoxygenases or other oxygenases can act on endogenous lipid substrates but also in model systems employing purified fatty acid. Kinsella et al. (43) described the flavors of some of the higher alk-2-enals and alk-2,4-dienals as oxidized, cardboard, oily, and painty.

On the other hand, 2-pentyl furan and 3-*cis*-hexenal both contribute to the green-beany flavors of reverted soybean oil (44,45). 2-Pentyl furan can be formed from enzymically generated hydroperoxide (39) and also by autoxidation of linoleic acid (44). It has been found in commercial soy protein isolate (46) and reverted soybean oil (38). A similar isolate (5) and reverted soybean oil both taste green-beany. 3-*cis*-Hexenal which can cause the green-beany flavor in reverted soybean oil (45) and other vegetables readily isomerizes to 2-*trans*-hexenal during blending and steam distillation (47). If this is the case, the reported presence of 2-hexenal in model systems of soybean lipoxygenase and linoleic acid (48), in peas (12), and in reverted soybean oil (45) actually represents the isomerization of 3-*cis*-hexenal during its isolation. The flavor of hex-2-enal is described as oily, grassy (43). The green-beany essence predominant in raw soybeans is rapidly lost on processing flakes with steam or hot solvents. Perhaps the change in flavor from green-beany to cooked beany characteristic is accounted for in part by an isomerization of some of the carbonyl compounds.

Mattick and Hand (49) reported that the formation of a green-beany odor and flavor during the preparation of full-fat soy beverage can be attributed in part to the presence of ethyl vinyl ketone. This compound was also isolated from soybean oil in the early stages of autoxidation (50). When combined with an equal amount of pentanol and added to freshly deodorized oil, this mixture imparted to the oil a flavor reminiscent of the oxidized oil. Based on these findings, 2-pentyl furan, 3-*cis*-hexenal, and ethyl vinyl ketone can be considered key flavor compounds for the beany character of soybeans and reverted soybean oil.

Most studies on flavor chemistry are qualitative and provide little information on the relative importance of the many compounds present in products having off-flavors. Odor and flavor threshold values for compounds described as green, beany, or grassy are given in Table VI. Generally as solvent polarity is increased, the flavor threshold decreases. Therefore, thresholds for tasting in water and milk would be even lower than those given in Table VI. For example, Kinsella (52) reports a threefold difference in flavor threshold values for hexenal in oil versus milk (i.e.,

TABLE VI

Compounds Contributing to Green Vegetable Flavors of Green Peas and Soybeans

Compound	Flavor description	Threshold (ppm in oil)		Reference no.
		Oil	Taste	
n-Hexanal	Green grassy	0.32	0.15	51
3-*cis*-Hexenal	Green beany[a]	0.11	0.11	51
n-Pentyl furan	Beany	2	1-10	44
Ethyl vinyl ketone	Green beany	5 (milk)		49

[a]See Ref. 45.

0.15 ppm vs. 0.05 ppm) and a 25-fold difference for 2-*trans*-hexenal with 2.5 ppm detected in oil vs. 0.1 ppm in skimmed milk. These volatile compounds have even lower thresholds in water alone if proteins such as those in milk irreversibly bind them. The interaction of flavor compounds with amino acids and proteins and subsequent effect on flavor will be discussed in a later section. If we assume that the compounds listed in Table VI all contribute to the green-beany flavor of raw soybeans, generation of small amounts of these by oxidation during the processing of soybeans into oil and meal could greatly affect flavor since the grassy-beany threshold value for raw defatted soy flour tasted in water is 300 ppm (5).

Nonvolatile Flavor Compounds

In general, free fatty acids of low volatility (above C_{12}) do not taste acid or sour and do not have much flavor (22) other than that described as candlelike and sometimes soapy. A bitter taste is not usually associated with lipids or their oxidation products. However, an intensely bitter taste developed when oil-free phosphatides were irradiated with ultraviolet light (33). More recently, Sessa et al. (32) reported that purified soy phosphatidylcholine (PC) oxidized in aqueous suspensions at 25 C developed a bitter taste, whereas hydrogenated soy PC similarly treated did not.

Based on values given in Table VII, the bitter threshold level of autoxidized soy PC was calculated to be 0.006%. Defatted soy flakes contain at least 0.08% PCs which taste bitter and also contain oxidized fatty acid constituents. From these data (32,35), we concluded that oxidized PC may be largely responsible for the bitter taste of raw soybeans, defatted flakes, and other soy protein products.

Schiff bases formed by the reaction of saturated or unsaturated aldehydes with soy phosphatidylethanolamine (53), as well as autoxidation of free unsaturated fatty acids (37) or their methyl esters (54), reportedly develop bitter taste. Most likely these compounds contribute little to the bitterness of soybean products, since only trace amounts of free fatty acids are present in defatted soy flour (55). Other phospholipids in soy flakes such as phosphatidylethanolamine and phosphatidylinositol do not appear to taste bitter (35). Flavors of the isolated, nonvolatile oxidation products from reaction of pea enzymes on their unsaturated fatty acids have not yet been evaluated (56).

INTERACTION OF FLAVOR COMPOUNDS WITH PROTEINS AND AMINO ACIDS

Oxygenated products derived from lipid hydroperoxide decomposition contain hydroxy, epoxy, and carbonyl functional groups that can react with active sites in proteins such as the ϵ-amino group of lysine and thiol group of cysteine (57) to form lipoprotein complexes. Not all lipid decomposition products form stable lipoprotein complexes (58). For example, soy proteins appear to have a much stronger affinity for binding aldehydes and ketones compared to alcohols (59). In fact, aldehydes, especially when unsaturated, react strongly with the protein (60-62), whereas ketones bind weakly and alcohols (C_6 and above) do not bind at all. According to Arai et al. (63), the amount of bound ligand increases with denaturation of the protein.

Epoxy compounds readily react either with the free carboxylic groups of dicarboxylic amino acids or with hydroxyl groups of serine or threonine (64). However since the epoxy derivatives readily polymerize or hydrolyze, the extent of interaction with proteins is less than that of the side reactions (57).

According to Beyeler and Solms (59), soy protein shows a distinct affinity for certain flavor substances. Anderson and Warner (65) found that specific soy proteins, referred to as acid-sensitive fraction, bind the grassy-beany, bitter, astringent soy flavor components. Removal of this fraction from soy protein preparations caused reduction in intensity of these flavors.

Flavor compounds that become irreversibly bound to the protein lose their olfactory effect because they are no longer volatile. Bitter-tasting nonvolatile constituents lose their effect because they are no longer available to the bitter taste sites on the tongue. The primary objective in producing a bland-tasting product should be to remove the unbound flavor constituents, irreversibly bind those that cannot be removed, and prevent further formation of new flavor constituents.

TABLE VII

Bitter Response to Autoxidized Soy Phosphatidylcholine[a]

Concentration (%)[b]	Bitter response (%)[c]
0.025	100
0.010	63
0.005	44
0.003	40
0.001	0

[a]Autoxidized as aqueous suspension with Cu^{++} for 432 hr. See Ref. 32.
[b]Percent by weight in carbon-filtered tap water.
[c]Percentage of panelists giving positive response.

TABLE VIII

Flavor Evaluation of Alcohol Treated Legumes[a]

Legume	Flavor score: Untreated		Flavor score: Treated	Δ
Split peas *(Pisum sativum)*	4.8	-- *b --	6.3	+1.5
Black-eyed peas *(Vigna sinensis)*	4.6	-- **c --	6.1	+1.5
Soybeans *(Glycine max)*	3.8	-- ** --	6.7	+2.9

[a]See Ref. 71.
[b]Significant difference at 95% confidence level.
[c]Significant differende at 99% confidence level.

PROCESSES TO IMPROVE ORGANOLEPTIC PROPERTIES

Solvent Extraction of Flavor Constituents

Taste panel evaluations of raw full-fat and defatted soy flours show flavor scores of about 4 based on a 10-point scale (66-68). The beany, bitter, astringent flavors of soybeans remain after extracting 97% of the lipids with pentane-hexane. Hydrogen bond-breaking solvents containing alcohol, such as an azeotropic mixture of hexane-ethanol (82:18, v/v), can remove residual lipids and flavor constituents from defatted soy flakes to yield products with flavor scores of 7 and above. Combinations of extraction with toasting procedures yield even blander products with scores approaching 8 (68).

The significant improvement in flavor scores with azeotrope extraction is attributed to large reduction in the flavor intensity value of the green-beany component(s), whereas the intensities of bitter and astringent flavors are reduced to a lesser extent. Apparently solvent and heat treatments extract, distill, or modify the beany flavor principles and also inhibit the enzymes such as lipoxygenase and peroxidase that can generate off-flavors (69). The nonvolatile bitter and astringent principles are not completely extracted with the hexane-ethanol azeotrope and some perhaps are generated by autoxidation during the processing with solvent and steam.

Inhibition of Lipid Oxidation

In addition to reducing objectionable flavors by solvent extraction, it is also possible to improve the flavor of food products by inhibiting, in situ, lipoxygenases and other enzymes that degrade lipids. Studies on the relationship between lipoxygenase activity and the formation of off-flavors in soybeans were recently reviewed by Wolf (70). Blanching of green peas is a common practice used to preserve these legumes from oxidative deterioration.

Flavor scores of legumes can also be improved significantly by steeping or wet milling whole legumes with aqueous ethanol (71). Flavor scores of various legumes treated with 50% ethanol are given in Table VIII. Over 99% of the lipoxygenase activity originally present in the raw legumes is destroyed by the alcohol treatment. The peroxidase enzymes which can catalyze deterioration of lipid hydroperoxides are also very sensitive to this alcohol treatment and, according to Rackis (unpublished data), are almost completely inactivated. Whether the improvement in flavor can be attributed to direct inactivation of these enzymes or to irreversible binding of the objectionable flavors with alcohol-denatured proteins, which can also reduce intensity of flavor perception, remains to be determined.

Alcohol treatments, therefore, are not only used to extract substantial amounts of lipids and flavors but also to inactivate enzymes which generate off-flavors. However, alcohols denature some of the major proteins thereby causing undesirable changes in solubility, grainy texture, and loss in certain functional characteristics. It may be possible to preserve seeds and to prevent lipid oxidation by the infusion of antioxidants into the dry seeds or beans. Mayer and Poljakoff-Mayber (72) found that chemicals can be introduced into dry seeds with the aid of solvents such as dichloromethane and acetone. Siddiqi and Tappel (73) showed that the antioxidants, nordihydroguariaretic acid, propylgallate, and α-tocopherol, each inhibited oxidation of linoleate with soybean and pea lipoxygenases to different degrees. The three antioxidants were more effective in the pea reaction system. Some acetylenic compounds can also act as powerful competitive inhibitors of lipoxygenase (74). Sherwin and Thompson (75) showed that tertiary butyl hydroquinone is a potent antioxidant for fats and oils and fat-containing foods. Its antioxidant effect in peas and beans has not yet been established.

FUTURE RESEARCH

Identification of the large number of volatile and nonvolatile flavor components derived from lipids provides us with information pertaining to the mechanisms by which the lipids are degraded. Formation of off-flavor can be inhibited by hot water or steam blanching and alcohol treatments. Because of the denaturing effect of these processes on the proteins, direct infusion of chemical antioxidants into the seed may be the area where future efforts should be made. Also, knowledge on the binding characteristics of degraded lipids to proteins should provide us with information concerning development of processing methods that can remove the flavor components more effectively without seriously changing the functional properties of the food system.

Proposed research that should provide the means to prepare bland legume protein products include the following.

(a) Determination of the role that lipoxygenases and peroxidases have on polar and nonpolar lipids. It has been reported that pea phospholipase action on phospholipids is a prerequisite to oxidation of the unsaturated fatty acid constituents by pea lipoxygenase (29). Sessa et al. (35) identified PCs from soybeans that contained oxidized fatty acid constituents. Whether these arose enzymically by an oxygenase or nonenzymically has yet to be determined.

(b) Development of model systems to investigate extent of lipid oxidation in various lipid-matrix combinations. With pea lipids and their oxidation on carbohydrate and protein matrices (20), it was found that polarity of the lipid rather than unsaturation has a primary influence on lipid oxidation. Different proteins play a significant role in lipid oxidation. For example, pea globulin rather than albumin can act as a prooxidant.

(c) Development of model systems to test the effects that antioxidants have on stabilizing lipid oxidation in oil-water=protein emulsion systems. With a model of spray-dried emulsion containing safflower oil, emulsifier, carbohydrate, antioxidant and protein, Fioriti et al. (76) accurately predicted flavor scores by following oxygen absorption and carbonyl values.

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