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NUTRITIONAL ASPECTS OF IRRADIATED SHRIMP: A REVIEW

ASPECTS NUTRITIFS DE LA CREVETTE IRRADIEE: UN EXAMEN

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RÉSUMÉ

On a examiné les renseignements de la documentation sur les aspects nutritifs de la crevette irradiée; ceux-ci indiquent que l'irradiation de la crevette à une dose allant jusqu'à environ 3,2 kGy n'influe pas d'une façon importante sur le niveau de protéine, graisse, glucide et cendre de celle-ci. Il n'y a pas de renseignements sur l'effet de l'irradiation de la crevette, à plus 3,2 kGy, sur ces éléments. Les renseignements limités qui existent indiquent que certains changements insignifiants de composition d'acide gras se produisent par suite de l'irradiation. L'irradiation produit également certains changements de composition d'acide aminé; des changements semblables se produisent en raison de la mise en boîte et du séchage à l'air chaud. Il y a perte de certaines des vitamines telles que la thiamine en raison de l'irradiation mais cette perte est moins grande que chez la crevette traitée à la chaleur. La qualité protéique de la crevette, d'après la croissance des rats, ainsi que celle de Tétrahymena pyriformis, n'est pas influencée par l'irradiation. On n'a constaté aucuns effets nuisibles dûs à l'irradiation non seulement lors des essais d'alimentation animale à court terme mais aussi lors de ceux à long terme.

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ABSTRACT

Data available in the literature on the nutritional aspects of irradiated shrimp are reviewed and the indication is that irradiation of shrimp at doses up to about 3.2 kGy does not significantly affect the levels of its protein, fat, carbohydrate and ash. There are no reports on the effect of irradiation of shrimp above 3.2 kGy on these components. Limited information available indicates that there are some minor changes in the fatty acid composition of shrimp as a result of irradiation. Irradiation also causes some changes in the amino acid composition of shrimp; similar changes occur due to canning and hot-air drying. Some of the vitamins in shrimp, such as thiamine, are lost as a result of irradiation but the loss is less extensive than in thermally processed shrimp. Protein quality of shrimp, based on the growth of rats as well as that of *Tetrahymena pyriformis*, is not affected by irradiation. No adverse effects attributed to irradiation were found either in short-term or long-term animal feeding tests.

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CONTENTS

1. INTRODUCTION

Fish and crustaceans are highly perishable, limiting their distribution as a fresh, unfrozen product to markets within a few hundred kilometres of landing. Various methods are used to preserve fish, such as freezing, drying, salting, smoking and pickling. Most fish products are frozen, although some quality losses may occur with this process. Canning is limited to a few species such as salmon, tuna and sardine.

The reasons for spoilage of fish and crustaceans, such as shrimp during postmortem storage, include autolytic enzymes, loss of moisture and nutrients as 'drip', and bacterial action. The chemical makeup of seafoods, e.g., high post-rigor pH, high levels of low molecular weight nitrogenous materials and high water content, is the predominant factor promoting growth of spoilage bacteria. Endogenous autolytic enzymes, e.g., proteases, compound the problem by degrading tissue, resulting in the loss of characteristic texture, and by providing more nutrients for bacterial growth. In addition, combined actions of autolytic enzymes and bacteria result in the formation of volatile odorous compounds found in spoiled products.

Refrigeration delays spoilage by slowing down the growth of bacteria and the actions of autolytic enzymes. Fish and crustaceans harvested from cold regions contain enzymes active even at refrigeration temperature and their microflora is dominated by organisms capable of spoilage at low temperatures. Therefore, the preservative effect of refrigerated storage for these species is also limited.

Freezing effectively stops the actions of most bacteria and enzymes; however, it does not have any significant lethal effect on microorganisms. Any pathogenic bacteria inadvertently contaminating the product during handling are likely to survive freezing and storage.

Since ionizing radiation is capable of inactivating bacteria without an appreciable rise in temperature, the process is especially suited to the extension of the shelf life of fresh fish products and to the control of pathogenic organisms in frozen products. As a result, irradiation of fish and crustaceans has received considerable attention in the past 30 years (Nickerson et al. 1983; Licciardello and Ronsivalli, 1982). These studies have resulted in various potential applications of irradiation of fishery products as shown in Table 1. Each application has particular objectives and requires a specific range of radiation doses.

For commercially sterile seafood products intended for ambient temperature storage, a very high dose is required and the irradiation has to be carried out at -20 to -40°C to avoid radiation-induced off odor, thus making the process less economical than the conventional canning. However, radiation processing is highly attractive for the extension of shelf life of high value fresh products such as shrimp, cod fillet and for the decontamination (radicidation) of frozen shrimp, cod, haddock, etc., with respect to non-sporeforming pathogenic bacteria.

Extension of refrigerated shelf life through the elimination of most of the radiation-sensitive population of spoilage organisms requires relatively small doses and there is usually no radiation-induced flavor defect. However, radicidation requires relatively high doses and irradiation is usually carried out in the frozen state to avoid any flavor defects. The product is stored and shipped frozen.

Shrimp is one of the high-value fishery products. World catch of shrimp and prawns in 1976 and 1977 was 1.414 and 1.446 million metric tons respectively (Food and Agriculture Organization, 1979). Canadian harvests in these two years were 8.5 and 9.4 thousand metric tons, respectively.

From a nutritional point of view, shrimp does not make any significant contribution to the Canadian diet; per capita shellfish consumption here is 1.07 kg/a (Food and Agriculture Organization, 1979). Nonetheless it is a valuable product since it adds to the variety of the Canadian diet. Per capita seafood consumption in other countries, i.e., Korea, U.S.S.R., Norway and Japan is much higher than in Canada (Kumta and Sreenivasan, 1970). Shrimp will likely make a substantial contribution to the nutritional needs in these, as well as in the developing countries, especially in the coastal areas of harvest.

Shrimp and prawns are important in both national and international trade. To the developing countries the export of shrimp and other seafoods is a significant source of foreign exchange (Kumta and Sreenivasan, 1970). Contamination of frozen shrimp with pathogenic organisms and consequent failure to meet the bacteriological specifications of importing countries leads to substantial loss of products (Kumta and Sreenivasan, 1970; Kasemsarnt and Rattagool, 1970; Nouchpramool et al., 1983) and restricts trade. As shown in Table 2, Canada imported 11.83 thousand metric tons of frozen shrimp in 1986/87 and a substantial fraction (7.4%) of this import was rejected because of microbiological and other reasons (Fisheries and Oceans, 1987). Low-dose irradiation is a potential solution to such losses; however, acceptance of the process by the regulatory agencies is required to take advantage of this technology.

This report reviews the information available in the literature on the nutritional aspects of irradiated shrimp and related foods of aquatic origin.

2. NUTRIENTS IN SHRIMP - A GENERAL OVERVIEW

2.1 PROXIMATE COMPOSITION OF SHRIMP

This section deals with the influence of natural factors on the nutritional composition of shrimp. Many species of crustaceans are called shrimp or prawn; they vary in size from 1.5 to 30 cm in length. The larger ones usually command higher price. The yield of edible portion and the nutrient composition vary from species to species (Table 3) and between individuals of the same species (Shaikhmahmud and Magar, 1957, 1961;

Gallagher and Brown, 1975; Johnson et al., 1983; Chanmugam et al., 1983; Dabrowski et al., 1969).

As in any other muscle food, water is the main component of shrimp and prawns, ranging from 67.5 to 80.6% of the total edible portion by weight. Most of the solid is protein varying from 60.1 to 89.4% of the total solid, with the exception of the Acetes indicus prawn having a protein content of only 44.2%.

The fat content (1.5 to 5.0%) of Indian shrimp and prawns tends to be somewhat higher than that of brown shrimp (P. aztecus, 1.32%) from the Gulf of Mexico (not shown in Table 3) reported by Chanmugam et al. (1983). The authors also reported the fat content of a freshwater species of prawn (Machrobrachium rosenbergii) to be about three times that of the brown shrimp.

Carbohydrates make up a small component of shrimp meat. Gallagher and Brown (1975) reported the fibre content of San Francisco Bay brine shrimp (Artemia salina) to be 3.5% (not shown in Table 3). The glycogen contents of the Indian species listed in Table 3 varied from 213 to 460 mg/100 g dry matter. Glycogen content can vary depending on the physiological state of the shrimp before processing; physical exhaustion due to struggle during harvest depletes the glycogen levels in seafoods.

Shrimp and prawns are rich in minerals, particularly Ca and P, but do not appear to be rich sources of vitamins. Levels of vitamin A in shrimp have been variously reported as 25 IU (Osborne and Voogt, 1978) and 73.3 IU (Gordon and Martin, 1982) per 100 g edible portion of shrimp. However, a much higher level of vitamin A (6,650 IU/g) was reported for San Francisco Bay brine shrimp by Gallagher and Brown (1975). This figure is possibly an error although the difference may be due to the particular shrimp species used in the reports cited above.

2.2 AMINO ACID COMPOSITION OF SHRIMP

Certain amounts of free amino acids occurring in shrimp and prawns (Dabrowski et al., 1969) change during processing and storage. Although free amino acids form only a small fraction of the total amino acids, they make a significant contribution towards shrimp flavor and are subject to change during processing and storage.

Total amino acid composition varies from species to species (Srinivas et al., 1974; Yeh and Hau, 1988; Dabrowski et al., 1969; Shewbart et al., 1972; Galagher and Brown, 1975). Nonetheless, some generalizations can be made about the amino acid pattern. Tryptophan data, where available, show that this essential amino acid is present in very small quantities in all of the shrimp species (Table 4). Cysteine and histidine contents are also low in some of the species. However, when compared with standard reference proteins, i.e., casein and egg albumin, amino acid composition of brine shrimp compares well (Gallagher and Brown, 1975). Also when compared with egg albumin, shrimp proteins contain less methionine (Tables 4 and 5).

2.3 NUTRITIONAL QUALITY OF SHRIMP LIPIDS

Like other muscle foods shrimp lipids contain cholesterol. However, lipids from shrimp and other lean seafoods contain a higher proportion of phospholipids and polyunsaturated fatty acids than do lipids from land animals. Polyunsaturated fatty acids in the diet are believed to reduce the risk of atherosclerosis. Some polyunsaturated fatty acids are termed essential fatty acids because our metabolic system is unable to synthesize them. These essential fatty acids and phospholipids are essential for the structural integrity and function of cell membranes. Table 6 shows the composition of various types of lipids in five different species of Indian prawns, and Table 7 shows the total fatty acid composition of lipids extracted from those species.

3. EFFECTS OF RADIATION ON FOOD AND FOOD COMPONENTS - A GENERAL OVERVIEW

Radiation affects food in two ways: there is a direct impact of radiation and a secondary effect due to interactions of the products formed as a result of direct impact. When ionizing radiation strikes an atom or a compound, the absorbed energy leads to the formation of ion pairs and radicals, which are usually unstable and highly reactive. Such ion pairs and radicals are also produced by other processes. In foods containing no liquid (such as frozen or dry foods) the movements of the reactive species formed as a result of direct hit are restricted; therefore, the indirect effect is insignificant.

Factors that influence the radiation-induced changes in food-components include dose and dose rate of radiation, concentrations of the individual food components, presence of oxygen and temperature. Much of the present knowledge of the radiation chemistry of foods evolved from work on model systems involving the irradiation of pure substances, e.g., amino acids, proteins, fatty acids, triglycerides, etc. (Urbain, 1986a, 1986b; Simic, 1983; Nawar, 1983; and Taub, 1983). It has been found that these components are sensitive in simple solutions, but rather stable when irradiated as complex food components. "The most striking difference between the radiation chemistry of pure substances and of complex food stuffs is quantitative rather than qualitative" (Diehl, 1983). Therefore, irradiation at a given dose will result in the major component absorbing most of the energy, thus providing protection to the minor components.

Since shrimp is primarily a protein food, any radiation impact on the nutritional value of proteins deserves the broadest consideration. Irradiation leads to degradation of peptide bonds and intermolecular cross-linking. Heating also causes cross-linking of proteins (Cheftel et al., 1985) and enzymatic digestion of proteins involves peptide bond degradation. Secondary and tertiary structures of proteins are also changed as a result of irradiation (Urbain, 1986b). These changes are not important from a nutritional point of view, however. The most important consideration is the retention of the constituent amino acids after irradiation.

Studies show only minor changes in amino acid composition even at the high radiation doses used to process some seafoods (Brooke et al., 1964; 1966; Proctor and Bhatia, 1950).

4. NUTRITIONAL ADEQUACY OF IRRADIATED SHRIMP

4.1 EFFECTS OF RADIATION ON PROXIMATE COMPOSITION OF SHRIMP

Irradiation does not cause any detectable change in the proximate composition of shrimp. For example, Reber and Bert (1968) observed that the proximate composition (protein, fat, fibre and ash) of irradiated (1.5 or 3.0 kGy) shrimp was practically the same as that of the frozen control after 30 d of ice storage, followed by freeze-dehydration. Slightly lower protein levels were found in the samples irradiated at 1.5 and 3.0 kGy. However, unirradiated cooked samples had lower protein content than the samples irradiated at 1.5 kGy and much higher ash content than any of the other samples.

Proximate composition of Indian shrimp under various processing conditions including irradiation was reported by Srinivas et al. (1974) as shown in Table 8. Shrimp meat was blanched, partially dehydrated in hot air (55 to 60°C) to 40% moisture content prior to irradiation at 2.5 to 3.2 kGy at ambient temperature. The protein content of the partially dehydrated shrimp was about 7% lower than that of the fresh shrimp. However, the sum of the percentages of all the constituents of partially dehydrated shrimp falls short of 100%, and the authors do not explain this discrepancy. Nonetheless, comparison of the data on partially dehydrated shrimp with those of irradiated shrimp show that there was practically no further reduction in the protein content as a result of irradiation. The levels of the other constituents listed in the table were also not appreciably reduced as a result of irradiation.

Therefore, it appears that irradiation of shrimp, up to a dose of about 3.2 kGy, has no significant effect on the levels of protein, fat and the minerals in shrimp.

4.2 EFFECTS OF RADIATION ON AMINO ACID COMPOSITION OF SHRIMP

Srinivas et al. (1974) observed that irradiation (2.5 to 3.2 kGy) did not change the total amino acid composition of partially dehydrated shrimp, whereas air-drying and canning led to some loss of certain essential amino acids such as methionine, lysine and tryptophan as shown in Table 9. However, an increase of up to 40% in the levels of some of the free amino acids was observed after irradiation as shown in Table 10.

Vervack et al. (1977) compared the total amino acid composition of Belgian shrimp (*Crangon vulgaris*) processed by a variety of methods, namely freezing, canning and irradiation. They observed that the mean percentages of threonine, glutamic acid, methionine, isoleucine, leucine, and available lysine in the irradiated samples were lower (6.7 to 23.5%)

than in the fresh shrimp samples. The percentages of aspartic acid and proline were higher in the irradiated than in the fresh samples by 35 and 14%, respectively. Similar changes in some amino acids were also observed in frozen and canned samples. No information was provided as to the conditions used in processing the shrimp, e.g., radiation dose, temperature, etc., which are important factors in the nutritional evaluation of a process. Therefore, no meaningful conclusion can be drawn.

Yeh and Hau (1988) found only slight changes in the amino acid composition of frozen grass shrimp (Penaeus monodon) when irradiated at 2.5, 10.0, 50.0 and 100.0 kGy at -10°C. The percentage of valine in the irradiated samples was higher than in the unirradiated sample as shown in Table 11. The percentages of cysteine, cystine and tryptophan were not reported by the authors, and no explanation on the observed increase in the level of valine in the irradiated shrimp was given.

Tryptophan, a limiting amino acid in shrimp, is also one of the essential amino acids for humans. Antunes and Novak (1978) examined the tryptophan-protein ratio (g tryptophan/100 g protein) in shrimp (P. setiferous) irradiated at 2, 10 and 45 kGy at -18.9, 3.9 and 26.7°C. Both fresh and freeze-dried shrimp were irradiated. The decreases in the tryptophan-protein ratios due to radiation were very small (1.5 to 1.86%).

Available lysine content is also an important quality index for processed foods containing proteins. Lysine is one of the essential amino acids, and irradiation as well as heat treatment cause changes in available lysine content in some protein foods (Ford and Salter, 1966; Vervack et al., 1977). Available lysine determined chemically was not affected by irradiation of partially dehydrated (40% moisture) shrimp as shown in Table 12, (Srinivas et al., 1974); whereas drying in hot air (65 to 70°C) resulted in loss of available lysine by as much as 15%.

In vitro enzymic digestibility of processed shrimp is also considered an important quality index for processed foods which tests release of α-amino nitrogen as a result of peptide bond cleavage. Srinivas et al. (1974) observed a slight increase in the in vitro enzyme digestibility of partially dehydrated shrimp after irradiation (Figure 1).

4.3 EFFECTS OF RADIATION ON FATTY ACID COMPOSITION AND CHOLESTEROL CONTENT OF SHRIMP

Effects of radiation on lipids have been widely discussed (Vajdi et al., 1982; Nawar, 1978; Urbain, 1986a). Some fatty acids were degraded as a result of irradiation of cod and haddock fillets, especially at high doses (28 and 56 kGy) (Ronsivalli et al., 1971; King et al., 1972). Novak and Liuzzo (1964) analyzed the free fatty acid composition of irradiated (1.5 kGy) and unirradiated shrimp and observed only slight changes in the percentages of certain long-chain fatty acids in the irradiated shrimp compared with the unirradiated shrimp (Table 13). The analysis by Novak and Liuzzo involved hydrogenation of the fatty acids before gas chromatography and therefore did not show the unsaturated fatty acids except $C_{22:1}$. Fatty acid composition of total lipids extracted from unirradiated and irradiated shrimp (1.5 or 8 kGy) was reported by Ismail (1971). As shown in Table 14, shrimp irradiated at 1.5 kGy initially had a lower percentage of palmitic acid that increased during ice-storage; however, the percentage of palmitic acid in the sample irradiated at 8 kGy was similar to that of the unirradiated control. Also the percentages of some of the unsaturated fatty acids were somewhat higher in the irradiated samples compared with the unirradiated samples. Ismail did not specify the sample size or units for the fatty acid values shown in the table.

Yeh and Hau (1988) irradiated frozen, uncooked headless grass shrimp (*P. monodon*) at doses of 2.5, 5.0, 10.0, 50.0 and 100.0 kGy and analysed the fatty acid composition. The authors reported only some of the long-chain fatty acids usually occurring in shrimp (Table 15). At 2.5 kGy, the percentage of stearic ($C_{18:0}$) and palmitic ($C_{16:0}$) acids dropped by 11.5 and 1.8% respectively, whereas those of oleic ($C_{18:1}$) and linoleic ($C_{18:2}$) acids increased by 8.3 and 4.3%, respectively. Changes in fatty acid composition also occurred at high doses. Thus some decrease in the percentage of linoleic acid ($C_{18:2}$) occurred in samples irradiated at 100.0 kGy and the percentage of palmitic and stearic acids rose slightly. However, the changes in the fatty acid composition were not proportional to radiation dose and could be due to experimental variations.

The effect of irradiation of shrimp on the cholesterol level was examined by Novak and Liuzzo (1964). As shown in Table 16, the mean level of cholesterol in the irradiated shrimp was not significantly higher than that of the unirradiated shrimp. Cholesterol in shrimp appears to be stable at the 10 kGy dose used in the study.

Although reports on the effects of low-dose irradiation on fatty acid composition of shrimp are not quite comprehensive, there are enough indications that the overall change in the cholesterol and fatty acid composition is minor.

4.4 EFFECTS OF RADIATION ON CARBOHYDRATES IN SHRIMP

Carbohydrates form a minor component of shrimp meat. Shaikhmahmud and Magar (1961) reported the glycogen content to vary from 213 to 435 mg/100 g muscle calculated on dry basis. Fibre content of San Francisco Bay brine shrimp (*Artemia salina*) was reported as 3.5% on a dry weight basis (Gallagher and Brown, 1975). Information on the analysis of carbohydrates in irradiated shrimp is not available in the literature. Reports on radiation effects on pure carbohydrates, as well as carbohydrate-rich foods such as starch, include cleavage of glycosidic bonds, formation of low molecular weight acids, aldehydes and sugars (Dauphin and Saint-Lèbe, 1977). However, in high-protein low-carbohydrate foods, such as oysters irradiated at doses up to 4 kGy and stored in ice for up to 20 d, no significant increase in soluble sugars or decrease in glycogen content was observed (Liuzzo et al., 1970). This is consistent with the view that other components in the shellfish provided radiation protection to the minor components. It seems reasonable to conclude that shrimp carbohydrates are probably not appreciably changed by low-dose irradiation.

4.5 EFFECTS OF RADIATION ON VITAMIN CONTENT IN SHRIMP

Some vitamins are highly sensitive to ionizing radiation and this sensitivity depends on whether the vitamin is in pure solution or present as a minor component of food. For example, vitamin C is easily destroyed when irradiated as a simple aqueous solution, but the vitamin is quite stable in irradiated fruits and vegetables. Radiation-induced loss of thiamine is substantial in some foods; however, irradiation in the frozen state improves retention (Wilson, 1959). Other water-soluble vitamins, namely niacin, vitamins B_6 and B_{12}, are only moderately affected by irradiation of foods (Urbain, 1986b).

Yeh and Hau (1988) measured the retention of thiamine and niacin in headless grass shrimp (P. monodon) irradiated at various doses at -10°C. The loss of thiamine increased almost linearly with dose up to 10 kGy; above that dose additional loss was low. Niacin loss also showed a linear increase up to 25 kGy, and the loss at 50 kGy was about the same as at 25 kGy. Up to 4.5 kGy niacin loss appeared to be very small (1.6%), but thiamine loss was substantial (about 20%) as shown in Figure 2a and 2b. However, Srinivas and co-workers (Srinivas et al., 1974; Aravindakshan et al., 1973) reported an even higher loss of thiamine (35.5%), when partially dehydrated shrimp was irradiated at 2.5 to 3.2 kGy at ambient temperature (Table 17). Loss of other B vitamins was between 8 and 18%; however, blanching and partial dehydration at 55 to 60°C prior to irradiation led to 36 to 59% losses of some B vitamins. Radiation-induced losses were minimized by irradiation in vacuum or in nitrogen atmosphere. It should be noted that losses due to drying in the air at 65 to 70°C as well as canning (40 min at 70 kPa) caused higher vitamin losses than those due to irradiation. Post-process storage also caused loss of some vitamins as shown in Table 18. After three months storage at ambient temperature, losses in thiamine and riboflavin were similar to products processed by other various methods. Again, losses were less in samples processed and stored in vacuum or nitrogen atmosphere than in the presence of air.

Radiation-damage of some B vitamins in clam meat was examined by Brooke et al. (1964). There was no significant change in the levels of thiamine, riboflavin and niacin when clam meat was treated with irradiation at doses up to 45 kGy followed by steaming for 15 min. Pyridoxine level decreased moderately when the clam meat was irradiated at 4.5 and 45 kGy and stored at 0.6°C for 30 days. Heat processing at 115.6°C for 20 min slightly decreased the level of niacin and vitamin B_{12}.

Radiation sensitivity of vitamin A differs widely from one food to another. Kung et al.(1953) reported 55% loss of vitamin A in butter irradiated at 2.4 kGy, whereas margarine lost only 9%. To our knowledge, the effect of radiation on vitamin A in shrimp is not known; however, loss of carotenoids in shrimp irradiated at low doses is not significant (Snauwaert et al., 1973; Kumta and Sreenivasan, 1966). Some carotenoids are precursors of vitamin A (Simpson, 1982).

Therefore, the loss of some vitamins such as thiamine occurs as a result of irradiation, but the losses are generally low compared with those due to some of the other processes. Loss of vitamins in irradiated shrimp can be minimized by adequate packaging and temperature control.

5. WHOLESOMENESS OF IRRADIATED SHRIMP

So far, nutritional adequacy of irradiated shrimp has been considered on the basis of chemical tests. Although chemical tests are generally preferable from the viewpoints of rapidity, reproducibility and cost, such tests do not necessarily reflect the bioavailability of the nutrients. The component in question may not be accessible to digestive enzymes or the metabolic function of one nutrient may moderate those of others. Therefore, biological tests have been traditionally considered as the ultimate tests for the wholesomeness of foods from nutritional and other points of view. Both animal feeding and microbiological assays are used to determine wholesomeness.

Srinivas et al. (1975) used both microbiological and animal feeding methods to evaluate shrimp processed by various methods including irradiation at 2.5 to 3.2 kGy. For microbiological assay, the test material was extracted with ether and suspended in appropriate media containing other nutrients required for maximum growth. Protein content of the medium was 0.3 mg N/mL. Tetrahymena pyriformis culture was grown aerobically at 25°C for 4 d and cell counts determined. Casein was used as a reference protein for comparison. As shown in Table 19, growth was better with shrimp protein than with casein. The final cell population was almost the same for shrimp unirradiated or irradiated under various conditions. Ambient temperature storage of unirradiated and irradiated shrimp had no appreciable effect on the protein quality.

Srinivas et al. (1975) also assessed the food efficiency ratio of irradiated shrimp. Young rats were fed irradiated shrimp for eight weeks rather than four weeks as in the protein efficiency test; the diets had the same formulations as well, except that the percentage of shrimp powder was increased to 25% of the diet and the level of starch was correspondingly reduced. Results of the tests were similar to those of protein efficiency ratio tests. Food efficiency ratio, defined as the ratio of weight gain to food intake for irradiated shrimp, was not significantly different from that of the unirradiated shrimp.

To assess protein efficiency based on animal feeding, young albino rats of both sexes were fed formulations containing 10% protein from the test material, namely shrimp powder or casein, for four weeks, (see Table 20). As with T. pyriformis assay, shrimp was found to have higher protein efficiency than casein and this was not appreciably changed by radiation. Similar observations were made by Reber and Bert (1968); the protein efficiency ratio of shrimp was higher than that of casein and the protein efficiency ratios of irradiated shrimp samples were not significantly different from that of unirradiated shrimp.

Multigeneration feeding tests on irradiated shrimp and additional seafoods have been reported by Miller et al., 1958). The primary objective of such studies was to test any possible toxic effects of irradiation. Dogs and rats were fed diets containing up to 70% seafoods irradiated at 28 or 56 kGy with gamma rays. Feeding continued for up to three years and observations included gross food utilization, growth, hematology, reproduction, and lactation through at least three generations in the rats and one generation in dogs. No evidence was noted of any abnormal responses that could be attributed to irradiated foods.

For 90 days, van Logten et al. (1972) fed seven groups of rats (each containing 10 males and 10 females) either a standard diet or formulations containing unirradiated or irradiated (1.5 or 3.0 kGy) shrimps representing up to 28% of their diets on a dry basis. Measurements were made on growth, food intake, blood composition, serum glutamic-pyruvic transaminase, weights of organs and histopathology. No adverse effects on these parameters were observed that could be attributed to the ingestion of irradiated foods. However, the relative weights of liver, kidneys and ovaries of the animals were affected when the diet contained 28% shrimp regardless of whether the shrimp was irradiated or not. Similar observations were made by Aravindakshan et al. (1973). The shrimp was blanched and partially dehydrated to 40% moisture prior to irradiation at 2.5 kGy at ambient temperature. When rats of both sexes were fed a diet containing 25% of shrimp powder for up to four generations, no adverse effects were observed on growth, reproduction, lactation, longevity, organ histology or other biochemical characteristics.

Therefore, all the reports reviewed seem to indicate that irradiation has no significant effect on the nutritional value of shrimp. No adverse effects were found in the test animals that might indicate any toxic effects.

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TABLE 1

RADIATION DOSES REQUIRED FOR VARIOUS APPLICATIONS OF THE RADIATION PRESERVATION OF SEAFOODS[1]

Process	Objective	Dose (kGy)
Insect disinfestation	Control of insects	1.0
Radurization	Extension of shelf life	0.75 - 2.5
Radicidation	Inactivation of non-sporeforming pathogens	2.50 - 10.0
Radappertization	Commercial sterility	30.0 - 40.0

[1] From Giddings (1984)

TABLE 2

1986/87 ANNUAL INSPECTION REPORT ON FROZEN SHRIMP AND PRAWNS IMPORTED BY CANADA[1]

COUNTRY OF ORIGIN	IMPORTED			INSPECTED			REJECTED		
	Quantity Lots	Quantity Wt. (kg)	% Country Import[a]	Quantity Lots	Quantity Wt. (kg)	% Inspected of Imported	Quantity Lots	Quantity Wt. (kg)	% Rejected of Imported
ARGENTINA	5	7394	0	4	6146	83	0	0	0
AUSTRALIA	18	18323	0	9	9733	53	1	1280	7
BANGLADESH	16	38686	0	15	36970	96	6	8238	21
BELGIUM	3	689	0	0	0	0	0	0	0
BRAZIL	11	24318	0	11	24318	100	3	5477	23
BRITISH WEST INDIES	1	363	0	0	0	0	0	0	0
BURMA	56	358056	3	43	315296	88	4	26368	7
CHILE	20	38964	0	9	10392	27	1	1361	3
CHINA	618	1774161	15	289	831077	47	70	208329	12
COSTA RICA	56	38722	0	14	5011	13	0	0	0
CUBA	18	186569	2	11	84467	45	0	0	0
DENMARK	10	114710	1	3	73555	64	0	0	0
EDUADOR	390	794751	7	63	135191	19	7	4785	1
FRANCE	1	70	0	0	0	0	0	0	0
GREAT BRITAIN	3	19598	0	3	19598	100	1	41	0
GREENLAND	12	1957	0	0	0	0	0	0	0
GUYANA	4	2223	0	2	1906	86	0	0	0
HONG KONG	248	719590	6	143	265891	37	26	60388	8
ICELAND	10	34319	0	1	1134	3	0	0	0
INDIA	26	41496	0	26	41496	100	19	18609	45
INDONESIA	6	18648	0	6	18648	100	2	1554	8
IRAN	1	200	0	1	200	100	0	0	0
JAPAN	11	557680	5	1	288	0	0	0	0
MACAU	35	730973	6	22	58565	8	1	1089	0
MALAYSIA	7	6190	0	7	6190	100	5	5046	82

[a] Percent of all seafoods imported from respective country

[1] Fisheries and Oceans (1987)

continued ...

TABLE 2 (concluded)

COUNTRY OF ORIGIN	IMPORTED Quantity Lots	 Quantity Wt. (kg)	 % Country Import[a]	INSPECTED Quantity Lots	 Quantity Wt. (kg)	 % Inspected of Imported	REJECTED Quantity Lots	 Quantity Wt. (kg)	 % Rejected of Imported
MEXICO	137	148794	1	46	65077	44	12	10082	7
MISC.	2	9062	0	0	0	0	0	0	0
NICARAGUA	38	331775	3	37	255729	77	29	203898	61
NIGERIA	6	11797	0	5	8849	75	2	1361	12
NORWAY	13	87478	1	5	30718	35	0	0	0
PAKISTAN	4	4853	0	4	4853	100	0	0	0
PANAMA	6	6009	0	2	3856	64	1	1361	23
PERU	15	24030	0	10	19627	82	1	1066	4
PHILIPPINES	56	73876	1	36	48534	66	3	2018	3
SINGAPORE	14	6716	0	13	4757	71	3	722	11
SRI LANKA	1	648	0	1	648	100	0	0	0
TAIWAN	67	223154	2	34	57660	26	5	10214	5
THAILAND	154	184996	2	68	66274	36	27	24749	13
TRINIDAD	7	1153	0	0	0	0	0	0	0
TUNISIA	2	11753	0	1	1320	11	0	0	0
UNITED KINGDOM	106	251110	2	10	51174	20	1	5661	2
UNITED STATES	2968	4527719	37	483	970465	21	104	181913	4
VENEZUELA	14	53090	0	13	51729	97	9	46131	87
VIETNAM	105	347801	3	46	170948	49	19	60120	17
TOTAL:	5301	11827244		1497	3769090		362	891861	
PERCENT:	of all imported: 24.7			inspected of imported: 31.7 of all inspected: 18.1			rejected of imported: 7.4 rejected of inspected: 23.4		

[a] Percent of all seafoods imported from respective country

[1] Fisheries and Oceans (1986/87)

TABLE 3

COMPOSITION OF SOME SHRIMPS AND PRAWNS

NUTRIENTS	(Units)	AMOUNT in 100 grams, edible portion							
		Peneus penicillatus[1]	*Metapeneus affinis*[1]	*Parapenopsis stylifera*[1]	*Hippolysmata ensirostris*[1]	*Leander tenuipes*[1]	*P. carimatus*[2]	*P. indicus*[2]	*M. monoceros*[2]
PROXIMATE									
Water	g	67.5	75.8	77.5	80.6	80.5	67.5	70.1	77.2
Protein (N x 6.25)*	g	66.1	60.7	59.2	51.3	51.3	70.3	65.8	60.1
Total Lipid (fat)*	g	5.3	4.4	4.1	2.9	3.0	5.1	4.9	4.5
Glycogen*	mg	215.0	208.0	225.0	460.0	450.0	315.0	318.0	318.0
Lactic Acid*	mg	160.8	180.6	140.4	70.8	80.2	175.3	175.4	130.6
Ash*	g						9.5	9.81	10.5
MINERALS*									
Calcium	mg	527.0	513.0	519.0	465.0	460.0	470.0	510.0	535.0
Iron	mg	35.8	38.0	42.3	49.4	53.6	27.6	32.7	37.3
Phosphorus	mg	898.0	828.0	755.0	693.0	653.0	912.0	930.0	850.0
Molybdenum	mg	0.1	0.1	0.3	0.2	0.2	0.1	0.1	0.2
Copper	mg	40.4	37.3	45.46	43.46	43.45	22.5	29.7	40.3
VITAMINS*									
Ascorbic Acid	mg	4.2	3.1	2.5	10.6	10.6	Trace	4.1	5.0
Thiamin	μg	11.0	14.0	12.0	9.0	7.0	15.0	16.0	9.0
Riboflavin	mg	2.0	1.9	1.6	1.6	1.7	0.31	0.320	0.18
Niacin	mg	4.8	4.6	4.3	2.4	2.1	4.6	4.50	4.3

* On dry weight basis

[1] Shaikhmahmud and Magar (1957)

[2] Shaikhmahmud and Magar (1961)

[3] Dabrowski et al. (1969)

continued ...

TABLE 3 (concluded)

NUTRIENTS (Units)	AMOUNT in 100 grams, edible portion					
	M. brevicornis[2]	*P. sculptilis*[2]	*P. maxillipedo*[2]	*Solenocera indicus*[2]	*Acetes indicus*[2]	*Parapenaeus spp.*[3]
PROXIMATE						
Water	78.1	79.2	68.3	80.1	80.00	76.74
Protein (N x 6.25)*	61.3	60.1	65.7	70.2	44.2	89.4
Total Lipid (fat)*	4.8	3.5	4.6	3.1	1.5	3.6
Glycogen*	213.0	218.0	223.0	415.0	435.0	
Lactic Acid*	170.8	156.8	170.8	180.5	110.5	
Ash*	11.5	9.8	9.6	9.1	22.5	6.9
MINERALS*						
Calcium	525.0	515.0	510.0	495.0	825.0	
Iron	36.4	42.6	43.1	37.2	50.5	
Phosphorus	860.0	760.0	850.0	715.0	1975.0	1980.0
Molybdenum	0.2	0.3	0.2	0.3	0.4	
Copper	33.0	36.1	34.8	38.1	45.8	
VITAMINS*						
Ascorbic Acid	3.2	2.8	2.6	Trace	4.8	
Thiamin	13.0	11.0	13.0	8.0	14.0	
Riboflavin	0.17	0.16	0.18	0.15	0.015	
Niacin	3.9	3.8	4.6	3.9	2.1	

* On dry weight basis

[1] Shaikhmahmud and Magar (1957)

[2] Shaikhmahmud and Magar (1961)

[3] Dabrowski et al. (1969)

TABLE 4

TOTAL AMINO ACID COMPOSITION[a] OF VARIOUS SPECIES OF UNIRRADIATED SHRIMPS

Amino Acid	*P. indicus* *M. affinis*[1]	*Penaeus monodon*[2]	*Parapenaeus spp*[3]	*Penaeus aztecus*[4]	*Artemis salina*[5]
Aspartic acid	11.02	10.4	10.90	10.9	9.2
Threonine	4.00	3.4	3.63	5.3	4.6
Serine	4.04	2.9	3.35	5.0	4.8
Glutamic acid	20.12	17.4	14.5	13.4	14.2
Proline	2.18	5.2	3.99	3.1	5.2
Hydroxyproline				0.3	
Glycine	4.68	6.8	3.65	5.7	5.3
Alanine	6.04	6.3	5.60	5.6	6.9
½ Cystine	0.65		1.37	3.3	2.2
Valine	4.69	3.1	3.39	5.0	5.4
Methionine	2.80	2.8	2.36	3.4	2.7
Isoleucine	4.77	4.7	13.67[b]	4.4	5.3
Leucine	8.55	8.3		9.6	8.0
Tyrosine	3.24	3.7	3.95	2.7	4.5
Phenylalanine	4.78	4.6	4.05	5.6	4.7
Lysine	8.28	9.1	8.76	6.0	7.6
Histidine	1.82	2.2	3.02	3.1	1.8
Arginine	7.29	9.3	12.87	5.1	6.5
Tryptophan	1.56		0.98	1.0	1.0

[a] Expressed as g/100 g protein except for *P. indicus*/*Metapenaeus affinis* for which units are not specified by the author

[b] Isoleucine plus leucine

[1] Srinivas et al. (1974); authors did not specify which of the two species this amino acid composition corresponds to

[2] Yeh and Hau (1988)

[3] Dabrowski et al. (1969)

[4] Shewbart et al. (1972)

[5] Gallagher and Brown (1975)

TABLE 5

AMINO ACID COMPOSITION OF BRINE SHRIMP, CASEIN AND EGG ALBUMIN (g/100 g OF PROTEIN)[1]

Amino Acid	Brine Shrimp	Casein	Egg Albumin
Leu	8.0	7.9	9.9
Ile	5.3	6.4	7.0
Lys	7.6	8.9	6.5
Thr	4.6	4.9	4.0
Trp	1.0	1.6	1.2
Val	5.4	6.3	8.8
Met	2.7	2.5	5.3
Phe	4.7	4.6	7.2
His	1.8	2.9	2.9
Arg	6.5		6.0
Ala	6.9		7.6
Asp	9.2	8.4	9.3
Cys	2.2	0.4	2.8
Glu	14.2	22.5	16.5
Gly	5.3	2.3	3.6
Pro	5.2	7.5	3.8
Ser	4.8	6.3	8.2
Tyr	4.5	8.1	4.1

[1] Gallagher and Brown (1975)

TABLE 6

LIPID COMPOSITION OF INDIAN PRAWNS[1]

	Metapenaeus monoceros[a]	*M. dobsoni*	*M. affinis*	*Penaeus indicus*	*Parapenaeopsis stylifera*
Total lipid (g/100 g wet tissues)	0.7	1.2	1.0	1.0	1.0
Phospholipids (% of total lipids)	49	62	65	62	70
Triglycerides (% of total lipids)	9	11	14.5	14	10.5
Unsaponifiable matter (% of total lipids)	40.0	21.2	21.5	24.0	22.1
Cholesterol (% of unsaponifiable matter)	32	67	62	49	59

TABLE 7

FATTY ACIDS AS PERCENT WEIGHT OF TOTAL LIPIDS IN PRAWNS[1]

Fatty Acids	*Metapenaeus monoceros*[a]	*M. dobsoni*	*M. affinis*	*Penaeus indicus*	*Parapenaeopsis stylifera*
Saturated					
12:0			0.5		
13:0		0.4	0.2	0.2	0.5
14:0	3.0	1.9	3.8	2.5	1.5
15:0	1.7	0.7	1.2	0.6	1.0
16:0	32.5	24.3	20.6	26.3	22.3
17:0	2.4	2.2	2.7	0.9	1.4
18:0	9.8	13.1	14.2	12.1	11.7
Total	49.4	42.6	43.2	42.6	38.4
Monounsaturated					
14:1				1.8	
15:1		0.8			0.9
16:1	6.7	9.3	8.6	8.0	8.1
17:1	Trace	0.9	1.8	0.4	1.2
18:1	12.1	11.2	15.2	11.5	13.1
20:1	0.5	0.7	1.0	0.9	0.7
22:1	0.8			0.1	
24:1			0.6		
Total	20.1	22.9	27.2	23.7	24.0
Polyunsaturated					
18:2	2.8	2.2	3.0	1.8	2.0
18:3	2.7	0.5	1.3	0.3	0.6
18:4	0.5	0.9	0.4	1.2	1.0
20:3			0.6		
20:4	6.9	4.9	0.2	6.5	3.5
20:5	10.6	15.1	10.5	14.2	13.3
22:4	0.3	0.7			0.5
22:5	0.5	1.1	0.8	1.5	2.0
22:6	6.2	8.9	12.8	8.2	14.7
Total	30.5	34.3	29.6	33.7	37.6

[a] Brackish water species

[1] Gopakumar and Nair (1975)

TABLE 8[1]

PROXIMATE COMPOSITION OF SHRIMP PROCESSED BY IRRADIATION AND OTHER METHODS[a]

Constituents	Fresh	Freeze Dried	Air Dried	Canned	Dehydro-shrimp	Dehydro-irradiated Shrimp		
						Air	Vacuum	Nitrogen
Moisture (%)	86.8	2.5	2.8	75.0	40.2	41.0	40.5	40.0
Protein	88.9	89.5	88.9	83.6	81.9	81.5	80.9	82.0
Nonprotein nitrogen	0.45	0.5	0.7		0.4	0.5	0.45	0.5
Lipids	3.8	3.6	3.5	3.7	3.3	3.8	3.5	3.5
Ash	7.9	8.1	8.3	7.9	7.8	7.5	7.6	7.7
Ca	0.5	0.5	0.5	0.5	0.5	0.6	0.55	0.6
P	0.75	0.8	0.8	0.75	0.8	0.8	0.8	0.75

[a] Results, expressed on dry basis (% of total), are averages of triplicate analysis on three different batches of shrimp.

[1] Srinivas et al. (1974)

TABLE 9

TOTAL AMINO ACIDS IN SHRIMP PROCESSED BY IRRADIATION AND OTHER METHODS[1]

Amino Acid	Fresh	Freeze Dried	Air Dried	Canned	Dehydro-shrimp	Dehydro-Irradiated Shrimp[a]		
						Air	Vacuum	Nitrogen
g/16 g Nitrogen								
Aspartic acid	11.02	11.00	10.90	11.08	11.05	11.02	11.08	11.05
Threonine	4.00	3.98	3.98	3.94	4.02	4.00	4.02	4.06
Serine	4.04	4.02	4.00	4.05	3.98	3.88	3.82	3.88
Glutamic acid	20.12	20.45	21.60	20.80	20.14	21.25	20.02	21.06
Proline	2.18	2.24	2.09	2.19	2.28	2.26	2.28	2.30
Glycine	4.68	4.70	4.70	4.75	4.73	4.71	4.69	4.72
Alanine	6.04	6.01	6.05	6.02	6.02	5.88	5.86	5.79
½ Cystine	0.65	0.68	0.70	0.72	0.69	0.73	0.75	0.70
Valine	4.89	4.73	4.72	4.70	4.71	4.70	4.66	4.62
Methionine	2.80	2.81	2.58	2.65	2.79	2.74	2.78	2.76
Isoleucine	4.77	4.76	4.82	4.65	4.71	4.48	4.42	4.39
Leucine	8.55	8.53	8.32	8.38	8.23	7.97	7.88	7.85
Tyrosine	3.24	3.19	3.11	3.10	3.27	3.12	3.12	3.16
Phenylalanine	4.78	4.82	4.72	4.72	4.75	4.70	4.72	4.78
Lysine	8.28	8.23	7.62	7.67	8.23	8.39	8.41	8.44
Histidine	1.82	1.85	1.82	1.78	1.89	1.85	1.88	1.86
Arginine	7.29	7.20	7.08	7.11	8.42[b]	7.29	7.35	7.40
Tryptophan	1.56	1.58	1.45	1.40	1.56	1.54	1.56	1.55

[a] Irradiated at 2.5 to 3.2 kGy at ambient temperature

[b] Probably an error

[1] Srinivas et al. (1974)

TABLE 10[1]

FREE AMINO ACIDS IN PROCESSED SHRIMP[a]

Amino Acid	Fresh	Freeze Dried	Air Dried	Semi-Dried	Dehydro-Irradiated Shrimp		
					Air	Vacuum	Nitrogen
mg/g Nitrogen							
Aspartic acid	Traces	Traces	0.38	Traces	Traces	Traces	Traces
Threonine	0.55	0.59	1.13	0.09	0.14	0.15	0.13
Serine	0.35	0.38	0.80	0.11	0.14	0.13	0.15
Glutamic acid	0.79	0.88	1.80	0.30	0.39	0.41	0.38
Glycine	5.95	6.12	8.85	2.51	2.49	2.52	2.58
Alanine	1.81	1.94	4.10	1.02	1.15	1.08	1.12
Valine	0.55	0.60	1.28	0.30	0.32	0.38	0.39
Methionine	0.38	0.40	0.85	0.22	0.20	0.18	0.24
Isoleucine	0.44	0.46	0.98	0.21	0.25	0.26	0.21
Leucine	0.69	0.72	1.82	0.40	0.38	0.42	0.45
Tyrosine	0.68	0.63	1.10	0.50	0.48	0.53	0.56
Phenylalanine	0.49	0.41	1.18	0.42	0.34	0.36	0.40
Lysine	1.85	1.74	2.92	1.12	1.58	1.51	1.60
Histidine	Traces	Traces	Traces	Traces	Traces	Traces	Traces
Arginine	0.50	0.52	1.05	0.30	0.35	0.37	0.39
Total	15.03	15.39	28.24	7.55	8.21	8.30	8.60

[a] Values are mean of three independent determinations

[1] Srinivas et al. (1974)

TABLE 11

EFFECTS OF GAMMA IRRADIATION AT -10°C ON THE AMINO ACID COMPOSITION OF GRASS SHRIMP[1]

Amino Acid (weight percent)	Radiation Dose (kGy)				
	0.0	2.5	10.0	50.0	100.0
Lysine	9.1	8.9	8.7	8.8	8.9
Histidine	2.2	2.2	2.1	2.1	2.1
Arginine	9.3	9.0	9.7	9.3	9.1
Aspartic acid	10.4	10.3	9.9	10.0	10.1
Threonine	3.4	3.2	3.1	3.3	3.2
Serine	2.9	2.5	2.6	3.0	3.0
Glutamic acid	17.4	17.2	16.6	16.8	17.0
Proline	5.2	4.8	5.4	5.3	5.1
Glycine	6.8	6.7	7.2	7.0	6.6
Alanine	6.3	6.2	6.3	6.3	6.4
Valine	3.1	5.0	5.0	5.1	5.0
Methionine	2.8	2.2	2.5	2.3	2.6
Isoleucine	4.7	4.9	4.6	4.6	4.8
Leucine	8.3	8.2	7.9	8.0	8.3
Tyrosine	3.7	3.5	3.4	3.7	3.4
Phenylalanine	4.6	5.1	5.1	4.5	4.5

[1] Yeh and Hau (1988)

TABLE 12

AVAILABLE LYSINE CONTENTS OF PROCESSED SHRIMP[1]

Sample	Total Lysine	Available Lysine Content[a] Storage Period in Days 0	30	60	90
Freeze dried	8.23	7.86	7.77	7.71	7.62
Air dried	7.62	6.60	6.58	6.62	6.54
Canned	7.67	7.19	7.18	7.09	7.14
Dehydro-shrimp (40% moisture)	8.23	7.71	7.73		
Dehydro-shrimp, irradiated (2.5 kGy)					
in air	8.39	8.01	7.89	7.92	7.80
in vacuum	8.41	7.95	7.89	7.87	7.82
in nitrogen	8.44	8.00	7.96	7.88	7.80

[1] Srinivas et al. (1974)

[a] g/16 g nitrogen

TABLE 13

FREE FATTY ACIDS IN IRRADIATED AND UNIRRADIATED SHRIMP[1]

Short-chain fatty acids[a]

Compound (Fatty Acid)	Unirradiated Sample	Irradiated Sample (1.5 kGy)
C_1	0.0184	0.0086
C_2	0.0178	0.0189
C_3	0.8210	0.8431
C_4 (plus isoC_4)	1.315	1.3351
C_5 (plus isoC_5)	0.0072	0.0073
C_6	0.058	0.0745

Long-chain fatty acids[b]

C_{14}	0.0014	0.0016
C_{16}	0.0004	0.0004
C_{18}	0.0002	0.0002
C_{20}	0.0009	0.0004
C_{22}	0.0007	0.0008
$C_{22:1}$	0.0002	0.0001

[a] Expressed as moles (in unspecified amounts of sample)
[b] Expressed as peak area in square inches
[1] Novak and Liuzzo (1964)

TABLE 14

RELATIVE ABUNDANCE[a] OF TOTAL FATTY ACIDS IN LIPID EXTRACTS FROM IRRADIATED AND UNIRRADIATED SHRIMP STORED IN ICE[1]

Fatty Acid	0 kGy			1.5 kGy			8.0 kGy		
	0 day	12 days	24 days	0 day	12 days	24 days	0 day	12 days	24 days
Myristic	0.42	0.73	0.88	0.68	0.42	0.89	0.94	1.31	1.29
Pentadecanoic	0.21	0.20	0.35	0.31	0.28	0.58	0.32	0.28	0.54
Palmitic	15.80	13.91	15.00	9.38	13.89	12.80	15.11	16.64	15.79
Heptadecanoic									
Stearic	3.93	2.93	3.14	3.63	4.88	3.41	3.11	2.96	2.98
Myristoleic	Trace	Trace	< 0.2	Trace	Trace	< 0.2	Trace	Trace	< 0.2
Palmitoleic	1.14	1.62	1.62	1.25	1.14	1.43	1.33	1.52	1.63
Heptadecanoleic									
Oleic	9.10	7.42	7.56	9.44	10.68	9.05	10.44	10.83	11.09
Linoleic	Trace	Trace	Trace	0.56	0.79	0.98	1.00	1.04	0.98
Linolenic	0.29	0.34	0.31	0.36	0.31	0.34	0.34	0.52	0.58

[a] Arbitrary units

[1] Ismail (1971)

TABLE 15

EFFECTS OF GAMMA RADIATION ON THE FATTY ACID COMPOSITION OF GRASS SHRIMP[1]

Fatty Acid (weight percent)	Dose (kGy)					
	0.0	2.5	5.0	10.0	50.0	100.0
C 16:0	38.3	37.6	36.9	38.3	37.4	39.3
C 18:0	19.1	16.9	19.8	18.1	19.6	18.4
C 18:1	26.5	28.7	26.2	27.0	25.9	27.7
C 18:2	16.1	16.8	17.2	16.6	17.2	14.7

[1] Yeh and Hau (1988)

TABLE 16

CHOLESTEROL LEVEL IN IRRADIATED AND UNIRRADIATED SHRIMP (mg/100 g DRY SHRIMP)[1]

Experiment	Irradiated[a]	Unirradiated
1	690	580
2	630	720
3	670	650
Mean	663.3 ± 30.5	650.0 ± 70.0

[1] Novak and Liuzzo (1964)

[a] 10 kGy

TABLE 17

B VITAMIN CONTENT OF PROCESSED AND DEHYDRO-IRRADIATED SHRIMP[1]

Vitamins	Fresh	Blanching and Partial Drying	Dehydro-Irradiated[a]			Air Dried	Canned
			Air	Vacuum	Nitrogen		
Thiamine (µg/100 g)	128.6	52.0 (59.0)[b]	33.5 (35.5)[c]	42.2 (18.9)[c]	40.6 (22.0)[c]	54.0 (58.0)[b]	50.2 (61.0)[b]
Riboflavin (µg/100 g)	250.0	122.5 (50.8)	104.4 (14.8)	112.4 (8.2)	110.0 (10.2)	144.5 (42.2)	144.5 (42.2)
Nicotinic acid (mg/100 g)	14.7	9.4 (36.6)	8.7 (8.0)	8.6 (8.4)	8.8 (6.9)	12.1 (15.0)	10.8 (26.8)
Vitamin B_{12} (µg/100 g)	18.4	11.4 (38.0)	10.4 (9.0)	10.4 (9.0)	10.1 (12.0)	12.3 (32.8)	11.2 (39.0)
Folic acid (µg/100 g)	57.1	29.3 (48.6)	23.9 (18.5)	25.9 (11.6)	25.5 (13.0)	33.9 (40.5)	31.9 (44.0)

[a] Dose = 2.5 to 3.2 kGy

[b] Compared with fresh shrimp

[c] Compared with values for shrimp that was blanched and partially dehydrated

[1] Srinivas et al. (1974). Figures in parenthesis indicate percentage loss due to treatment.

TABLE 18

CHANGES IN SOME B VITAMINS[1] IN DEHYDRO-IRRADIATED SHRIMP ON STORAGE[a]

			Irradiated Semi-Dried Shrimp Packed in								
			Air			Vacuum			Nitrogen		
	Semi-dried[b]		Storage Period in Days								
Vitamin	0[c]	30	0[c]	30	90	0[c]	30	90	0[c]	30	90
Thiamine (µg/100 g)	52.0	47.8 (8.0)	33.5	31.3 (6.5)	27.0 (19.5)	42.2	39.5 (6.4)	37.0 (13.5)	40.6	37.4 (7.6)	34.9 (13.8)
Riboflavin (µg/100 g)	122.5	121.6 (0.7)	104.4	103.8 (0.6)	89.3 (14.5)	112.4	110.6 (1.6)	103.6 (7.8)	110.0	110.7 (0)	101.8 (7.4)
Nicotinic acid (mg/100 g)	9.4	9.0 (4.3)	8.7	8.2 (5.7)	8.2 (5.7)	8.6	8.2 (4.8)	8.1 (5.8)	8.8	8.3 (5.5)	8.2 (6.8)
Vitamin B_{12} (µg/100 g)	11.4	10.4 (8.9)	10.4	9.5 (8.7)	8.9 (14.2)	10.4	9.6 (7.7)	9.0 (13.5)	10.1	9.1 (9.8)	8.8 (12.4)
Folic acid (µg/100 g)	29.3	26.6 (9.3)	23.9	21.8 (8.8)	19.1 (19.9)	25.9	23.7 (8.4)	21.8 (15.8)	25.5	23.5 (7.7)	21.0 (17.6)

[a] Unirradiated and irradiated (2.5 to 3.2 kGy) semi-dried (40% moisture) shrimp samples were stored at 25 to 28°C. Values are on dry basis. Figures in parenthesis indicate percent loss over respective initial control values (0 day).

[b] Same as blanched partially dried shown in Table 17

[c] From Table 17

[1] Data modified from Srinivas et al. (1974)

TABLE 19

EVALUATION OF PROTEIN QUALITY OF PROCESSED AND STORED SHRIMP USING *Tetrahymena pyriformis* W.[1]

Protein Source	Storage[a] Time in Days			
	0	30	60	90
	Cell Count x 10^4/mL[b]			
Casein	72.2			
Freeze-dried shrimp	92.1	89.5	90.5	89.2
Dehydrated shrimp (2.5 to 3.0% moisture)	84.0	85.1	82.3	83.4
Canned shrimp	88.3	89.8	87.1	85.5
Dehydro-shrimp (40% moisture)	89.5	91.7		
Dehydro-shrimp, irradiated (2.5 kGy) - in air	91.8	88.5	89.7	92.5
- in vacuum	94.3	90.1	89.0	88.6
- in nitrogen	92.4	90.0	88.5	89.2

[a] Storage was done at 25 to 27°C

[b] Cell counts after 4 days of incubation at 25°C

[1] Srinivas et al. (1975)

TABLE 20

PROTEIN EFFICIENCY RATIO OF IRRADIATED AND UNIRRADIATED SHRIMP[1]

Rat Diet

Ingredients	Amount (%)
Starch	74.5
Shrimp powder/casein	12.5
Vitaminized sucrose[a]	5.0
Sesame oil[b]	6.0
Sodium chloride	1.5
Calcium lactate	0.5

Protein Efficiency Ratio

Diet	Sex	Gain in Body Wt. in 4 wk[c] (g)	Protein Intake (g)	Protein Efficiency Ratio
		A	B	A/B
Casein	Male	75.9 ± 1.3	33.1	2.3
	Female	73.7 ± 0.8	30.8	2.4
Shrimp (unirradiated)				
	Male	90.7 ± 1.1	28.1	3.2
	Female	94.7 ± 3.6	27.3	3.4
Shrimp (irradiated at 2.5 kGy)				
	Male	93.5 ± 1.6	27.6	3.3
	Female	87.3 ± 4.0	27.3	3.2

[a] This provided mg/100 g diet, thiamine 0.2, riboflavin 0.4, pyridoxine 0.4, choline 100.0, inositol 100.0, p-aminobenzoic acid 30.0, nicotinamide 10.0, calcium pantothenate 1.0, folic acid 0.25, vitamin B_{12} 0.005, biotin 0.01 and menadione 0.5.

[b] 1 g oil was fortified with 5 mg vitamin E, 400 IU vitamin A and 200 IU vitamin D.

[c] Mean ± standard error

[1] Srinivas et al. (1975)

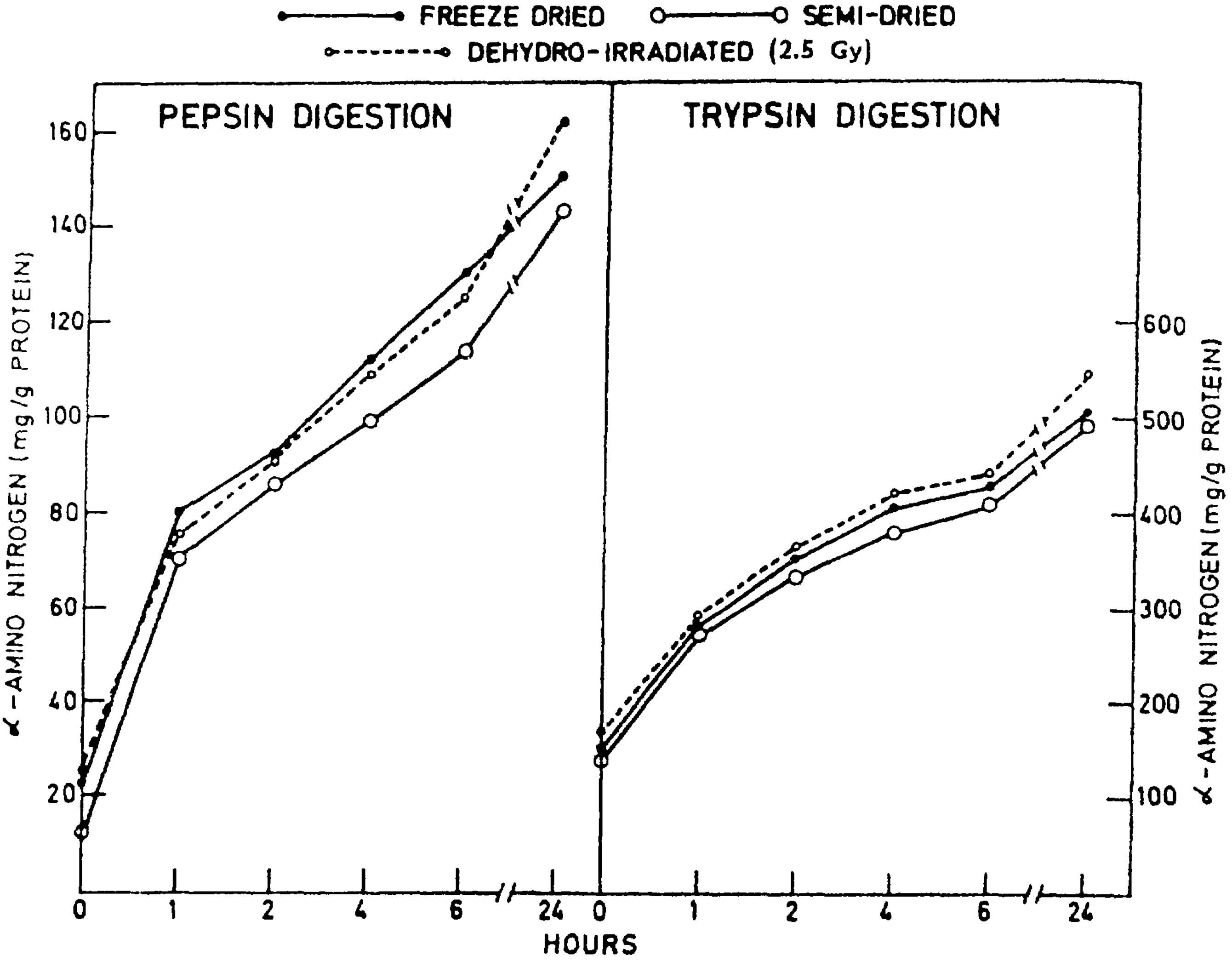

FIGURE 1: In Vitro Digestibility of Processed Shrimp (Srinivas et al., 1974)

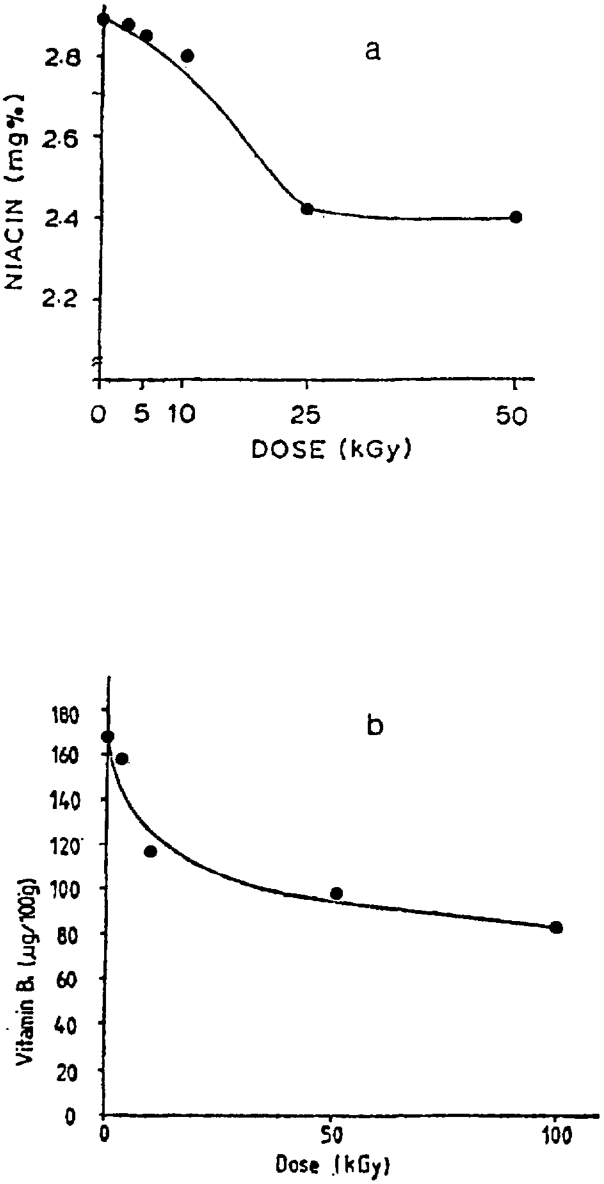

FIGURE 2: Effect of Irradiation at -10°C on (a) Niacin (b) Vitamin B_1, Levels of Grass Shrimp (Yeh and Hau, 1988)

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