EFFECT OF IONIZING RADIATION ON SOME MACRO- AND MICRO-NUTRIENTS OF SOME NIGERIAN SPICES

BY

PAUL CHIDOZIE ONYENEKWE
B.Sc. (Hons) Benin, M. Sc. (A.B.U.)

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Department of Biochemistry
Ahmadu Bello University
Zaria, Nigeria

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DECLARATION

I, Paul Chidozie Onyenekwe hereby declare that this thesis is a record of my own research work and has not been submitted for award of a degree of any other University. Information and excerpts from published and unpublished works of others have been acknowledged in the text.



Paul Chidozie Onyenekwe
October, 1992

DIGITIZED

CERTIFICATION

This thesis, titled, Effect of Ionizing Radiation on Some Macro- and Micro-nutrients of Some Nigerian Spices, by Paul Chidozie Onyenekwe meets the regulations governing the award of a degree of Doctor of Philosophy of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literal presentation

Prof. G. H. Oghadu
Supervisor

22nd Jan 93
Date

Dr. D. A. Ameh
Internal Examiner

April 13, 1993
Date

Prof. G. H. Oghadu
Head, Department of Biochemistry

22nd Jan. 93
Date

Dean, Postgraduate School

11/1/96
Date

DEDICATION

This work is dedicated to my late, loving and foresighted father, Mr. Sebastine Elemonu Onyenekwe (Igwe) who slept in the Lord on 3rd. May, 1990. May the Almighty God grant him eternal rest. Amen.

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ABSTRACT

The effect of gamma irradiation on the microflora of some Nigerian spices were investigated to determine the irradiation dosage required to produce commercially sterile spices without adversely changing their seasoning qualities. Whole and ground forms of red chilli pepper *(Capsicum frutescens)* coriander *(Coriandrum sativum),* ginger *(Zingiber officinale)* rhizomes and Ashanti pepper *(Piper guineense)* berries with initial microbial load of 10^4 to $1U^7$ colony forming units per gram (CFU/g) were subjected to 0, 2.5, 5.0, 7.5 and 10.0 kGy doses of gamma rays from ^{60}Co source. Samples were analysed monthly for a period of nine months.

The microbial load decreased by at least two log cycles as a result of irradiation with 5.0 kGy irrespective of spice and form. A dose of 7.5 kGy eliminated the fungal population, while sterilization was achieved with 10 kGy. Storage time enhanced the effect of the 7.5 kGy dose on the bacterial population.

The effect of irradiation on the oleoresin content of the spices differed from one spice to the other. Oleoresin content of capsicum was significantly ($P < 0.05$) increased from 25.45 to 31.61% whereas marginal decrease (7.4 and 9.93%) in oleoresin level of ginger for the whole and ground forms respectively was observed. The sensitivity of Ashanti pepper to irradiation was very similar to that of ginger. Coriander oleoresin level was not affected by the treatment. The observed effect on ginger and Ashanti pepper was overcome with time.

The essential oil content of the ground ginger sample significantly ($P < 0.05$) decreased from 2.39 to 1.89% (v/w) while that of the whole decreased from 2.40 to 2.18% (v/w). Form had a negative effect on the volatile oil content of ginger and Ashanti pepper as shown by GC-MS analysis of the oils. Like the oleoresin, the pungent principles of the spices showed varied sensitivity to radiation treatment. There was dose-dependent decrease in the pungent principles contents of ginger (gingerol) and Ashanti pepper (piperine) whereas capsiacin, the pungent principle of capsicum was radioresistant.

No appreciable change was observed with respect to the total available carbohydrate, proteins, moisture and ash contents. Irradiation caused a dose dependent decrease in sucrose level and slight increases in total lipid and reducing sugars at varying levels.

Irradiation of the spices with 10 kGy dose of gamma radiation completely eliminated the microflora and did not significantly ($P > 0.05$) affect the nutrient composition. The form of irradiated sample was observed to play a significant rofe,. Decontamination of capsicum, coriander, ginger and Ashanti pepper using gamma radiation should therefore be carried out with whole rather than the ground spice.

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INTRODUCTION

Flavour is an important attribute of products intended for consumption by humans and animals. Seasoning is a viable aid in making such products palatable, in exciting appetite and to a certain degree stimulating the activity of the digestive and hormonal systems. Spices and herbs are the most seasoning agents used in homes, food industries, perfuming and pharmaceutical industries. In the tropics, ginger (*Zingiber officinale*) red pepper, (*Capsicum species*) Ashanti pepper, (*Piper guineense*) Coriander (*Coriandrum sativum*), garlic (*Allium sativum*) alligator pepper (*Xylopia aethiopica*), etc. are commonly produced and used.

These spices contain some characteristic active principles and oils which determine their usage. The active principles or ingredients are usually non-volatile and are extracted by using appropriate solvents and the extract is usually referred to as the oleoresin. The active pungent principle of ginger has been implicated to be a group of phenolic ketones - gingerol, shogoals and zingerone (Paull, *et al.*, 1988). The gingerol, and shogoals are made up of three isomeric forms, the 6-, 8- and 10-isomers.

The capsicum fruits (the common pepper) contain a complex mixture of closely related amides which are called capsainoids as the active ingredients. These amides, the pungent principles of capsicum are capsaicin (the major pungent principle), dihydrocapsaicin, nordihydrocapsaicin, homocapsaicin and homodihydrocapsaicin. The capsicum oleoresin is widely used as flavouring agent for such foods as curry sauces and ointments and cough medicine. Piperine is derived from black pepper and is a potent stimulus of oral heat sensations characteristic of the spice.

Coriander noted for its celery aroma is an annual herb, cultivated for its aromatic young shoots and mature fruits. Linalool is the major constituent of the essential oil and the oleoresin and gives coriander its floral aroma. All the spices except capsicum yield volatile oils called the essential oil which consist of many compounds mainly terpenes. Ginger oil is known to contain not less than 200 constituents (van Beek, *et al.*, 1987) while black pepper contains more than 64

identified and unidentified compounds. (Ekundayo, *et al.*, 1987) However, the relative composition of each oil is a function of many factors including region of origin, variety, age and method of extraction and analysis. Hence, varieties of certain regions are preferred to others due to the presence or absence of certain compounds.

The production of spices are geographically localized, spices of tropical and subtropical origin have for centuries been among the most sought after objects of international trade. India is the major exporter of spices and ginger constitutes about 9.8% of India's export earning from spices. Nigeria and Sierra Leone are major African exporters of ginger. Between 1968 to 1970, Nigeria was the world's dominant exporter of the spice (Anand, 1982). The importers are developed nations that have efficient food manufacturing industries (Farkas *et al.*, 1973). United Kingdom is the major importer of Nigeria's spices. In December, 1985, Nigeria exported a total of 91066 kg of spices made up of 4% pepper, 86.8% ginger while other spices constituted the remainder (Anons, 1986).

Spices are virtually used in all categories of food industry - meat, fish, vegetable products, bakery products perfume products, beverages, pharmaceuticals, and other prepared and convenience foods. Although used in small quantities they are a source of food contamination (ICGFI-IAEA, 1989). Due to the unhygienic production and processing, spices are heavily contaminated with pathogenic micro-organisms such as anaerobic spoilage organisms, spore forming bacteria, proteolytic and gas producing bacteria. The bacterial counts of commercially available species were found to be in the range of 10^2 - 10^7 colony forming units per gram (CFU/g). Whereas the fungal count varied between 10^2 - 10^7 CFU/g (Sharma *et al.*, 1984).

Spices (whole) or their extracts have been shown to exhibit antimicrobial activities (Sharma, *et al.*, 1984; Tasie and Jones, 1989). this property has been observed to depend on a lot of factors and is more fungicidal than bacteriacidal. Hence some spices show high antimicrobial activity while others show low activities or even support growth.

Different methods of decontamination had been employed at different times and places. Some of these methods include:

1. Steam/heat treatment at 115°C for 55 minutes. However, because of the heat sensitivity of the delicate volatile and active components, regular heat sterilization can not be applied.
2. Fumigation with ethylene oxide (Et_2O) and other gases is another widely used method for decontamination of spices. Even though ethylene oxide is a relatively efficient antimicrobial agent, fumigation with ethylene oxide has been observed to be time consuming and it appears to be beset with problems of uniformity of decontamination and requires a complex process-monitoring (Frohnsdorff, 1981): Ethylene oxide in killing bacteria spore causes slight changes in colour and flavour of fumigated spices (Farkas and Andrsassy, 1988). Fumigation being a chemical process is not left out from the danger of chemical residues. The absorptive bound ethylene oxide has been found to remain fairly high after gassing (Kröller, 1966). This residual ethylene oxide together with food components represent a significant occupational health hazard for the handlers in the treatment plants. Hence its ban in some countries.
3. The efficiency of UV-irradiation has been limited by the thickness of the material irradiated. Microbial growth stimulation has been reported to occur in some case.

Increasing concern with the safety of certain chemical agents for decontamination and disinfestation of food has motivated a number of countries either restrict or ban their use. Several western countries have restricted or prohibited the use of ethylene oxide for decontamination of spices and other food products. Thus there is urgent need to introduce an alternative treatment to maintain international trade in various food commodities. Such an alternative should not only be effective but also residue-free and widely applicable to most commodities. Among the

available alternatives, the use of ionizing radiation appears the most viable since it can satisfy most of the demands for all the fumigants.

Gamma-radiation has been used for sterilization of medicinal materials, sprouting inhibition of onions (Ogbadu, 1981), ginger (Paull, *et al.*, 1988) and decontamination of some spices (Farkas and Andrassy, 1988). Since the effect of irradiation is species dependent and no work had been done on any of the chosen Nigerian spices, therefore, before the process could be used one need to ascertain the most effective dose that could be used to achieve the required result with minimum change in the composition of the spice.

Therefore the objectives of this work are to:-

1. assess the microbial load of some common Nigerian spices - ginger, capsicum, Ashanti pepper and coriander and determine the effective dose of gamma radiation for decontamination of the spices in different forms - whole or ground.
2. study post-irradiation behaviour of irradiated spices with regards to:-

   a. microbial load

   b. the active principles - gingerol (ginger), piperine (Ashanti pepper), Capsaicin (capsicum)

   c. the volatile oil contents of ginger and Ashanti pepper and

   d. chemical composition - protein, lipid, carbohydrates, moisture, ash and oleoresin contents.

Chapter Two

LITERATURE REVIEW

2.1 SPICES

Seasoning was first invented by Neolithic man possibly the most astute creature in human history when for the first time he deliberately added salt to his food to improve its taste (Root, 1980). We may presume of course, that during pre-agricultural period tastiness was not a particularly pertinent factor. Man ate to survive rather than to derive pleasure from what he was eating. But if at first he did not perceive a difference between his new diet and the old in terms of taste, there was another element which forced it upon his attention. When he began to eat more vegetable food and fewer animal foods, he found himself also eating lesser salt. The presence of salt, it has been remarked is felt only in its absence. Man began to build up what would become a richly variegated treasury of taste, some subtle, some strong, some caressing and some overwhelming. He drew his seasoners from the inexhaustible resources of the vegetable kingdom in the form of herbs, spices and condiments.

Herbs are the leaves and stems of soft stemmed plants of which the main stem dies down to the ground at the end of the growing season (Heath and Reineccius, 1986). Herbaceous plants may be annuals (complete their life cycle in one season) biennials (in two season) or perennials (exist for many years). However, herbaceous plants are not the exclusive source of substances considered as culinary herbs. For example, woody or semi-woody-stem plants, give rise to rosemary, sage and thyme and a large wood-trunked evergreen tree, the laurel is the source of bay leaves. An additional point of interest is that some herbaceous plants such as coriander and fennel are sources of herbs (the leaves) spices (the seeds) and vegetable (the bulk of fennel). Herbs are further distinguished from spices by their lower content of essential oils and are used to produce delicate or subtle flavours in contrast to the aromatic flavours imparted by spices (Dziezak, 1989).

Spices, derived from the Latin word "*species*" which means "fruits of the earth" (Root, 1980) has a number of different definitions. Generally, spices to be distinguished from herbs are derived from a variety of plants parts (Table 1). For example, the rhizome (ginger, turmeric) the seeds (black pepper, coriander) the fruit (capsicum) the buds (cloves) the flowers (saffron) or the secretions (balm, a gum). They are obtained from plants that normally flourish in semitropical and tropical climates where the sun's heat is said to influence the strength and pungency of the spice. Spices are highly aromatic due to their high content of essential oils. The American Spice Trade Association (ASTA) defines spices in very broad terms as dried plant products used primarily to season food. This definition encompasses all types of products usually sold as spices such as the true spices (e.g. pepper, nutmeg) as well as herbs (e.g. basil, marjoram), aromatic seeds such as sesame and cardamom, blends like curry powder and dehydrated vegetable seasonings (e.g. onion, garlic, paprika).

Another definition of spices by the U. S. Food and Drug Administration (USFDA) is any aromatic vegetable substance in the whole, broken, or ground form which is used primarily to season food rather than to contribute nutrients (FDA, 1987). However, unlike the ASTA definition, this definition excludes from the list of spices all dehydrated vegetables such as onion, garlic powder and celery powder. It also requires spices to be true to name unmodified so that no volatile oil or other flavouring principle has been removed. FDA regulations stated that spices may be labelled as spices, however, colour- contributing spices - paprika, turmeric and saffron must be declared as spice and colouring or by their common or usual names (FDA, 1987). Natural plant extractives, for example, essential oils and oleoresins may be declared as natural flavour. Dehydrated vegetables must be declared by their usual or common names.

Table 2.1: Sources, Flavour Characteristics, Principal Essential Oil Constituents and Commercial Application of Several Spices.

Spice	Scientific name	Plant part of origin	Flavor characteristics	Principal constituent of essential oil	Commercial applications
Allspice	*Pimenta dioca*	Berries of an evergreen tree of the myrtle family	Resembles mixture of nutmeg, cinnamon, cloves, and pepper	Eugenol	Mixed pickling spices, cakes, soups, vegetables, tomato catsup, chili sauce, lunch meats, pickled meats
Anise seed	*Pimpinella anisum*	Seeds of an annual herb of the parsley family	Very strong, licorice like flavor and odor	Anethol	Beverages, baked goods, confections, soups, lunch meats, sausages
Basil	*Ocimum basilicum*	Leaves of an annual herb of the mint family	Pungently aromatic; sweet, spicy flavor; anise like	*d*-linalool,methyl chavicol	Chicken dishes, pizza, processed meats, sausages, stuffings, canned spaghetti sauces, canned tomatoes, salad dressings
Bay leaf	*Laurus nobilis*	Leaves of an evergreen tree of the laurel family	Aromatic, bitter, spicy, pungent	Cineol	Barbeque sauces, bouillons, lunch meat, pickling spice, sausages, soups, tea
Capsicum, red pepper	*Capsicum frutescens*	Fruit, pod, of a member of the nightshade family	Intensely pungent, biting, hot, sharp taste; heat is due to capsaicin content	Little to no essential oil	Chili powder blends, pickling spices, meat seasonings, prepared meats, pickles, condiments, soups, baked goods, confections, beverages
Caraway seed	*Carum carvi*	Fruits of an annual or biennial of the parsley family, fruit splits into two seeds	Warm, biting, acrid but pleasant, slightly minty, medicinal	Carvone	Baked goods, teas, processed savory dishes, goulash
Cardamom	*Elettaria cardamomum*	Seeds from the fruits of a perennial herb of the ginger family	Sweet, pungent, highly aromatic, camphoraceous	Cineol and α-terpinyl acetate	Baked goods, Danish pastries, Indian curried dishes, lunch meats, pickles, ice cream
Celery seed	*Apium graveolens*	Fruits of a biennial, sometimes annual, herb of the parsley family	Warm and slightly bitter celery taste, hint of parsley and nutmeg	*d*-limonene and sedanolide	Meat seasonings, processed meats, soups, gravies, salad croutons, confections, baked goods
Chervil	*Anthriscus cerefolium*	Leaves of an annual of the parsley family	Aromatic; mixture of anise seed, parsley, caraway, and tarragon	Methyl chavicol, osmorhizol	Instant soups, baked goods, condiments, ice cream, beverages
Chives	*Allium schoenoprasum*	Leaves of a perennial of the onion family	Delicate onion flavor		Soup mixes, salad dressings, cocktail dips, sour cream, cottage cheese
Cinnamon and cassia	*Cinnamomum zeylanicum* and *Cinnamomum cassia*, respectively	Dried inner bark of an evergreen tree of the laurel family	Warm, spicy, aromatic, woody, pungent, slightly bitter	Cinnamic aldehyde	Confections, ice cream, beverages, cakes, cookies, pies, pickles, preserves, icings, soup bases, processed meats
Cloves	*Syzygium aromaticum*	Dried, unopened flower buds of an evergreen tree of the myrtle family	Warm, spicy, fruity, astringent, slightly bitter, with a warm numbing effect	Eugenol	Baked goods; confections; tomato catsup; chili sauce; beverages; pudding mixes; poultry stuffings; canned, spiced fruits; processed meats; preserves
Coriander	*Coriandrum sativum*	Fruits of an annual herb of the parsley family	Combination of sage, lemon peel, cumin, and caraway	*d*-linalool, *d*-α-pinene, β-pinene	Confections, pastries, chili sauces, gingerbread mixes, canned pea soup, pickling spices, curry powder, Mexican salsa
		Leaves	Leaves have a different flavor from seeds: combination of parsley and citrus		
Cumin seed	*Cuminum cyminum*	Dried, ripe fruits of an annual herb of the parsley family	Aromatic, warm, heavy, spicy, bitter	Cuminaldehyde	Chili powder, chili con carne, curry powder, salad dressings
Dill seed and dill weed	*Anethum graveolens*	*Dill seed*—seeds of an annual of the parsley family		*Carvone*	Baked goods, pickles, salad dressings, cheese spreads, tomato and vegetable juices, meat seasonings, sausage, processed meat
		Dill weed—leaves	Aromatic, fresh, green, herbaceous	Carvone	
Fennel seed	*Foeniculum vulgare*	Seeds of a perennial of the parsley family	Anise-like	Anethole, fenchine	Italian sausage, pizza, processed meat, curry powder blends, Italian-type breads, baked goods, sweet pickles
Garlic dehydrated	*Allium sativum*	Bulbs of a perennial of the onion family	Pungent and sulfurous	Diallyl disulfide, diallyl trisulfide, allyl propyl disulfide	Condiments, meat seasonings, bouillons, sauces, soups, gravy mixes, baked goods
Ginger	*Zingiber officinale*, Roscoe	Rhizomes of a perennial of the ginger family	Aromatic, pungent, biting, camphoraceous, spicy; pungency is attributed to zingerone, shogaol, and gingerol	Cineol, borneol, geraniol	Baked goods, beverages, curry powder blends, sauces, condiments, meat seasonings, processed meats, sausages, ice cream
Marjoram, sweet	*Origanum majorana*	Leaves and floral parts of a perennial of the mint family	Warm, aromatic, slightly sharp, bitter, camphoraceous	Linalool, methyl chavicol, cineol, eugenol, terpineneol	Gravies, soups, processed meats, dressings, flavored vinegar
Mint **Peppermint**	*Mentha Piperita*, variety vulgaris (Black mint)	Leaves	Fragrant, spicy, minty cool, sweet, very slightly pungent; aftertaste is sweet, minty, and cooling	α-pinene, β-pinene, limonene, cineol	Confections, ice cream
Spearmint	*Mentha spicata*	Leaves	Sharp, pleasantly pungent, herbaceous, sweet, and minty	l-carvone; characteristic spearmint notes come from dihydrocuminyl acetate, dihydrocuminyl valerate, dihydrocarveyl acetate	Confections, baked goods, gelatin desserts, jellies, beverages

Table 2.1 (contd)

Spice	Scientific name	Plant part of origin	Flavor characteristics	*Principal constituent* of essential oil	Commercial applications
Mustard seed		Seeds of an annual plant of the cabbage family	Slightly acrid	Little or no essential oil; allyl isothiocyanate forms from an enzymatic reaction	Prepared meat seasonings; prepared salad dressings; pickled products; condiments; and canned, deviled ham
White mustard	*Brassica hirta* or *B. alba*				
Brown mustard	*B juncea*				
Black mustard	*B. nigra*				
Nutmeg and mace	*Myristica fragrans*	Nutmeg—seed of a fruit of an evergreen tree	Spicy, warm, cineolic, camphoraceous, sweet, pungent	α-pinene, β-pinene, limonene, 4-terpineol, safrole, myristicin	Baked goods, mincemeat, dehydrated soup mixes, ice cream, confections, icings, syrups, processed meats
		Mace—aril, or membrane covering the seed	Spicy, warm, pungent	Monoterpene, monoterpene alcohols	Baked goods, confections, ice cream, pickles, processed meat, syrups, condiments, dehydrated soup mixes
Onions, dehydrated	*Allium cepa*	Bulbs of a biennial plant		*d-n*-propyl disulfide, methyl-*n*-propyl disulfide	Baked goods, pickles, tomato catsup, chili sauces, condiments, prepared meat seasonings, dry soup mixes, gravy preparations, salad dressings
Oregano (Wild *marjoram*)	*Origanum spp.*	Leaves of a perennial of the mint family	Warm, pungent, bitter	Thymol or carvacrol	Salad dressings, pizza, tomato sauce, breads, prepared entrees
Paprika	*Capsicum annuum*	Dried and ground, deseeded and destemmed fruits of a shrublike herb of the nightshade family	Mild and slightly sweet, some varieties can be hot due to capsaicin	No volatile oil	Frankfurters, bologna, sausages, tomato sauce, Mexican chili powder, condiments, baked goods, confections, soups, salad dressings, pickled products
Parsley	*Petroselinum crispum*	Leaves of a biennial	Grassy, herbaceous	Little volatile oil	Chicken and tomato soup bases, meat seasonings, condiments, beverages, salad croutons, salad dressings, baked goods, potato chips
Pepper	*Piper nigrum*	Berries or peppercorns from a perennial climbing vine			
Black pepper		Dried, unripened berries	Hot, biting, very pungent due to the piperine content	Monoterpenes, sesquiterpenes oxygenated compounds	All-purpose seasonings; dehydrated and canned soups, poultry dressings, pickles, condiments, baked goods, spice mixes, confections, curry powder blends, processed meat
White pepper		Dried, ripened berries with skins removed	Similar to black pepper, but milder	Similar to that of black pepper	Used where the dark specks of black pepper are undesirable
Poppy seed	*Papaver somniferum*	Seeds of an annual, biennial, or perennial plant	Nutty taste	No volatile oil	Baked goods and confections
Rosemary	*Rosmarinus officinalis*	Leaves of a perennial, evergreen shrub	Peppery, spicy taste, astringent; warm, piney, camphoraceous aftertaste	Borneol, cineole, camphor, bornyl acetate	Fried chicken, croutons, baked products, confections, beverages
Saffron	*Crocus sativus*	Stigmas of the purple autumn crocus flower; the plant is a bulbous perennial of the iris family	Earthy, bitter, fatty, herbaceous flavor	2,2,6-trimethyl-4,6 cyclohexadienal, crocin, picrocrocin	Not used extensively commercially because of expense; has been used in beverages, baked goods, ice creams, confections, condiments, and meats
Sage	*Salvia officinalis*	Leaves of a perennial semi-shrub of the mint family	Balsamic, bitter taste; fragrant, warm, astringent	Thujone, cineol borneol	Meat seasonings for pork sausage, fried chicken, meat loaf, baked goods, condiments, pickles, confections, beverages
Savory, sweet summer	*Satureja hortensis*	Leaves of an annual of the mint family	Spicy and pepper taste	Carvacrol	Baked goods, condiments, confections, dry soup mixes, gravy mixes, liqueurs, bitters
Sesame seed	*Sesamum indicum*	Seeds of an annual herb	Nutty flavor	No volatile oil	Breads, rolls, crackers, cakes, salad dressings, confections
Tarragon	*Artemisia dracunculus*	Flowering tops and leaves of a perennial herb	Similar to anise or licorice	Methyl chavicol	Baked goods, vinegar, mustard, pickles, condiments, salad dressings, soup bases, meat seasonings
Thyme	*Thymus vulgaris*	Leaves and flowering tops of a creeping shrublike perennial of the mint family	Biting, sharp, spicy, *phenolic, herbaceous*	Thymol	Salad croutons, fried chicken, prepared poultry stuffing, processed meats, canned soups, baked goods
Turmeric	*Curcuma longa*	Dried rhizomes of a perennial herbaceous plant of the ginger family	Bitter, pungent	Turmerone, free acids, borneol	Used to color pickled products, soups, mustards, pudding mixes, condiments, prepared seasonings for meats
Vanilla	*Vanilla fragrans*	*Fully grown fruit of an* orchid flower	*Chocolate-like*	*Little essential oil,* vanillin	Ice cream, chocolate beverages, cakes, custards, puddings, confections, baked goods

2.1.1 PRINCIPAL FORMS OF SPICES

Spices come in a variety of forms for adding the 'bite' or 'character' so desired in a food. They are sold whole, ground or as extractives - e.g. essential oils and oleoresins. Spice extractives are further formulated to produce secondary products such as essences, emulsions, liquid-soluble spices, dry-soluble spices, encapsulated spices, heat-resistant spices and fat -based spices (Heath and Reineccius, 1986). Each spice form is prepared by a different method and has unique properties which makes it more suitable for one particular application over others. The different forms of spices are as follows (Dziezak, 1989):-

a. Whole spices: - some spices such as allspice, sesame seeds and bay leaves have been reported to provide flavour and aroma as well as visual and textural effects that are not attainable with extractives (Dziezak, 1989). Generally, the spices' intact cellular structure and presence of natural antioxidants protect important flavouring constituents from volatilization and oxidation. However, whole spices may release flavour too slowly to be of value in some applications.

b. Ground spices:- These have been milled to the degree of fineness required by the food processor. Compared to whole spices, they can be incorporated more uniformly into the food mix, eliminating "hot spots". they also release their flavour more readily because the flavour- containing cells have been ruptured during milling. But, in spite of these attributes, finely ground spices have been observed to have a limited shelf life, they are subject to oxidation, flavour loss and degradation on storage. Heath and Reineccius (1989) recommended that they be stored for no longer than three months in manufacturing practice. In industrial applications ground spices are usually used to provide visual appeal and often supplemented with essential oils and/or oleoresins (Dziezak, 1989). Problems with shelf life and flavour loss are minimised in another form of ground spice,

and in cryo-milled spice. Here, milling operations are concluded at about 38°C as opposed to 93°C in ambient milling and involved feeding the whole spice and liquid nitrogen simultaneously into the milling zone. Cryo-milled spices had been reported to have better retention of aroma and flavour volatiles and colour (Dziezak, 1989).

c. Spice Extractives:- These serve as alternatives to whole and ground spices and provide the stability required in product formulation. Essential oils and oleoresins can be customised to meet specific product needs for solubility, dispersibility, aroma, flavour and colour. They have standardized flavour, colour and physical attributes and are microbiologically sterile

I. Essential oils:- Essential oil or ethereal oils is acquired as the volatile oil obtained by the steam distillation of plants (Haagen-Smith, 1948). They form the aromatic, volatile components present in most spices which provide the characteristic flavour and aroma of the spice. In some spices, they form only as a result of natural enzymatic reactions occurring when the wet plant tissue is crushed or macerated (Parsons, 1984). they also occur in form of oil droplets in glands or intercellular spaces in plant tissues similar to fatty or fixed oils. Essential oils and fixed oils have in common the properties of being immiscible with (and usually lighter than) water and soluble in ether and many organic solvents. On the other hand, the composition and properties of volatile oils differ greatly from fixed or fatty oils, the former consisting of various mixtures of different types of components; for example terpenes, straight chain hydrocarbons, benzene derivatives and miscellaneous compounds. While the later being for the most part acyl glycerol of fatty acids (Guenther, 1948 and Sterrett, 1962).

Essential oils unlike fixed oils are recovered from plant materials primarily by steam distillation, although some are expressed cold, dry distiled or vacuum distiled (Farrell, 1985). They could also be extracted with cold fat (*enfleurage*) or with hot fat maceration (Guenther, 1948). Eiserle and Rogers (1972) compared the oils obtained

by steam distillation of black pepper (*Piper nigrum*) with the oils produced by solvent extraction, the distiled spice oil, they observed, had above twice the amount of low-boiling terpenes and only two-thirds the amount of sesquiterpenes as compared to their amount in extracted oil. However, distillation conditions vary depending upon the spice type.

Essential oils offer a number of advantages. They do not impart colour to the end product, usually uniform in flavour quality and are free of enzymes and tannins. But, they have been observed to often provide an incomplete flavour profile because they do not include the non-volatile components. This can be noted in the essential oil of ginger and pepper *(Piper nigrum)* which provide much of the flavour of the spices but lack the pungency contributed by the non-volatile principles, gingerol and piperine respectively (Dziezak, 1989). Moreover, some essential oils oxidize readily due to their terpene and sesquiterpene fractions and are devoid of the natural antioxidants present in spices.

II. Oleoresins: The viscous-to-tacky materials extracted from the ground spice with volatile solvents provide a more complete flavour profile than essential oils. They consist of essential oils, organically soluble resins and other non-volatile principles - such as pungent components (e.g. piperine in black pepper), fixatives (e.g. in rosemary and sage) and pigments (e.g. capsicum), (Deline , 1985). The solvents typically used for oleoresin extraction include ethyl acetate, ethanol, acetone and ethylene chloride, super critical carbon dioxide is also used by some companies (Heath, 1985; Tuley, 1985). The oleoresin market includes numerous products formulated for particular applications. Examples of two such items are oleoresins that are specific for baking applications and blends of oleoresin and essential oils that are said to completely provide the aroma and flavour characteristics of the natural spices.

III. Derivatives of Oleoresins and/or Essential Oils. These include liquid solubles, dry soluble and encapsulated oleoresins. Liquid solubles, also called solubilized seasonings are blend of oleoresin and/or essential oils, polysorbate and gums. They

are available in oil-soluble or water-dispersible forms and are frequently used in icing, cookie doughs, prickling brines, canned soups, sauces and beverages. Dry solubles, sometimes called dispersed and plated spices are oleoresins that have been plated onto a dry carrier such as corn syrup, solids dextrose or salt. They reportedly impart the strength of a good quality freshly ground spice but not necessarily the same character (Heath and Reineccius, 1986). Dry solubles are used to flavour processed meats, cake mixes and frostings. Encapsulated oleoresins are prepared by spraying an emulsion of water, starch and oleoresin into a heated chamber. Water vapourizes from the atomised droplets as the starch envelopes the oleoresin particle. Encapsulated oleoresins are widely used in powdered foods that are prepared by reconstitution with water.

2.1.3 VARIETIES OF SPICES

2.1.3.1 Ginger (*Zingiber officinale* Roscoe).

Ginger (*Zingiber officinale* Roscoe [family: *Zingiberaceae*]) is one of the most important spices in the world. It is believed to be a native of tropical Asia, particularly the Pacific Islands and is now commercially cultivated in Jamaica, Brazil, Hawaii, Nigeria, India, China, Japan and the Philippines (Anand, 1982 and Anzaldo, *et al.*, 1986). Some countries produce ginger primarily for domestic consumption, only a relatively small proportion of the crop being exported, while others produce it principally as an export earner, local consumption being small and negligible.

The quality of ginger have been shown to differ according to origin (Anand, 1982 and Erler, *et al.*, 1988). Hence ginger is classified into three main groups represented by the Jamaican, Indian (cochin) and West African (Nigerian and Sierra Leone) gingers, which are distinct in character. The Jamaican ginger has a very fine flavour, while the Indian ginger is good with a distinct lemon-note and the West African ginger is known for its stronger, more pungent and coarser flavour (Anand, 1982).

Ginger not only contains the major micro and macro-nutirents, but contains essential oils (Herout, *et al.*, 1952 and Varma, *et al.*, 1962) which impart the characteristic ginger flavour and pungent principles such as gingerol, shagoal and zingerone (Connell and Sutherford, 1969). Ginger like other spices are not usually consumed because of the major nutrient contents but rather because of the flavour they impart to food and effect of the active ingredients on certain physiological processes (Kawada, *et al.*, 1988). Hug, *et al.* (1986) studied the chemical composition of Bangladesh ginger and observed that the rhizome of ginger contained 4% volatile oil on the basis of rhizome dried at 60°C for 19 hours and 0.8% on raw rhizome basis. The alcohol and acetone extracts as oleoresin were reported as 7.3% and 8.0% respectively. While protein, starch, ash, fat and crude fibre were found to constitute 12.3, 45.25, 6.5, 4.5 and 10.5% of the dried sample respectively.

The chemical composition of ginger has been observed (van Beek, et al., 1987 and Baranowski, 1986) to depend not only on the origin but on the time of harvest. Baranowski (1986) studied the changes in solids, oleoresin and 6-gingerol content of ginger during growth in Hawaii and observed that the solid content of the rhizome increased throughout the 34 weeks of growth. The 6-gingerol content increased with age on a wet weight basis, but declined on a dry weight basis after reaching a maximum at 16 weeks. Based on this observation, he suggested that an optimum harvest date can be determined for the dried root market where a mildly pungent product is desired and where fresh market yield is important.

The effect of age on the essential oil composition has been studied by Sakamura and Hayashi (1978). Age was observed to influence the relative proportion of the constituents. In this study, the oil composition of fresh rhizomes stored for 5 or 8 months and 3 years were investigated. Monoterpenes were found to be the major constituents of the oils with small percent of sesquiterpenes. Quantitatively, geranyl acetate, a monoterpenoid ester was observed to be the major component. However, stored ginger rhizomes were found to contain lower quantities of geranyl acetate and geranol than fresh rhizome.

Although age of rhizome at harvest and distillation play a vital role in the yield and composition of the volatile oil and hence the flavour, the major factor that determines its value in the international market is the origin (Anand, 1982). The oil yield of Vietnamese ginger has been reported (van Beek, *et al.*, 1982) to be 2.7% and made up of 28% monoterpene hydrocarbons, 37% oxygenated monoterpenes, 25% sesquiterpenes and 2% monoterpenoid compounds. They observed that the composition was similar to that of Sri Lankan ginger. The main component of the oil was geranial (16%) which together with neral gave ginger a lemon-like character. Erler, *et al.* (1988) have shown that Indian ginger oil differ markedly from Australian ginger oil. They noted that while the main components of Indian ginger oil are the sesquiterpenoid hydrocarbons are curcumene, zingiberene, α-farnesene, β-bisabolene and β-sesquiphellandrene, the essential oil from the Australian ginger consists mainly of the monoterpenoid hydrocarbons - camphene and phellandrene and their oxygenated derivatives neral, geranial and 1,8-cineole. A total of 127 constituents have been identified (Lawrence, 1983, van Beek, *et al.*, 1987) in ginger rhizome volatile oils.

The pungency of ginger is an important sensory characteristic attributable to the presence of gingerol compound (6-, 8- and 10-gingerol) and its decomposition product zingerone and reduction product shagoal (Connell and Sutherland, 1969). These principles are contained in the oleoresin usually extracted with organic solvents namely acetone and ethanol (Purseglove, *et al.*, 1981 and Govindarajan, 1982). The major pungent constituents of ginger oleoresin have been shown to be the gingerol-1-(4'-hydroxy-3-methoxyphenyl)-5-hydroxydecan-3-one (Connell and Sutherland, 1969; Connell, 1970; Purseglove, *et al.*, 1981, and Wood. 1987). According to Govindarajan (1982) [6]-gingerol accounted for 18 - 36% of oleoresin from different sources of ginger and the oleoresin yield of Jamaican ginger was given as 4.4 - 5.0% (w/w) while Yamahara, *et al.* (1985) found that Japanese ginger contained 3.39 - 3.68% oleoresin. These results have recently been confirmed by Spiro and Kandiah (1990). Spiro and Kandiah (1990) observed that the amount of oleoresin extracted from Jamaican ginger ranged between 3 - 6% (w/w). However their result showed that the amount of

extract was solvent-dependent, hence acetone yielded the highest value 6.4% and isopropanol the least 3.4%. The concentration of [6]-gingerol, the major active principle, was found by Wood (1987) to constitute between 61.9 and 82% of total gingerol.

One of the major spices with widespread uses in food, beverages and medicine is ginger. In the food industry, it is often employed in the oleoresin form. Several investigators in Japan reported that ginger or ginger extract added to lard or other foods showed reasonably strong antioxidant property (Kihara and Inone, 1962; Fujio, *et al.*, 1969; Saito *et al.*, 1976). Lee, *et al.* (1986) observed that ginger extract was effective in improving the shelf life of meat products. Hence with the growing ban on the use of synthetic antioxidants in many meat products, spice extracts are the only possible alternative.

Ginger has been known to have medicinal properties and used world-wide as aromatic stomachic and pungent appetite stimulant (Yamahara, *et al.*, 1985). As a Chinese medicine, it has been used for increasing body metabolism. Ginger roots have been reported to possess central nervous system depressant, analgesic (Aburada, *et al.*, 1982) cough suppressant, anti-vomiting (Kasahara, *et al.*, 1983), anti-convulsant and prostaglandin synthesis inhibition activities (Kiuchi, *et al.*, 1982). It has been said that the pungent principles of ginger do act to stimulate the thermoregulatory receptors (Jancso-Gabor, 1980). This stimulation influences stomach and bile secretions by reflex action (Yamahara, *et al.*, 1985). It is also known that bile acids facilitate absorption of fat and electrolytes and peristalsis of the small intestine and by increasing bile secretion, small gallstones may be excreted.

2.1.3.2 Capsicum

Red pepper belongs to the family *Solanaceae* which also includes the egg plant and tomatoes. The genus, *Capsicum* contains over 200 varieties (Huffman, *et al.*, 1978). Three main species have been identified (Wilson, 1960) in West Africa. These range from the very hot jalapenos and cayennes to heatless bell peppers. Based on the pungency, Smith (1982) grouped capsicum into three basic categories - the highly

pungent, moderately to mild pungent chillies and paprika (sweet pepper). Chillies is a generic term for all capsicum except paprika and the sweet vegetable peppers.

Botanically the highly pungent chillies mainly comprise of *Capsicum frutescens*, *C. baccatum* and *C. chinense*. (Jacobs, 1951). These groups of capsicum are valued purposely for their pungency. The moderately pungent chillies although have considerable bite are primarily required for use as ground products valued for their combination of pungency and colour. They are obtained from the larger fruited varieties of *Capsicum annum*. Whereas paprika is valued both for colour and flavour and are also obtained from *Capsicum annum* cultivars.

Capsicum species are not consumed for the macronutrients, rather for the micronutrients. As a vegetable, fresh capsicum contains as high as 91% water (Pellet and Shadarevian, 1970) whereas other macronutrients like protein, lipid and carbohydrate constitute about 1.1 - 1.5, 0.2 - 0.3 and 6.9 - 9.4% respectively. The micronutrients for which capsicum are consumed include vitamin c, carotene and the pungent principle capsaicin.

A study of the total capsaicinoid content of some capsicum species grown in northern Nigeria (Ogbadu *et al.*, 1989) showed that capsaicin was found in the flesh than in the seeds. The *C. annum* varieties were found to contain capsaicinoids ranging from 0.00 - 107.2 mg/100 g whereas *C. frutescens* had capsaicinoids ranging from 21.7 - 266.5 mg/100 g. The study of Ogbadu *et al.* (1989) showed that total capsaicinoid increased from the unripe to the ripe stage.

Spices with hot taste, have long been used as important seasonings to enhance the palatability of food and also as medicinal drug all over the world (Pruthi, 1980). Empirical evidence have shown that capsicum peppers form an important condiment in the diet of Nigerians for whom pungency is the most important property of the fruit, adding flavour and aroma to food, thereby stimulating appetite. Apparently this stimulatory effect of chillies is associated with the pungent principle, capsaicin, an amide, which supposedly induces a warming action. Recently it has been postulated (Kawada, *et al.*, 1986a, Watanabe, *et al.*, 1987ab) that capsaicin enhanced the energy metabolism in rats through activation of the sympathetic nervous system and

stimulated lipid metabolism (Kawada, *et al.*, 1986b). The energy metabolism enhancement of capsaicin has been demonstrated (Watanabe, *et al.*, 1988) to be due to its stimulation of the catecholamine secretion from the adrenal medulla through the action of the central nervous system.

For pharmaceutical preparations, highly pungent and low colour types are usually preferred, hence solvent extracts of highly pungent varieties are used externally as counter irritant for treatment of lumbago, neuralgia, rheumatic disorders and sore-throat. Internally, as tonic or given by mouth for carminative action of gastric and intestinal flatulence associated with stomachic dyspepsia (Mathew and Shankaracharya, 1971). Capsaicin is also externally used in products like pain balm, prickly heat powder, capsicum wool. capsicum tissue and soap liniments. The action is fairly lasting and has the advantage that it does not injure the skin but care must be taken that it does not get on the conjunctiva.

In the food industry, bright red colour and moderate pungent types are preferred to improve the taste flavour and colour of food products, like biscuits, ginger soft drinks etc. as well as for curing chewing tobacco (Mathew and Shankaracharya, 1971). Paprika for example, is valued by the food processors largely for its colouring properties which have food application in processed meats, snacks, while chillies required by industrial users have wide range of pungencies serving as ingredients in curry powders, spice mixes, canned meats, fish and other seasoned products (Smith, 1982).

2.1.3.3 **Coriander** (*Coriandrum sativum*)

Coriander (*Coriandrum sativum* L [family: umbelliferae]) is an annual herbs native to South-Eastern Europe. It was reported to tolerate a wide range of climatic conditions and hence cultivated extensively throughout the world (Smith, 1982).

Coriander is mainly grown for its fruit which, when dried, is the spice known as coriander seed valued for its sweet but pungent, sage-lemon flavour (Dziezak, 1989). Good quality seed contains upwards of 0.7% of essential oil, of which the principal

constituent is linalool (Smith, 1982 and Heath, 1985). Macleod and Islam (1976) observed that linalool constituted about 60 - 70% of the essential oil.

The preferred cultivars of the plant for essential oil production are the small seeded varieties grown in the Soviet Union and other Eastern Europe countries, their seeds are reported having a volatile oil content of 4% or more and possessing flavour characteristics not reproduced in seeds from other origins (Smith, 1982). But, it has been the larger seeds from Morocco and Romania that are most commonly preferred, even though their volatile oil content may be low and flavour less appreciated, the main criteria being clean seeds of good appearance and uniform light colour.

Fresh coriander according to Pellet and Shadarevian (1970) contains about 84% moisture, 4.3% protein and 0.7% lipid. Hence when dried could serve as a good source of protein. The seeds are also reported to be rich in some vital vitamins such as niacin and vitamin C. the seed yielded high quantity of oleoresin which was reported to have much smaller field of application than the essential oil because it tends to cloud liquids.

Dried coriander is extensively used for both bulk and flavour in sausage, corned beef and similar meat products as well as in fish cakes and some bakery and confectionery lines. It is also a standard ingredient in most curry powders and in other mixed spices. It is used as a pickling spice and in such products as pickled gherkins and canned fish where its appearance resembles peppercorns. Whole and ground coriander seeds are also available in retail packs and they are used in oriental, Mediterranean and Latin American type cuisine.

Coriander oil has both fragrance and flavour applications. In perfumery it is used in colognes and some cosmetic products, while in flavours it has a wide range of applications including soft drinks, beverages such as gin, vermouths and liqueurs, sauces and seasonings, some meat, tobacco and sweets (Farrell, 1985, Heath and Reineccius, 1986). In the Soviet Union the oil is used in galenicla products to mask unpleasant tastes (Smith, 1982).

Coriander oleoresin has a much smaller field of application than has the essential oils. One of its drawbacks being that it tends to cloud liquids. Moreover, in

its undispersed form, it lacks the bulk of the ground spice and therefore, coriander being a cheap item, there is little advantage in extracting the oleoresin if it is necessary to add back bulk to give the desired result. Nevertheless, coriander oleoresin does find uses in sauces seasonings and some processed food products. It is also used in combination with the essential oil reinforcing aroma and flavours.

2.1.3.4 Ashanti pepper (*Piper guineense*)

Ashanti or West African black pepper (*Piper guineense* Schum and Thom) is a herbaceous climber commonly found in the African tropical forest zones. Occasionally cultivated or left on clearings and trained on the remaining trees (Dalziel, 1936). It belongs to the group of varieties of *Piper* species called 'false cubebs' in the spice trade (Guenther, 1952) and berries are often used as substitutes for the edible black pepper (*Piper nigrum*).

Although much work have not been done on the spice, Ifon and Bassir (1980) reported that it had some degree of nutritive value because of its fairly high protein and fat content. However, it is mostly consumed because of the flavour and aroma it imparts to food and food products and the bite characteristics. Recently, Ekundayo, *et al.* (1988) analysed the volatile oil of *Piper guineense* and identified 56 compounds which amounted to 90% of the essential oil constituents. They observed that the oil was very rich in phenylpropanoid derivatives and myristicin was the most abundant constituent. Other analogous components in the oil were sarisan, safrole, elemicin, methyleugenol, eugenol, dill apiole and isoelemicin while the minor components were predominantly mono- and sesquiterpanoids. The mono- and sesquiterpanoid compositions of *P. guineense* oils as reported by Ekundayo *et al.*(1988) resemble to a certain extent that of black pepper (*P. nigrum*) (Lawrence, 1985) and *P. betle* (Rawat, *et al.*, 1989). But, the phenylpropanoid contents differ considerably.

The essential oil yielded by steam distillation of dried pepper represents only aromatic, odorous constituents of the spice it does not contain the pungent, non-volatile principles for which pepper is so highly esteemed as condiment. To obtain all the constituents in concentrated form, ground pepper berries is percolated with

volatile solvents - alcohol, acetone or ether. The extract which is the oleoresin contains the active ingredient. The quantitative composition of the oleoresin has been reported (Guenther, 1952). The composition ranges from the active principle, piperine, to fixed oil including some of the components of the volatile oil.

Piperine an alkaloid of the empirical formula $C_{12}H_{19}NO_3$ is a crystalline compound very sparingly soluble in water. Piperine which constituted the overwhelming proportion of the alkaloid mixture has been shown to be heat labile (Purseglove, et al., 1981).

P. guineense is used as medicine for colds, coughs and considered as a counter-irritant or stimulating ointment. This use of the spice may be due to the action of the active ingredient, piperine, on adrenal catecholamine secretion (Kawada et al., 1988). It is also used in flavouring soup, rice etc. The leaves are taken with food and is supposed to improve the chances of conception (Dalziel, 1936). When the grains are pulverised they are said to have insecticidal effect.

2.2 MICROBIAL CONTAMINATION OF FOOD

Dry plant materials often harbour a variety of microorganisms as a consequence of growing and harvesting conditions and post harvest handling as well as the selective actions characteristic of a given substrate (Katusin-Razem, *et al.*, 1988). Katusin-Razem, *et al.* (1983) conducted a survey of the microbiological quality of the materials on the retail market and observed the presence of both a wide variety and a large number of microorganisms.

The survival and multiplication of bacteria and fungi in dry materials was said to be limited but Goepfart, *et al.* (1972) have reported that contaminated spices are vehicles of spoilage and food poisoning. Hence, Konuma, et al. (1988) opined that the main source of *Bacillus cereus* contamination in meat products was contaminated meat product additives.

Although organisms of public health significance such as *Salmonella* and *Clostridia* are encountered infrequently in spices (Wilson and Andrews, 1976; Baxter and Holzapfel, 1982) populations of spoilage bacteria ranging from 10^2 to 10^8 colony

Among the *Staphylococcus aureus* toxins (alpha, beta, gamma and leukocidin) the *Staphylococcus* alpha-toxin is one of the best studied and understood. Although there are similarities in the biological effects of these toxins, some differences exist (Balogh, 1984). Toxicological investigation of most of Staphylococcus toxins have shown that they are hemolytic proteins exotoxins. Beside hemolysis, dermonecrosis and myotoxic effect on smooth muscles which usually lead to paralysis, are common occurrences (Arbuthnott, 1970).

Unlike the Staphylococcus toxin related disease, the human disease outbreak of *Clostridium botulinum* toxin, botulinum toxin is associated with consumption of meat, fish or with proteins of animal origin (Balogh, 1984). However, other *Clostridia* are known to produce toxins and are widespread spore formers and extremely resistant to adverse conditions and hence could be isolated from a range of food products. These toxins are said to be neuroparalytic poisons and are known to produce similar syndromes on muscles, eyes and respiratory systems (Balogh, 1984).

The toxin produced by *B. cereus* has been extensively studied with respect to its structure, significance and mode of action. It has been demonstrated that *B. cereus* produces different amounts of enzymes such as penicillinase, phospholipase c and hemolytic enzyme which can readily be detected in culture filtrate (Boventre and Johnson, 1970). In their mode of action the enzymes act extra-cellularly and have different degrees of toxicity alone or when in combination it has been reported (Onayemi, 1984) that *B. cereus* food-borne illness was more of a food intoxication rather than a food infection. The toxin produced could change the electrolyte balance in the host intestine or get bounded very quickly to the intestinal tissues of the host. It was suspected that one or two of the enzymes (phospholipase c or proteolytic enzyme) in the composition of the toxin were responsible for the food poisoning syndrome which are similar to those of *botulinium* (Onayemi, 1984).

Fungi microflora like bacteria are known to infest foodstuffs. Kurata and Hitokolo (1985) examined a total of nearly 6500 samples of 26 categories of food from normal marketing channels and observed that spices ranked either in the middle or towards the higher risk end of the list evaluated as potential hazards to health.

Their assessment was based upon the fungal flora including species of *Aspergillus, Penicilium* and *Fusarium*. Similar observations have been made by Garrido *et al.* (1988) and Martinez, *et al.* (1988). In these two studies, the genera of *Aspergillus* and *Penicillium* were dominant. among the *Aspergillus* species *A. flavus, A. niger* and *A. glaucis* were frequently identified (Garrido, *et al.* 1988). Further studies of the *A. flavus* of which 8.22% turned out to be aflatoxigenic. Earlier, Dandavate and Shindle (1986) screened Chilli peppers collected from 8 markets in India and ascertained that the spice was infested by *Aspergillus, Fusarium* and *Macrophomina* which has not been reported by others. they observed that 7 out of 19 cultures of *Aspergillus flavus* showed mycotoxin producing potentials.

In Nigeria, the story is not different from those reported in other countries. Uzuegbu and Emifoniye (1984) carried out a survey of important genera of fungi causing post harvest spoilage of fruits and vegetables in Ondo State. The product studied included red peppers, onions, melon among others. Out of the 15 products studied 13 spoilage fungi species were identified, *Aspergillus* and *Fusarium* were the major and most abundant species in all the samples. Other fungi species isolated were *Penicillium*, *Geotrichium*, mucor and yeast.

Fungal contamination of spices and foodstuffs have been demonstrated to show no definite correlation with the environment possibly because most fungal contaminations occurred before the spices reach the retail shops with the fungal spores remaining dormant unless conditions are favourable for germination and growth (Llewellyn, *et al.*, 1988).

The most important mycotoxins likely to be encountered in spices are of course, the aflatoxins (Flannigan and Hui, 1976) produced by the related species of *A. flavus* and *A. parasticus*. which regularly grow on a variety of agricultural commodities under favourable environmental conditions. Of the four parental aflatoxins in the known series of these secondary metabolites aflatoxin B_1 (AFB_1) is reported to be the most hepatocarcinogenic (Buttler, 1965). Cell and tissue damage (Golumbic and Kulik, 1969) result primarily from its toxicity and carcinogenicity but it is also mutagenic. Aflatoxins have been reported to be involved in the aetiology of human

liver cancer in certain areas of the world (Denizel and Kosker, 1972; Karapinar, 1986) and aflatoxicosis has also occurred where man has been exposed to substantial quantities of the mycotoxins in his diet (Deger, 1976). Because of the widespread use of spices, it is important, therefore that contamination by aflatoxigenic and other mycotoxin producing fungi be controlled.

2.3 METHODS OF DECONTAMINATION

2.3.1 The Antimicrobial Activity of Spices

Many of the spices and herbs used today were known to the people of the ancient cultures throughout the world and they were valued for their preservative and medicinal qualities. Scientific experiments on antimicrobial properties of spices, herbs and their components have been documented in the 19th century and interest continues to the present (Corran and Edgar, 1933; Zaika and Kissinger, 1979; Hitokoto, *et al.*, 1980 and Zaika, 1988). It was also recognised quite early that the antiseptic power of spices and herbs resides in the essential oils and in some cases can be attributed to major components of the oils. Numerous experiments that have been carried out over the years indicated that many spices, herbs and their constituents possessed at least some antimicrobial activity. Examination of the available literature suggest that spices and herbs may be grouped according to their antimicrobial activity as shown in Table 2.2. Cinnamon, clove and mustard are mentioned most often as being the strongest inhibitors for a variety of microorganisms (Thompson and Cannon, 1986; Graham and Graham, 1987). Significant inhibitory properties have been reported for allspice, bay leaf, caraway, coriander, cumin, oregano, rosemary, sage and thyme. On the other hand, red pepper, ginger and black pepper possess little if any antimicrobial properties. This property of spices has been attributed to some of the components of the essential oils. Examples of these are given in Table 2.3.

2.3.2 Chemical Method

Although spices have antimicrobial properties, their action is selective and hence do not provide enough protection against contamination, therefore applicable

Table 2.2: Antimicrobial Activity of Spices and Herbs (Zaika, 1988)

Inhibitory Effect	Spice
Strong	Cinnamon
	Clove
	Mustard
Medium	Allspice
	Coriander
	Rosemary
	Bay leaf
	Cumin
	Sage
	Caraway
	Oregano
	Thyme
Weak	Black pepper
	Red pepper
	Ginger

Table 2.3: Antimicrobial Constituents of Spices and Herbs (Kellner and Kober, 1955)

Compound	Occurrence
Linalool	Coriander, Sage, rosemary basil
Carvacrol	Oregano, thyme
Carvone	Caraway, dill
1,8-Cineole	Sage, rosemary, cardamom
Cinnamaldehyde	Cinnamon Cassia
p-cymene	Cumin, thyme, oregano
Limonene	Celery seeds, caraway
Thymol	Thyme, oregano

decontamination methods are of considerable concern from economic, public health and environmental aspects. Different chemicals have been used at one time or the other.

Naito and Sakai (1988) used ozone in food preservation of cereals, grains, peas and spices. They exposed these agricultural products to air containing 0.5 to 50 ppm of ozone at 10°C and a flow rate of 100L/ min for an hour and then stored in polythene pouches at 10° and 30°C for 30 days. The decrease in microbial counts (*Bacillus* and *Micrococcus*) were predominant and of order 10 to 10^3. Further decrease in count was observed during storage due to residual effect of the ozone. The effect of ozone has been attributed to formation of peroxides and other oxide radicals and reduction in pH (Ben-Ghedalia, *et al.*, 1980). The reduction in pH of cotton straw treated with ozone from 6.11 to 2.28 was suggested to may have stemmed from organic acids derived from oxidation of lignin by ozone. Although they reported increased *in vitro* organic matter digestibility by ozone treatment, the increased phenolic compounds raised more doubts than joy.

Another method of fumigation is the use of ethylene oxide, ethylene bromide or propylene oxide (Frohnsdorff, 1981; Farkas and Andrassy, 1988). This method of decontamination has been shown to be a time consuming batch procedure and it appears to be beset with problems of uniformity of decontamination and requires a complex process of monitoring (Frohnsdorff, 1981). However, when properly carried out it was effective (Farkas and Andrassy, 1988) but not without affecting the sensory and/or other quality characteristics of the treated product (Farkas and Andrassy, 1988; Hayashi, *et al.*, 1991). A comparison was made (Farkas and Andrassy, 1988) between the antimicrobial efficacy of ethylene oxide treatment (800 g T gas per m^3 at 20°C for 6 hours) and irradiation with 4 or 8 kGy gamma radiation and their respective effect on the volatile oil content of black pepper and sensory characteristics of ground black pepper, ground paprika, onion powder and garlic powder and the water uptake of the later two seasonings. They observed that 4 kGy was sufficient to achieve a reduction of the viable cell count equivalent at least to the effect of ethylene oxide, but without affecting their sensory quality or other quality

characteristics. Neverthless, their investigation revealed that ethylene oxide treatment when carried out according to industrial practice caused a substantial reduction of the volatile oil of black pepper and aroma intensity of garlic powder. Another defect of fumigation has been shown to be reduction in protein solubility (Hayashi, *et al.*, 1991).

Despite the antimicrobial efficacy of fumigation, the process is not devoid of danger of chemical residues which represent a significant occupational health hazard for the handlers in the treatment plants hence its ban by many countries. (Pryde, 1977 and Handlos, 1979).

2.3.3 Heat/Steam

Heat sterilization has been the most regular method of decontamination. Usually the sample being decontaminated is heated to about 115°C for about 55 minutes. The method has been found effective at low temperature and shorter time. Hayashi *et al.*, (1991) observed that the total plate count after holding a 1% solution of plasma of initial microbial load of 2.2×10^4/g and after holding dehydrated sample for 20 minutes at 100°C was 1.1×10^3/g.

Heat treatment has been implicated to cause severe deterioration of quality (Saito and Taira, 1987). They opined that considering the heat sensitivity of the flavour and essential constituents of spices regular heat sterilization cannot be used.

2.3.4 Gamma Irradiation

Due to the observed effects and the resultant health consequences of other methods of food decontamination there has been a call for a more viable non-residual process and irradiation has proved very effective.

2.3.4.1 Irradiation as a Process

Food irradiation involves exposing foods to ionizing radiation, either to gamma rays emanating from a radioactive source such as Cobalt-60 or high energy electrons from an electron beam machine (O'Beirne, 1989). The concept is somewhat

analogous to exposing food to microwaves in a microwave oven though the equipment and effects are different. Only gamma rays come into contact with food and there is no radioactive contamination.

Gamma rays, one of the ionizing energies and most widely used in food and industrial radio-processing is an electromagnetic radiation of very short wavelength and belongs to the same family as ultraviolet waves, visible and infra-red lights, microwaves and radiowaves used for communication (IAEA, 1984). The use of other radiations for a wide field of different purposes, including the use of microwaves to cook food have been accepted. The failure of food irradiation to gain wider acceptance is not difficult to fathom. In the minds of millions of people radiation is associated with war on a scale the earth has never seen with accidents that pose health threats lasting for generations and with nuclear wastes that will be dangerous 10,000 years from now. Even recognising that radiation is an invaluable aid in diagnosing and treating diseases, sterilization of medical devices and pharmaceutical products, producing many kinds of manufactured goods, vast numbers of people are genuinely afraid of anything that would appear to increase the risk of exposure to radiation. In addition, there has been apparently wide public misunderstanding of what the process is, how it works and what it will and will not do. A major misconception is that food processed by radiation becomes radioactive (WHO, 1988).

In gamma irradiation, only the gamma rays come into contact with the food or whatever that is irradiated and therefore there is no radioactive contamination. In radiation processing of food, only gamma rays from cobalt-60 or caesium-137, X-rays generated by a machine at a maximum energy of five megavolts or electrons generated by a machine at a maximum energy of 10 megavolts can be used. Energies from these radiation sources have been shown to be too slow to induce radioactivity in any material including food exposed to them (IAEA, 1989).

2.3.4.2 Types of Irradiation Process

Although irradiation has not been universally accepted as a vital tool for the modern day technological advancement. It has been employed for the achievement of

many objectives ranging from agriculture to medicine. Screenivasan (1970) outlined five distinct objectives which can be achieved by exposing food to ionizing radiations and these are:-

a. radappertization - this is the total elimination of food - spoilage or disease causing organisms. Thus making the prepackaged food stable without refrigeration,
b radurization - the reduction of spoilage organisms sufficiently to retard spoilage,
c. radicidation - inactivation of all organisms posing public health hazard
d. destruction of insects infesting stored cereals, cereal products, grains and fruits and
e. control of physiological process e.g. delay of post harvest ripening in fruits and inhibition in tubers and bulbs thus extending shelf life.

These major biological effects and functional benefits of irradiation are summarised in Table 2.4. With increasing dose, the biological effects range from inhibition of cell division, slowing of plant physiological processes, to destruction of living organisms (insects, fungi and bacteria).

In all applications, the dose of irradiation is carefully selected in order to minimise any damage to quality. In fruits and vegetables, the use of higher doses than recommended can lead to excessive softening, surface lesions and bleaching of chlorophyll (Massey, 1968; Maxie and Sommer, 1968; Monselise and Kahan, 1968; Hayashi and Kawashima, 1983).

2.3.4.3 Mechanism of Action of Ionizing Radiation

When matter is tranversed by any of the forms of ionizing radiation (beta, cathode, gamma or X-rays) energy is absorbed and in some cases ion pairs are produced. Energy is absorbed by collision of ionizing radiation with particles of food, causing excitation of thousands of atoms in its path and occurring in time period less than 0.001 sec (Zirkle, 1935; Spencer and Fano, 1951). As a primary radiation distributes its energy throughout the volume of the absorber, many of the electrons

which one stripped from atoms in the process of ionization may themselves possess sufficient energy to ionize other atoms (Desrosier and Desrosier, 1987). These excitation and ionizing events produce a large portion of biological effects of radiation.

The biological effects of ionizing radiation on a living organism are associated not only with the impairment of a sensitive site (DNA) controlling the cellular reproduction and synthesis of cell components but with metabolic changes influencing the chemical composition (Graham, 1980). The primary radiation chemical changes in molecules can be produced by direct and/or indirect effects of radiation.

Direct effect involves those changes that appear as a result of the absorption of radiation energy by the molecules being studied ("target"). The theory of direct effect proposes that if a swiftly moving charged particle struck a molecular complex of biological material, the biological function of the complex was altered and/or destroyed (Desrosier and Desrosier, 1987). However within the past decade evidence abound that indicated that the direct "hits" may be responsible for some specific biological effects but that many of the effects are caused in whole or part by radiation induced ionization of the solvent system of the biological material.

In moist systems, the primary action of irradiation is the radiolysis of water, forming hydrated electrons, hydroxyl radicals and hydrogen atoms. These radicals contribute substantially to the biological effects of ionizing irradiation. These primary products are transient in nature and disappear either in reaction with each other and/or other food constituents, hence there is an indirect effect of irradiation of moist tissues, caused by these free radicals due to "activated water" (Desrosier and Desrosier, 1987; Yarmonenko, 1988).

In the radiolysis of water, a molecule is ionized by a charged particle which causes it to lose electron:-

$$\sim \quad H_2O \quad \rightarrow \quad H_2O^+ \quad + \quad e^-$$

Table 2.4: Biological Effects of Irradiation and Functional Benefits

Main Biological Effect	Functional Benefit	Dose (kGy)
Inhibition of cell division	Preventing sprouting	0.1 - 0.2
Slowing of harvest physiology	Retard spoilage/ senescence	0.25 - 0.75
Inhibition of fungal growth	Retards spoilage (soft fruits) Retards post harvest growth (mushroom)	1 - 2.5
Reduction of bacterial population	Retards spoilage (especially in meat poultry and fish). Decontamination of ingredients (spices, etc.)	up to 10 kGy
Elimination of *Salmonella*	Improves food safety (especially in poultry)	2.5 - 7.0

Adapted from O'Beirne (1989)

The ionized water molecule reacts with another neutral water molecule to form the highly reactive hydroxyl radical $OH^{\bullet}$:

$$H_2O^+ + H_2O \rightarrow H_3O^+ + OH^{\bullet}$$

The ejected electron very rapidly interacts with the surrounding water molecules and a highly excited molecule H_2O^* appears. It dissociates, in turn, with the formation of two radicals $H^{\bullet}$ and OH°:

$$H_2O^+ + e^- \rightarrow H_2O^* \rightarrow H^{\circ} + OH^{\circ}$$

These free radicals contain unpaired electrons and are therefore distinguished by an exceedingly high reactivity. The reactions are very fast, of the order of 10^{10} - 10^{11} $m^{-1}s^{-1}$ and reaction rates are controlled by diffusivity of the primary reaction products (Simic, 1983).

In the presence of oxygen it has been known that other radiolysis products are formed that have oxidizing properties namely, the hydroperoxide radical $HO_2^{\bullet}$, hydrogen peroxide H_2O_2 and atomic oxygen.

$$H^{\bullet} + O_2 \rightarrow HO_2^{\bullet}$$

$$HO_2^{\bullet} + HO_2^{\bullet} \rightarrow H_2O_2 + 2O_2$$

In addition to these oxidation products a stabilized electron form, that is hydrated electrons (e^-_{aq}) appears in the hydrolysis of water.

Among the radiolytic products of water hydroxyl radicals are said to be most reactive towards unsaturated compounds especially those with conjugated polyene chain while hydrated electrons and hydrogen atoms react with conjugated polyene chains forming free radicals by addition reactions.

2.3.4.4 Effects of Ionizing Radiation on Food

The effects of ionizing radiation on proximate composition of some spices have been studied. Bachman, *et al.* (1978) followed the changes in the chemical composition of caraway and cardamom irradiated with ^{60}Co γ-radiation in the dose range of 5 - 30 kGy. The result of their investigation showed that the volatile oil yield decreased with increasing radiation dose. A dose of 10 kGy was observed to decrease the yield by 10% and that of 30 kGy by about 20%. They opined that this might be due to changes of the structure of the caraway cell membrane which speeded up the evaporation of oils in the irradiated samples. A further evaluation of the major components of the oil carvone (53%) and limonene (46%) showed no significant change in content even at higher doses. With cardamom a similar result was obtained, 7.5 kGy dose decreased the oil content by 15.2%. However, they observed that the amount of terpinyl acetate increased a little up to 6% at 12.5 kGy dose but cineole was observed to decrease slightly.

Farnesenes (α and β isomers) are known as one of the major constituents of many spices and contribute to the aromatic sensory characteristics. It has been demonstrated that UV irradiation of α-farnesene simply led to the cis-trans isomerization (Courtney and McDonald, 1969). When the β-isomer was directly irradiated there was formation of a mixture of bicyclohexanes plus a substituted cyclobutene and a compound which was suspected to be cis-β-bergamotene. However, the direct irradiation of myrcene has been reported (Crowley, 1962) to yield a substituted cyclobutene; 5,5-dimethyl-1-vinyl bicyclo-2,1,1-hexane, β-pinene and four unidentified products. The formation of β-pinene was proposed to presumably proceed via a six-membered ring intermediate and probably involved excited singlet states of the molecule



Changes in the hydrocarbon composition of contaminated spices after gamma irradiation have been studied by Gruiz and Biacs (1978). They observed that the effect of the treatment on hydrocarbon content of the spices was species-dependent and on the total lipid content. At a dose of 4.5 kGy a slight decrease in %-total hydrocarbon was observed in paprika and black pepper but with nutmeg a decrease up to 15% was ascertained. Considering the specific (C_{15} - C_{18}) hydrocarbons, it was found that in the nutmeg there was a 16% increase while in paprika and black pepper they decreased.

Josimovic, *et al.* (1978) did not observe any changes except an increase in carbonyl compounds in irradiated powdered paprika which they found to be directly proportional to the dose. Some of those carbonyl compounds are known to contribute immensely to the sensory characteristic of spices. The influence of radiation dose on the sensory quality was established by Uchman, *et al.* (1983). According to their report with increasing radiation dose, the constituents of the essential oils and aromatic carbohydrates in black pepper were also observed to change. Threshold of detection and recognition and difference became higher. Irradiation of black pepper was observed to have a negative influence on its sensory quality. But, Farkas and Andrassy (1988) observed that radiation treatment enhanced the intensity components of onion flavour as well as the water uptake of the onion powder. However, Zehinder (1981) observed that the "biting" quality was not affected by this treatment. Orange peel, lemon peel and fenugreek powders were found to have lost their typical aroma after irradiation. Similarly, coriander powder was known to be relatively sensitive to ionizing radiation.

Bachman, *et al.* (1978) investigated the alteration in the chemical composition of spices and spice mixes. No distinct changes in lipid fraction composition were noted although a total increase with a dose up to 20 kGy was found. this they suggested may be due to apparent increase in extractability. Just like the effect of irradiation on essential oil compounds was constituent-specific, the effect of γ-irradiation on fatty acid levels and composition depends on the fatty acids present. Katta, *et al.* (1991) studied the effect of various levels (0 - 3 kGy) of gamma irradiation on fatty acid

levels in breast meat of chicken and observed a significant decrease in the amount of palmitic acid and a concomitant increase in oleic acid level as irradiation dose level was increased. Earlier, oleic acid has been shown (Maxwell and Rady, 1989) to increase steadily with increased doses of gamma irradiation in polar lipid fractions. Katta, *et al.* (1991) reasoned that the decrease in palmitic acid and increase in oleic acid could be due to lipolysis induced by irradiation.

Changes resulting from the irradiation of lipids may be grouped as :-

a. gross changes in physical and chemical properties;

b. auto-oxidative changes and

c. non-oxidative radiolytic changes.

The general mechanism of the radiolysis of fats involved primary ionization, followed by migration of positive charges towards carboxyl groups and the double bonds and cleavage at preferential positions near the carbonyl group. The resulting free radical engage in various reactions leading to the formation of stable radiolytic products, which have been classified as primary, recombination and secondary products according to the mode of their formation. In the case of unsaturated fatty acids dimerization reaction appeared to be of major importance. The cause of radiolysis in fats was shown to be significantly influenced by the phase state and temperature (Nawar, 1977).

Carbohydrates are components of many foods. They also are available as isolates. Their response to irradiation varies with the circumstances in which the carbohydrate existed, pure carbohydrates are very sensitive to radiation when in the crystalline state and gives a response which is dependent upon the particular crystalline form irradiated. Imperfections of the crystalline lattice as for example, produced by freeze drying reduce the effectiveness of energy transport in a crystal and probably account for variations related to crystalline form. Depending upon the carbohydrates irradiated a great many substances have been identified including hydrogen, carbon dioxide, aldehydes, ketones, acids and other carbohydrates (Dauphin and Saint-Lebie, 1977).

Lower molecular weight sugars such as glucose, maltose, erythrose, ribose and mannose are formed in dose dependent yield for instance 20 nmol of maltose/g of starch at 10 kGy, 40 nmol at 20 kGy (Berger, *et al.*, 1973). Many substances provide protection against radiation degradation of carbohydrates (Phillips, 1972). among these are amino acids and proteins (Diehl, *et al.*, 1978). These observations point to the influence that compounds associated with carbohydrates in a food can exert on the end results and care must be exercised in extrapolating findings obtained for pure substances to the complex systems that exist in foods.

The radiation dose employed in food irradiation do not have adverse effect on protein. Nevertheless, protein molecules respond to radiation. The effect of irradiation on a protein had been reported to depend on a number of factors such as the protein structure, its composition, the presence of other compounds and its state (Urbain, 1978). Because they are large molecules, proteins generally provide a number of loci for action by irradiation. Although the energy may be absorbed at one location, it can be transferred to another within the molecule, where, at what might be called "sensitive site" bond breaking occurred. Elias and Cohen (1977) have indicated that deamination, decarboxylation and denaturation are the primary results from the irradiation of proteins while the indirect results arose from the decomposition and/or recombination of the free radicals generated during the primary process.

The efficacy of gamma irradiation for decontamination of whole and ground spices examined by several authors (Farkas and Andrassy, 1988; Sharma, *et al.*, 1984; Sharma, *et al.*, 1989 and Munasiri, *et al.*, 1987) have shown that a dose of 10 kGy was effective in eliminating spice microflora. Moulds are moderately sensitive to irradiation (Wills, 1983). In grains and pulses, which are liable to support toxigenic moulds if mishandled, all moulds are greatly reduced in number by irradiation (Ingram and Farkas, 1977). For example Bridges, *et al.* (1956) reported the destruction of *Aspergillus flavus* strains with a dose of 3.5 kGy in ground corn samples containing 12.5 - 23% moisture. In studies on flour, white bread and raisin bread, Harting, *et al.* (1973) reported that an irradiation dose of 0.5 kGy reduced the total number of viable moulds by approximately half. Ito, *et al.* (1973) in their studies on

Aspergillus spoilage of rice, corn meal and wheat concluded that the sterilization doses for spoilage moulds of cereal grains should be 5 to 6 kGy. Recently, Toofanian and Zare (1987) examined the effect of gamma irradiation on *A. flavus* growth and aflatoxin production on cranian pistacho and ascertained that a dose of 3 - 4 kGy has a significant effect on delaying of the fungus growth and toxin production.

Spices exposed to 10 kGy of gamma irradiation have been demonstrated to be devoid of the presence of *E. coli* or *B. cereus* (Sharma, *et al.*, 1989) which shows that bacteria are more resistant to irradiation than fungi.

2.3.4.5 Factors Affecting Radiation Effect in Food

The effect of irradiation and reduced moisture content has been studied on the keeping quality of commercial spices, nutmeg, black pepper and white pepper. Saputra, *et al.* (1981) found that a dose of 5 kGy could reduce the microbial load of the spices by as much as 2 - 4 log cycles for the total plate count and 1 - 3 log cycles for the total mould and yeast count. The microbicidal effect achieved by irradiation was found to be less in more humid products. Hesepeels (1982) reported that a dry enzyme preparation (a_w = 0.25) was found to be highly radiation resistant, enzyme activity being unaffected even at a dose of 25 kGy. This high radiation resistance was attributed to the strongly bound nature of the available water which makes it unavailable for radiolytic reactions. With increasing water activity, the enzyme was found to be more susceptible to radiation damage. At a water activity of 0.86 approximately 20% enzyme activity was lost with a dose of 20 kGy. This increased radiation effect could mean that probably some of the components of the enzyme preparation went into the solution absorbing large amount of water. This observed partial deactivaion could also be caused by the radiolytic products of water.

The influence of water activity on degradation of polysaccharides was investigated using dextran as a model (Adam, *et al.*, 1979). When solid dextran was irradiated, degradation reaction was observed to predominate whereas when aqueous solutions of dextran were irradiated, cross linking and branching reactions were more pronounced.

The effect of water content on radiation effect on isolates have been reported to be same with that of whole plant products. This effect of water content in the radiosensitivity of seeds was first observed by Ehrenberg and Nybom (1954) and Caldecott (1954) separately. They demonstrated that the sensitivity of barley seeds to x-rays decreased as the water content of the embryo increased from about 4 to 8%. Later, Caldecott (1955) reported that a plateau was reached at about 8% moisture level and further addition of water to the embryo (up to 60%) did not result to additional modification of sensitivity, provided that cellular activity was inhibited by low temperature. If however cellular activity was not inhibited, it was observed that there was a rise in the radiosensitivity beyond about 16% moisture content (Notani and Gaur, 1962).

It has also been shown that the free radical signal in irradiated barley seeds of about 10% water content decreased slowly during post-irradiation storage *in vacuo* at room temperature. Furthermore, Conger, *et al.* (1966) deduced that this decrease was directly correlated with a reduced oxygen response. Two years later, Conger, *et al.* (1968) offered a possible explanation for the observed change in oxygen sensitivity with small change in seed water content. According to the report, water provided a medium for movement of radicals, the amount and physico-chemical nature of the water present would be of utmost importance. The water molecules may be bound to the molecules of cell constituents by forces of hydration or van der Waal's forces, thus preventing mobility of some of the water molecules.

There may be specific water content, e.g. about 11% at which the proportion of free water in the seed would be of extreme importance in terms of regulating the mobility and hence the chemical interactions of radicals. Therefore a small increase in seed water content beyond the specific point might provide a medium for radical movement and radical-radical recombinations. Potential damage would be reduced because the radical-radical recombinations excludes radical-oxygen interactions. However, they noted that the critical point at which the change of oxygen sensitivity occurred in relation to water content was probably not absolute. Rather this point may shift with temperature, oxygen availability, ionization density of the radiation

dose rate and particularly with post-radiation storage and time. Ahnström and Sanner (1971) demonstrated the effect of temperature on the disappearance of oxygen sensitive centres of irradiated seeds. Oxygen-sensitive centres were present for more than 6 hours when the seeds were soaked at 0°C but most of them disappeared within 1 hour at 20°C.

Chapter Three

MATERIALS AND METHODS

3.1 SAMPLE COLLECTION AND PREPARATION

About 10 kg each of ginger (*Zingiber officinale*) Roscoe knobs, hot red pepper (*Capsicum frutescens*) fruits and Ashanti pepper (*Piper guineense*) berries were bought from Sabon Gari Market in Zaria, Kaduna State. Coriander (*Coriandrum sativum*) fruits were purchased from Maiduguri main market in Borno State of Nigeria.

The samples were sun dried to constant weights and then divided into two portions each. A portion of each was ground to fine powders and then packaged in 50 polythene bags. The other unground (whole) portions were equally packaged into 50 polythene bags. Each of the sample portions was later divided into five sets of 10 each and labelled 0, 1, 2, 3 and 4 signifying 0 kGy, 2.5 kGy, 5.0 kGy, 7.5 kGy and 10.0 kGy respectively.

The samples were exposed to pre-determined radiation doses (2.5, 5.0, 7.5 and 10 kGy) at a dose rate of 3.3898 kGy/hr from a ^{60}Co gamma irradiator (Gamma cell 220 Canada Atomic Energy Limited) at Bicot, Vom. The grinding and radiation treatment were carried out within 24 hours. After irradiation the samples were stored on shelves in a well ventilated room and collected monthly for the different analyses.

3.2 REAGENTS

The piperine, capsaicin, vanillin, gingerol and linaool were products of SIGMA Chemical Co. USA. The acetone used was obtained from Riedil-De Haen, Ag. Silica gels, alumina, activated charcoal, selenium oxide, diethyl ether and chloroform were obtained from BDH Chemical Ltd. (London) and were of analytical grade. Calcium chloride, sodium hydroxide, ethanol, petroleum spirit (60 - 80°), benzene, methanol, xylene, hydrochloric acid, sulphuric acid, sodium acetate, glucose, sucrose, starch, fructose and liquid paraffin were of M & B Ltd. England. Boric acid was of Phillip

Harris Medical Ltd. Birmingham. All other reagents were general purpose reagents (GPR) grade obtained from Hopkin and William Ltd. England.

3.3 MICROBIOLOGICAL STUDIES

One gram of each sample was taken immediately the package was opened and added under sterile conditions to screw cap bottles containing 9 ml of sterile distiled water and well mixed by manual agitation for 1 minute. Dilution were made according to standard method of the American Spice Trade Association (Anon, 1976).

Viable bacterial count: One millilitre of the diluted samples were transferred into duplicate sterile plates of nutrient agar and incubated at 30°C for 48 hours and the number of CFU counted.

Viable Spore Forming Bacteria: The procedure was analogous with that of viable bacterial count except that the samples were heated for 10 minutes at 80°C to eliminate all vegetative cells. Inoculated plates were incubated at 30°C for 72 hours.

Number of Yeast and Fungi: One millilitre of the diluted samples were inoculated to duplicate plate of Wort Agar and incubated at 30°C for 72 hours and the number of yeast and mould colonies were counted.

Identification of Isolates: The surface colonies appearing on each countable plate were grouped on the basis of colony morphology. Gram reaction, and spore shape and location. One isolate from each morphological group was selected for further studies and subculture on the appropriate Agar. These isolates were subsequently identified according to Obi and Krakowiak (1983).

3.4 PROXIMATE ANALYSES

The whole samples were ground, after the removal of the sample for microbiological studies with mammonlex blender.

3.4.1 Protein Estimation

The protein content was determined using the improved micro-Kjeldahl method for nitrate free samples (AOAC, 1980). A small quantity, 0.2000 g of the ground

sample was accurately measured using a preweighed filter paper, properly folded and placed into a digestion flask. Into the flask were added 0.08 g of catalyst (containing 96% Na_2SO_4, 3.5% $CuSO_4$ and 0.5% SeO) and 2.5 ml of H_2SO_4 (nitrogen free). The flask was placed in an inclined position and heated gently until frothing ceased. It was briskly boiled until solution became clear and then for another 30 minutes. The flask and its contents were allowed to cool to room temperature and 20 ml of distiled water added. After cooling few granules of Zn was added (to prevent bumping) then 3.5 g of solid NaOH. The flask was immediately connected to a distillating bulb and the tip of the condenser immersed in standard acid (0.1M HCl) containing 5 drops of screened methyl blue as indicator in a receiver, into which ammonia was trapped. The heating was continued until about 15 ml of the distillate was collected.

The excess acid in the distillate was titrated with standard NaOH (0.1 M). a correction blank was prepared by subjecting the same mass of filter paper (used for weighing the sample) to the above conditions.

Calculation

$$\%N = \frac{(\text{ml std. acid x molarity of acid}) - (\text{ml NaOH x molarity of NaOH}) \times 1.400)}{\text{weight of sample}}$$

Total Protein = % N x 6.25

3.4.2 Lipid Estimation

The official final action of AOAC (1980) was used. Three grams of the ground sample was weighed into properly dried and weighed fat-free thimble. The thimble was plugged with cotton wool and reweighed. The thimble was then placed in the soxhlet extractor and solvent petroleum ether (60 -80%) added until it siphoned over once into a preweighed 500 ml flask. More solvent was added until the barrel of the extractor was half full. The condenser was replaced and placed on the heater. The heater was adjusted so that the solvent boiled gently and siphoned over approximately for 6 hours. After the 6th hour when the solvent has fully siphoned

over and the barrel of the extractor was empty, the condenser was detached and the flask quickly removed. The extracted fat was concentrated in rotary evaporator and the flask was reweighed. The percentage of fat was calculated thus:-

$$\% \text{ fat} = \frac{\text{weight gained in flask}}{\text{weight of sample}} \times 100$$

3.4.3 Acid Value and Free Fatty Acid Content

The method described by Cock and van Rede (1966) was used. Ten grams of petroleum ether extract was dissolved in 50 ml of freshly neutralized 96% ethanol-diethyl ether (1:1 v/v) mixture. The resultant solution was titrated with 0.1M NaOH using phenolphthalein as indicator.

Calculation:-

Wt of sample = w

Volume of NaOH used = v

molarity of NaoH = N

molar mass = M = 282 (molar mass of oleic acid was used)

$$\text{Acid value} = \frac{56.1 \times Nv}{w}$$

$$\text{FFA \%} = \frac{vN \times M}{10w}$$

3.4.4 Moisture Content

The AOAC (1980) method was used. Clean petri dishes were dried in the oven at 80°C for about 30 min. cooled in a desiccator and weighed (w_1). Five grams portions of the ground samples were accurately weighed in the prewieghed dishes (w_2). The samples were then dried in an oven at 50 - 60°C for about 5 hours for the first drying, quickly transferred to a desiccator to cool and then weighed with minimum exposure to the atmosphere. The procedure was repeated, drying for about

3 hours each time until constant weights (w_3) were obtained. The loss in weight in relation to the sample weight was expressed as the moisture content.

$$\text{Moisture (\%)} = \frac{\text{Loss in weight due to drying}}{\text{weight of sample}}$$

3.4.5 Total Available Carbohydrate (TAC)

The method outlined by Oyeleke (1984) was used. About 20 mg of each sample was accurately weighed and transferred to a graduated 100 ml measuring cylinder. Ten millilitres of distiled water added and stirred with a glass rod to thoroughly disperse the sample. Thirteen millilitres of 52% perchloric acid reagent was added and frequently stirred with a glass rod over a period of at least 20 minutes. The rod was washed down with water and the content diluted to 100 ml with distiled water. The whole volume was transferred into a 250 ml volumetric flask and made up to volume with distiled water. The flask was thoroughly shaked and filtered through a filter paper.

One millilitre of the filtrate was pipetted into a test-tube in duplicate. Into two test-tubes were added 1 ml of distiled water each. Standard glucose solutions (0.05, 0.1 and 0.15 mg/ml) were pipetted out in duplicates into another set of test-tubes. Rapidly 5 ml of freshly prepared anthrone reagent (0.1% in H_2SO_4/H_2O 76:33) were added and thoroughly mixed. They were then placed in a boiling water bath for exactly 12 minutes, quickly cooled and the absorbance of each tube read at 630 nm against the reagent blanks.

Calculation:

$$\text{TAC (as \% glucose)} = \frac{2.50 \times b}{a \times w}$$

where a, is the absorbance of standard, b, is the absorbance of sample and w, is the weight of sample.

3.4.6 Extraction of Sugars

A modified method of Bell (1955) was used for the extraction of 0.02 g sugars of each sample (ground) was weighed into a round bottomed flask and into this was poured 50 ml of 80% (v/v) ethanol. The resultant mixture was refluxed for 6 hours at 84 ± 2°C. At the expiration of the 6 hours, the flask and its content were cooled and the mixture centrifuged at 400 rpm for 20 min. The supernatant was concentrated *in vacuo* with rotary evaporator at about 50°C. The concentrated solution was diluted to 100 ml with distiled water.

3.4.6.1 Estimation of Total Sugars (Hexose)

Total sugars was analysed by a colorimetric method (Dubois *et al.*, 1956). Two millilitres of the diluted sugar extract was pipetted into a test-tube in duplicates. Into each tube was added 0.05 ml of 80% phenol solution and 5 ml of concentrated H_2SO_4 to the surface of the liquid. The reaction mixture was allowed to stand for 10 minutes after which it was shaken and placed in a water bath at 30°C. The absorbance was read at 490 nm. a standard curve was prepared using 0 - 70 μg/ml glucose solutions.

3.4.6.2 Estimation of Reducing Sugars

The reducing sugar content was determined colorimetrically by the dinitrosalicylate (DNS) method (Clark and Switzer, 1964). One millilitre of the diluted sugar extract was pipetted into two test-tubes and made up to 2.5 ml with distiled water and 2 ml of DNS added. The tubes with their contents were thoroughly shaken, heated for 5 minutes in a water bath maintained at about 100°C and cooled under tap water. the content of each tube was diluted to 2 ml with distiled water and the absorbance of the solution were taken at 540 nm. A standard curve was prepared using a 0 - 1.08 mg of glucose and fructose in a reaction mixture.

3.4.6.3 Estimation of Sucrose Content

van Handel (1968) method of direct micro-determination of sucrose was used. To 0.1 ml of the reagent blank, standard sucrose solutions (containing 20, 40, 60, 80

200 μg sucrose) and test solutions were added to 0.1 ml of 30% aqueous KOH and each mixture was heated at 100°C for 10 minutes to destroy the reducing sugars, then cooled to room temperature. Three millilitres of freshly prepared Anthrone reagent (150 mg of anthrone dissolved in 76 ml of H_2SO_4 and 30 ml H_2O) was added and heated at 40°C for 15 minutes. The absorbance was taken at 620 nm.

3.4.6.4 Fructose Estimation

A colorimetric method (Hessler, 1959) was used in the estimation of fructose content of the spices. The alcoholic extract was used. Two ml of the different concentrations (0.05 - 0.3 mg ml^{-1}) of fructose standards or the unknown was measured into large borosilicate glass test-tubes in duplicates. To each tube was added 4 ml 0.5% ρ-anisidine reagent (0.5 g in 100 ml of 85% phosphoric acid). The reaction mixture was heated to boiling and then cooled to room temperature. A greenish yellow colour developed after 30 mins of cooling. Absorption was read at 450 nm.

3.4.7 Ash Content

The method described by AOAC (1980) was used. Porcelain crucibles were ignited in a muffle furnace for one minute, transferred to a desiccator to cool and weighed. Three grams of the ground samples were weighed into the crucibles. The crucibles were heated in muffle furnace at 500°C to burn off all organic matter. the crucibles were removed when white ash was obtained. The crucibles were then transferred to the desiccators to cool and weighed.

$$\% \text{ Ash} = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

3.4.8 Volatile (Essential) Oil Extraction

The AOAC (1980) official final action methods were used. Pulverized portion of the samples (about 20 g) were accurately weighed into 1-L flask and about 500 ml of water added. This was heated for eight hours and the distillate trapped in a lighter than water clevenger volatile oil trap. The percentage of volatile oil was calculated thus:-

$$\% \text{ Volatile oil (v/w)} = \frac{\text{volume of oil}}{\text{weight of sample}} \times 100$$

3.4.8.1 Analysis of Volatile Oil

Analytical gas chromatography (GC) of the essential oil was carried out on a Hitachi 663 -30 fitted with FID detector at 250°C. An FFS bonded PEG 20 M column (50 m x 0.25 mm (i.d)) with 0.3 μm phase thickness was used. The carrier gas was helium at a flow rate of 30 ml/min and an inlet pressure of 1.2 kg/cm^2. The column temperature was programmed from 80 to 240°C at 3°C/min increase rate. The injection temperature was 250°C. GC data were recorded at a chart speed of 5 mm/min with a chromatoprocessor 833 -A linked to the GC.

For the combined GC-MS, a Hitachi GC-MS M-80B (M-0101 CPU) was used. The GC using the FFS bonded PEG 20M column was programmed from 70 - 210°C at 3°C/min with mass spectrometer operating at 70 eV and ion source temperature of 180°C. The GC/GC-MS analyses were carried out at Tokyo Research Lab., Nagoka Perfumery Co., Tokyo Japan (courtesy of Dr. Seiji Hashimoto).

3.4.9 Oleoresin Extraction and Estimation

Different solvents were used for different spice samples, however, the procedure was essentially the same. In each case 5 g of the ground sample was weighed into a fat-free thimble and the thimble plugged with cotton wool and reweighed. The thimble was then placed in the soxhlet extractor and enough of the appropriate extrant (methanol for capsicum, ethanol for ginger, chloroform for *piper*

guineense and 2-methyl butene for coriander) added. The condenser was replaced and system heated. The solvent was allowed to siphon over a period of 6 hours. After which the solvent was removed using rotary evaporator and the flask which was previously weighed, reweighed. The percentage of oleoresin was calculated as follows:

$$\% \text{ Oleoresin} = \frac{\text{weight gained by flask}}{\text{weight of sample}} \times 100$$

3.5 DETERMINATION OF ACTIVE PRINCIPLES

3.5.1 Extraction and Determination of Linalool: Coriander

Extraction: Five grams of ground coriander seeds were homogenized in 15 ml of triply distiled 2-methly butane. The homogenate was allowed to stand for 10 min, then filtered through Whatman No. 1 filter paper. The process was repeated three times with the residue. The filtrate were combined and concentrated using rotary evaporator.

Determination of Linalool: (Manolov and Georgiev, 1967). Into 5 ml of toluene was dissolved 0.15 g of the extract. Then 1 ml of 50% $NaNO_3$ solution (w/v) and 1 ml of 25% HCl(v/v) were added and the mixture shaked. After 3 minutes, 2 g of anhydrous Na_2SO_4 was added to the toluene phase which had been separated from the aqueous layer. The reaction mixture was allowed to stand for another 3 minutes after which the absorbance was read at 680 nm. Pure linalool was used in preparing a standard curve.

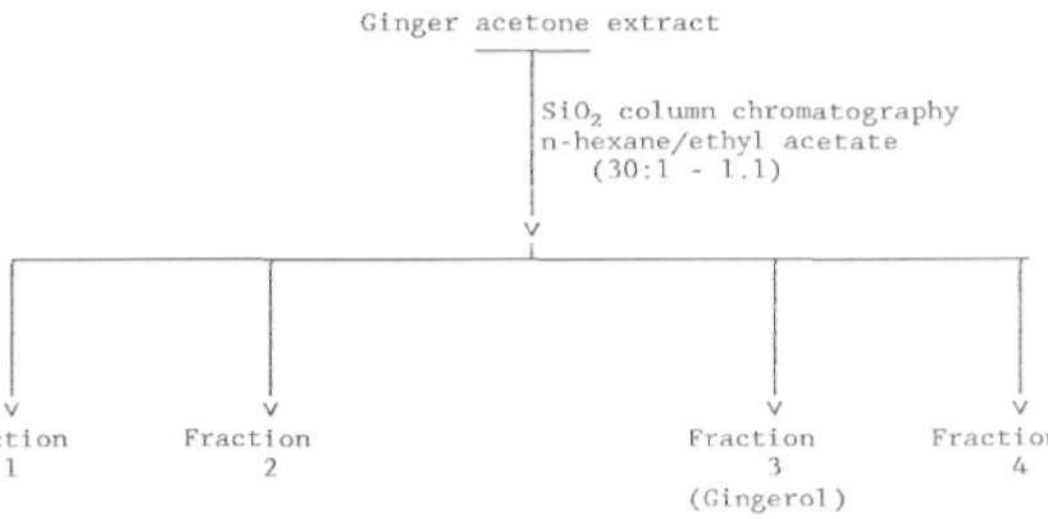
3.5.2 Extraction and Determination of Piperine from Ashanti Pepper

Piperine was extracted using the same method for linalool extraction however, the extractant was chloroform. The extract was purified by thin-layer chromatography on silica gel developed with a mixture of benzene, hexane and methanol (2:2:1 (v/v)) as described by Sardi and Lasiano (1978). The piperine was identified with UV light,

eluted with ethanol and determined spectrophotometrically at 343 nm with ethanol as blank. A standard curve was prepared using standard solutions of piperine in ethanol.

3.5.3 Determination of Gingerol

Separation of the active principle was achieved as shown below using column chromatography with silica gel as the absorbent. The acetone extract was fractionated with an eluting solvent on n-hexane/ethyl acetate with gradient of 30:1 - 1.1 (Yamahara, *et al.*, 1985)



The fraction containing the gingerol (Fraction 3) was concentrated with rotary evaporated and dissolved in ethanol and the gingerol content determined spectrophotometrically (725 nm) with Follin-Denis reagent using vanillin as standard (Nambudri *et al.*, 1975)

3.5.4 Determination of Total Capsaicinoids

Total capsaicinoids was determined as described by Ogbadu, *et al.* (1989). Extraction of the capsaicinoids were carried out in a soxhlet apparatus for 6 hours using 5 g methanol as the solvent. After extraction, the volume of the extract was reduced to 50 ml using rotary evaporator. The extract was purified by column chromatography method. The column was packed with 24 g of alumina made into

slurry with methanol followed by two other layers of 1.6 g and 0.8 g of activated charcoal and silica gel respectively each made into slurry with methanol. The eluate obtained was then used in the determination of capsaicinoids using the spectrophotometric method. A calibration curve was also prepared for the spectrophotometric quantification of capsaicinoids using commercial standard capsaicin.

3.6 STATISTICAL ANALYSIS

All experiments were done in duplicates. Data were analysed using a Statistical Analysis System Package (SAS, 1980). The significance of variation in types, levels and time were determined using analysis of variance. Duncan multiple range test was used to determine significance of differences within treatments.

CHAPTER 4

RESULT AND DISCUSSION

4.1 MICROBIOLOGICAL STUDIES

Table 4.1 shows the prevalence of microbial species in the spices before irradiation. The genera of *Aspergillus* and *Penicillum* were the dominant fungi and were found in all the spices. These species had earlier been identified as the principal moulds that infest red Ashanti pepper (Llewellyn *et al.*, 1988). However *Micrococus* was found in the capsicum (red pepper). *Fusarium* spp were prevalent in capsicum, Ashanti pepper and ginger.

Moulds are known to be relatively sensitive to irradiation (Wills, 1983). Irradiation reduced the total fungal load by 2 and 3 log cycles for all the spices irradiated at 2.5 and 5.0 kGy respectively (Fig 4.1). There was complete elimination of the fungi in all the spices except capsicum at 7.5 kGy.

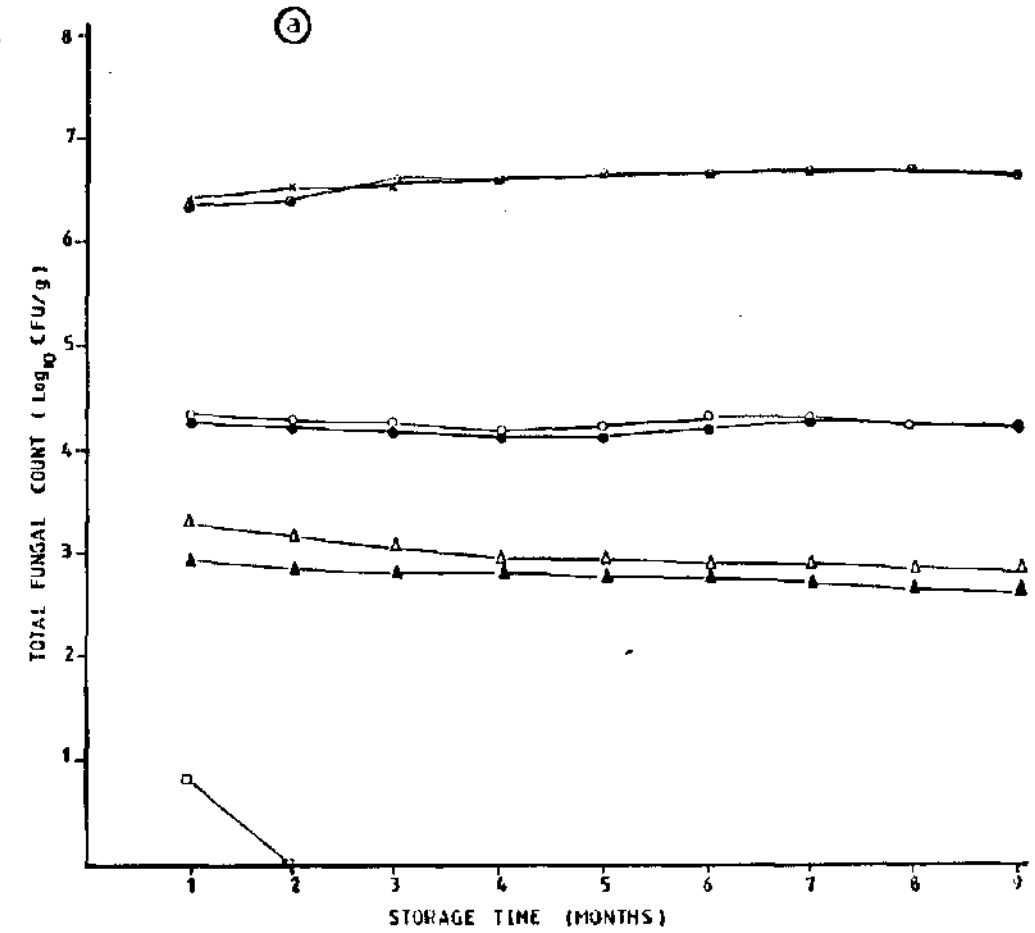
Coriander was observed to be highly contaminated by fungi (log 7.23 colony forming units per gram) followed by capsicum. The Ashanti pepper had the least fungal count (log 5.57(CFU/g)). The lower fungal count of Ashanti pepper may be attributed to some inherent properties of the spice. Black pepper (*Piper guineense)* has been considered as a poor substrate for fungal growth and aflatoxin production (Madhyastha and Bhat, 1984). This property of black pepper was attributed to the active principle - piperine and the essential oil.

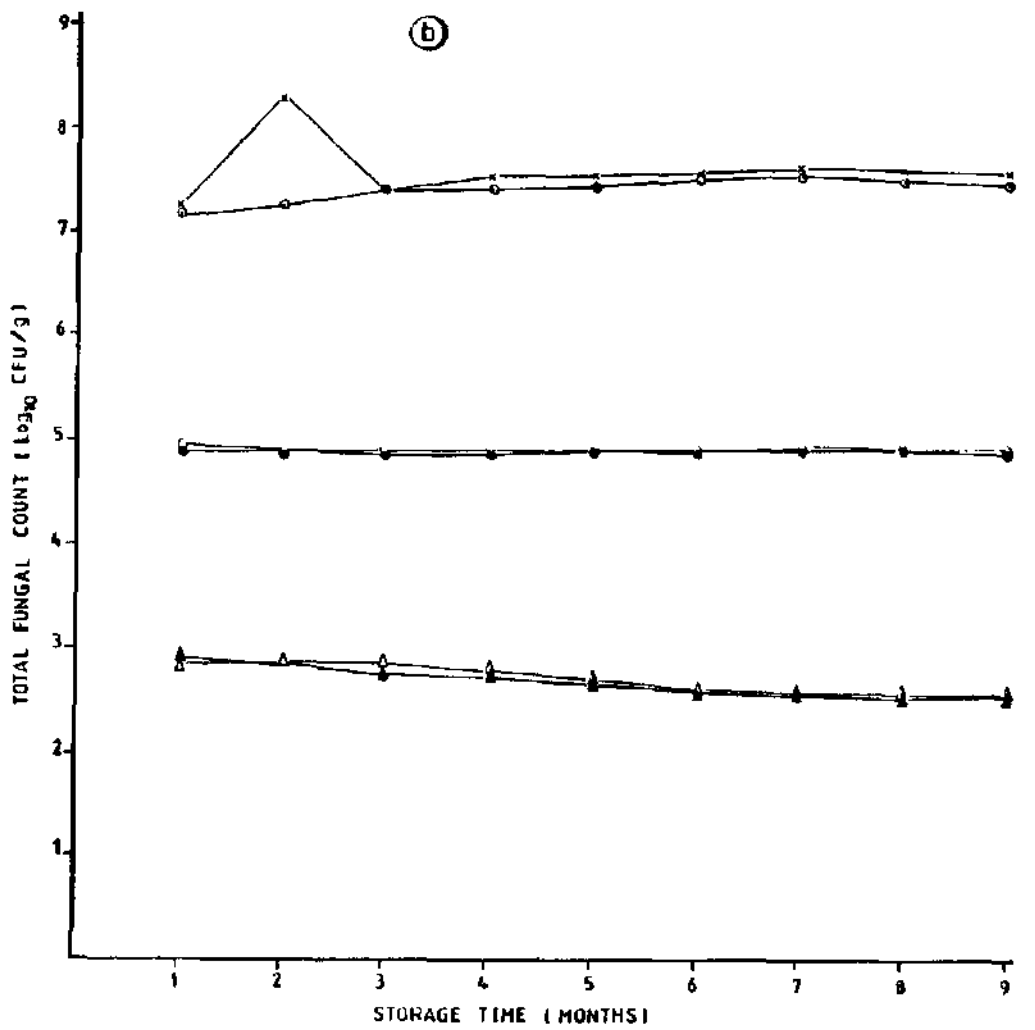
The form (that is whether whole or ground) also affected the fungal load in both irradiated and unirradiated samples. Although statistically insignificant ($P > 0.05$), the ground samples in all cases had slightly lower count. The form - effect could apparently be due to increased exposure of the microbes to the antimicrobial principles of the spices. Zaika, (1988) classified spices according to their antimicrobial effects into three categories, namely: strong, medium and weak. Coriander was

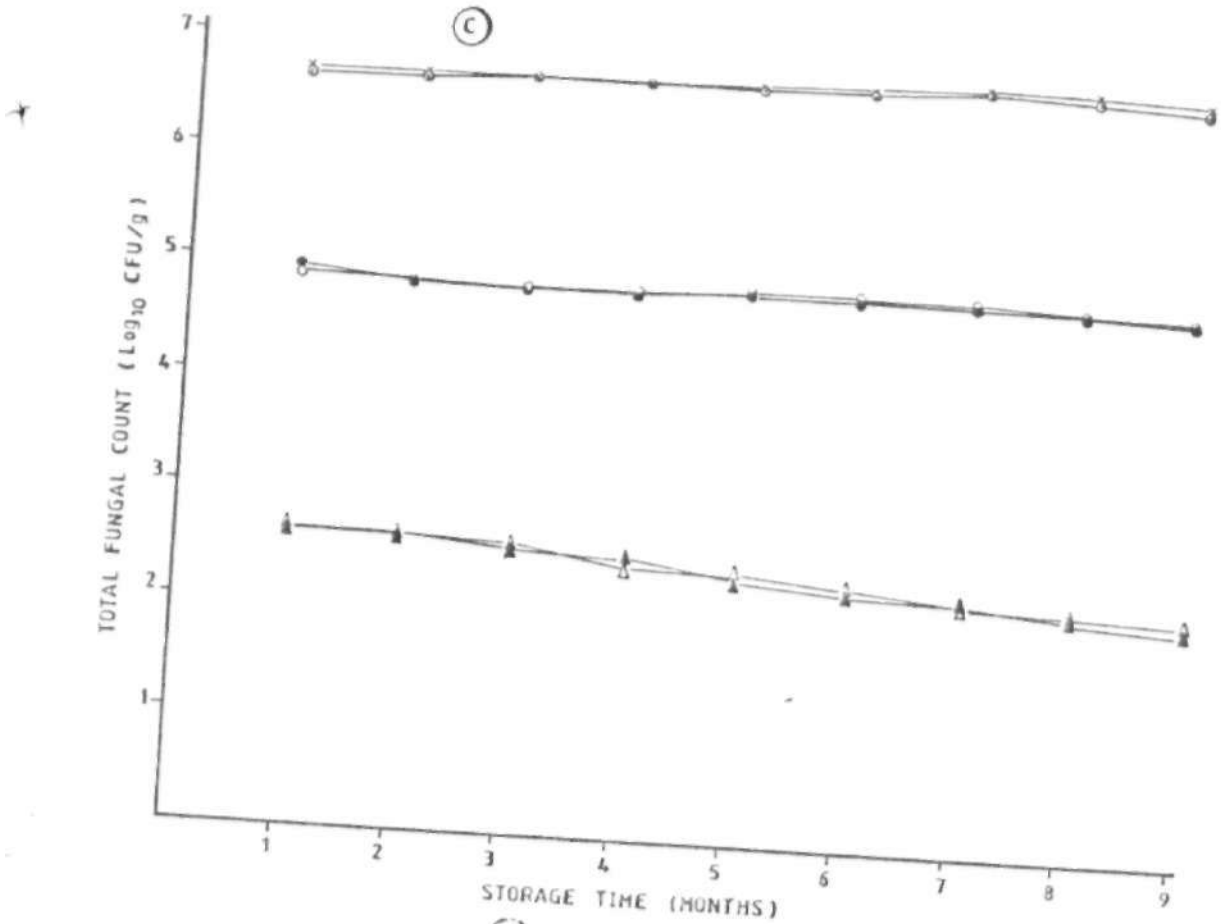
Table 4.1. Prevalence of Fungi in the Spices

Contaminant	Spices			
	Capsicum	Coriander	Ginger	Ashanti pepper
Aspergillus Spp				
Aspergillus flavus	+ + +	+ - -	+ - -	+ - -
Aspergillus niger	+ + +	+ + -	+ + -	+ + -
Penicillum Spp	+ + -	+ + -	+ + -	+ + -
Fusarium	+ + -	- - -	+ + -	+ + -

* Each + or - symbol, respectively means presence or absence of the microorganism in one of triplicate examinations.


(a)
TOTAL FUNGAL COUNT (Log_{10} CFU/g)
STORAGE TIME (MONTHS)


(b)
TOTAL FUNGAL COUNT (Log_{10} CFU/g)
STORAGE TIME (MONTHS)


(c)
TOTAL FUNGAL COUNT (Log10 CFU/g)
STORAGE TIME (MONTHS)
(d)
TOTAL FUNGAL COUNT (Log10 CFU/g)
STORAGE TIME (MONTHS)

classified among the medium class spices that have significant antimicrobial properties. On the other hand capsicum, ginger and black pepper possess little antimicrobial properties. The high fungal count observed in this work may mean that the antimicrobial activity of coriander observed by Zaika (1988) was bactericidal rather than fungicidal.

The total fungal load of the controls were influenced by storage time. There were increases in CFU as storage progressed until the eighth month when decreases were recorded, However the 2.5 kGy dose irradiated samples showed a decrease in total fungal count up to the 4th month after which an increase in total fungal load was observed. This continued growth could have been due to proliferation of relatively radiation resistant strains. Another possibility may apparently be due to the recovery and growth of some sublethally injured micro-organisms (Dymsza, *et al*., 1990).

The main bacterial flora found in the spices were mainly *Bacillus* spp, *Clostridia*, *Stphylococcus* spp and *Diplococcus* spp (Table 4.2). Similar to the observations of Obuekwe and Ogbimi (1989) on spices, Katusin-Razem, *et al*. (1988) on tea herbs and Hanis, *et al*. (1988) on cereal meals, *Clostridium* spp was the prevalent bacteria. Capsicum was the most contaminated, log 7.26 CFU of viable bacteria per gram sample and log 5.65 CFU of spore- forming bacteria per gram sample, whereas coriander had the least, log 4.71 CFU viable bacteria per gram sample and 3.81 CFU spore-forming bacteria per gram sample (Fig. 4.2 and 4.3). The low bacterial count of coriander have stemmed from the antimicrobial constituents of the spice. Linalool which is the major constituent of coriander oil is known to exhibit antimicrobial activity.

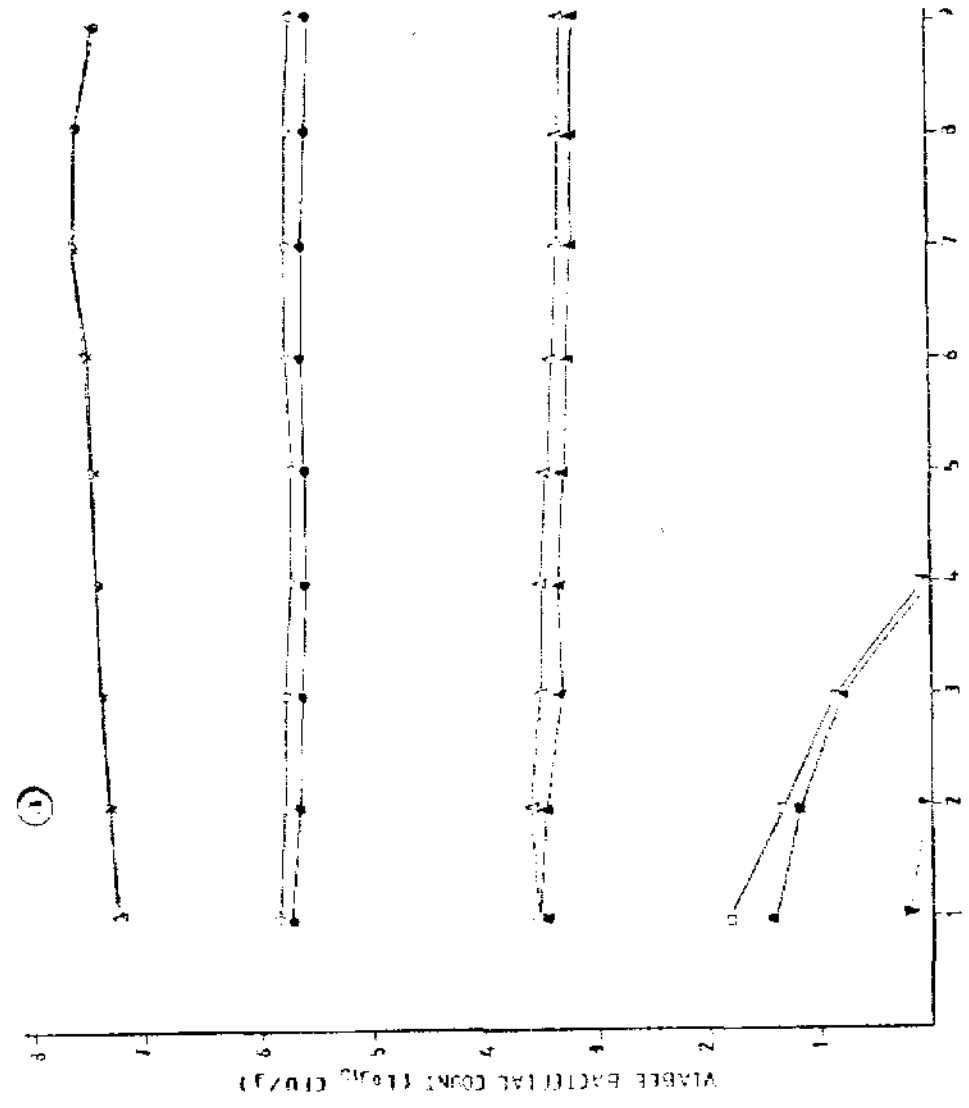
A dose of 2.5 kGy reduced the total viable bacterial population by 2 log cycles in all the spices except coriander where only a log cycle reduction was observed. This low reduction in bacterial load of coriander may be due to relatively high proportion (80%) of spore formers (Fig. 4.3) Sporogenic bacteria are known to be radioresistant.

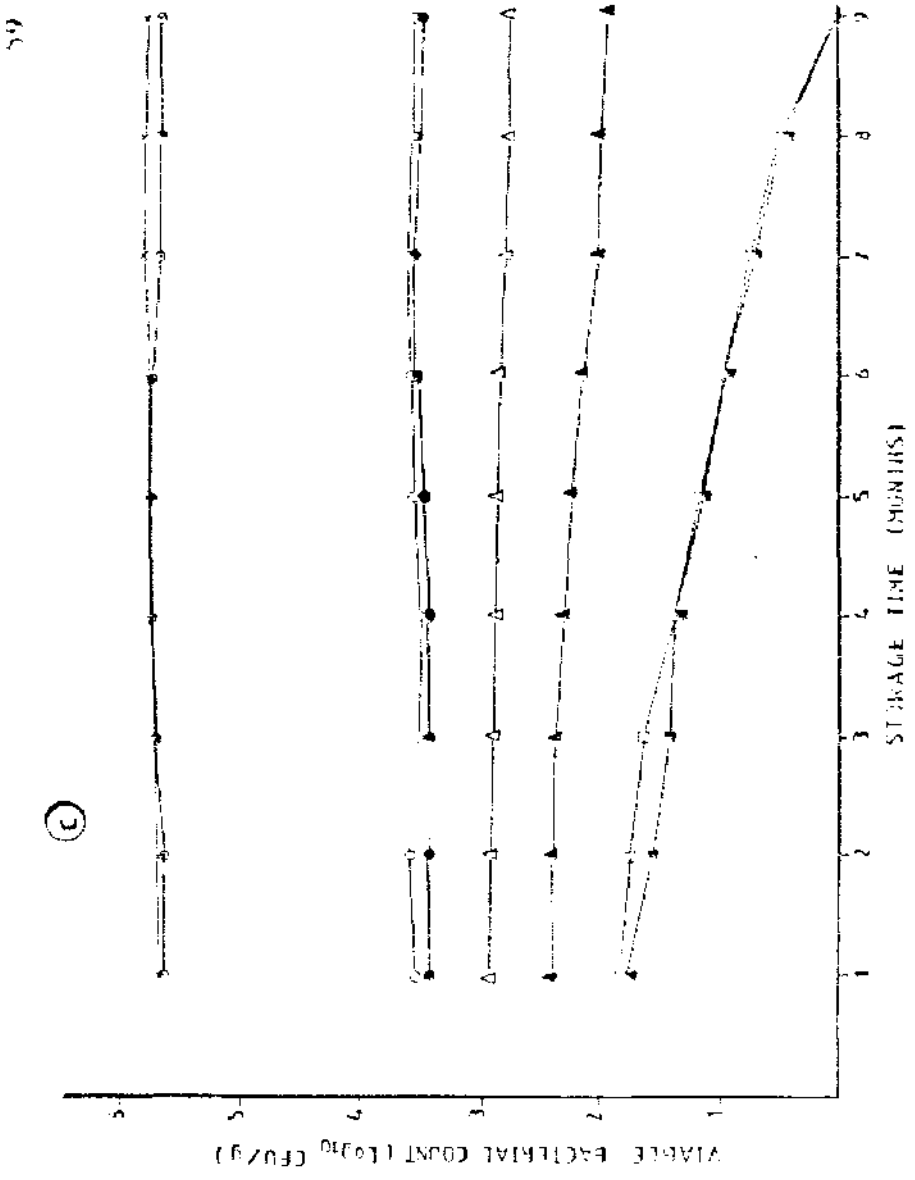
The radiosenstivity of total aerobic microflora in the spices is similar to that found in other dry materials of vegetable origin such as spices (Grecz *et al.*, 1986) and tea herbs (Katusin-Razem *et al*., 1988). The major bacteria found in the high-dose-

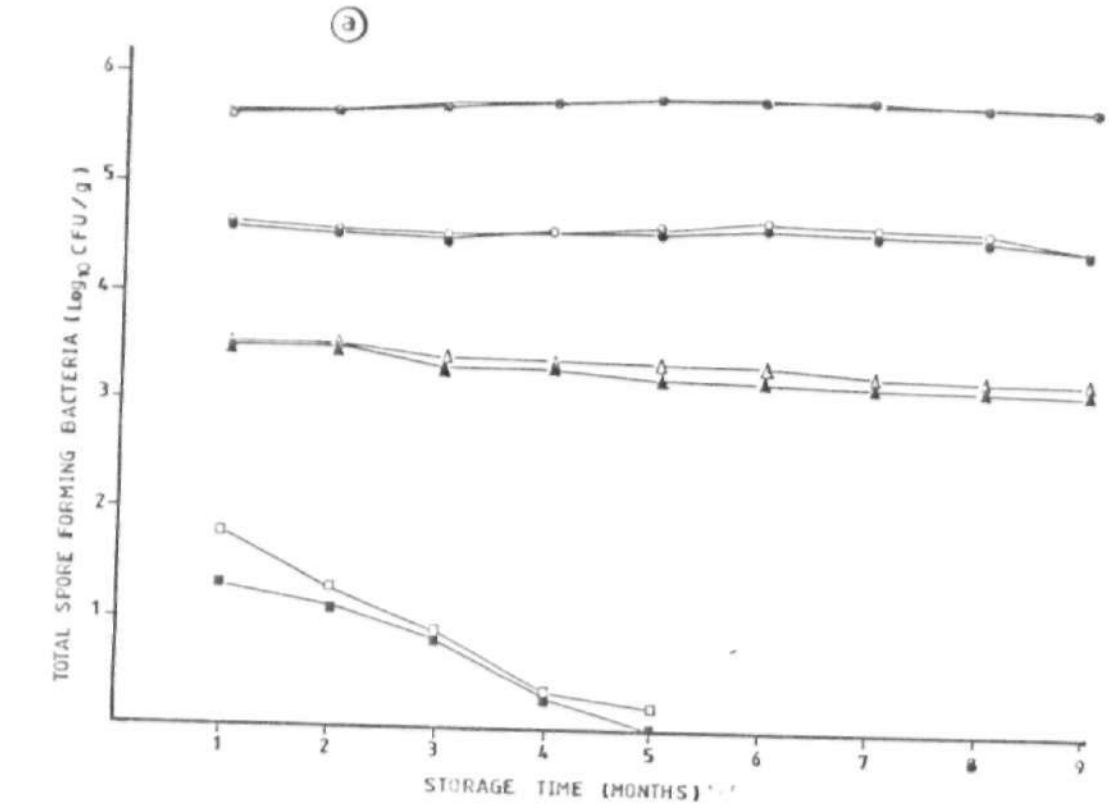
Table 4.2 Prevalence of Bacteria in the Spices

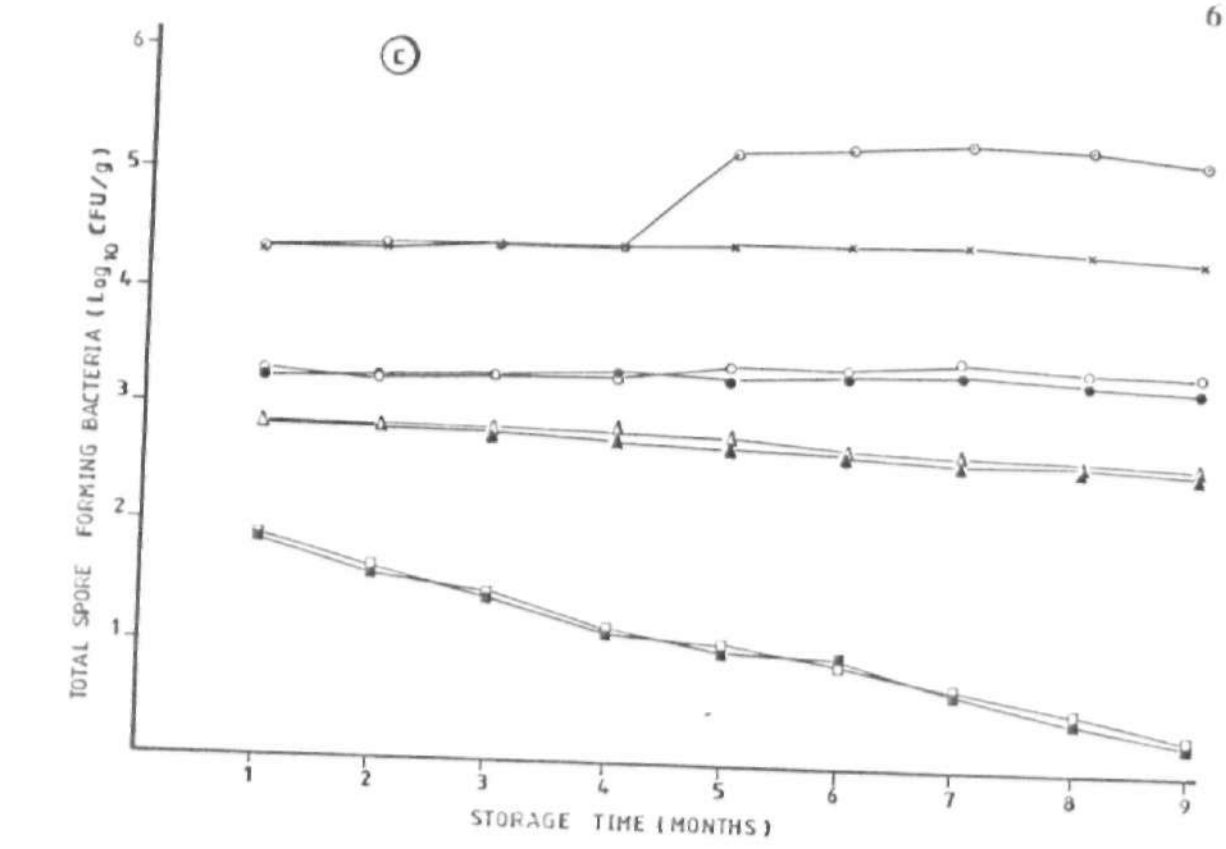
Contaminant	Spices			
	Capsicum	Coriander	Ginger	Ashanti pepper
Bacillus Spp	+ + + -			
Bacillus cereus	+ + + -	+ + +	+ + + -	+ + + -
Bacillus subtilis	+ + + -	+ + +	+ + + -	+ + + -
Micrococcus	+ + - -	- -	- - -	- - -
Staphylococcus Spp	+ + -	+ + -	+ + -	+ + -
Clostridia	+ + + +	+ + + +	+ + + +	+ + + +
Diplococcus Spp	+ + - -	+ + - -	+ + - -	+ + -

+ Each + or - symbol respectively presence or absence of the micro organism in one of quadruplicate examinations active principle - piperine and the essential oil.


(a)
VIABLE BACTERIAL COUNT (log10 CFU/g)
STORAGE TIME (MONTHS)
(b)
VIABLE BACTERIAL COUNT (log10 CFU/g)
STORAGE TIME (MONTHS)


(c)
VIABLE BACTERIAL COUNT ($\log_{10}$ CFU/g)
STORAGE TIME (MONTHS)
(d)
VIABLE BACTERIAL COUNT ($\log_{10}$ CFU/g)
STORAGE TIME (MONTHS)


(a)
TOTAL SPORE FORMING BACTERIA (Log_{10} CFU/g)
STORAGE TIME (MONTHS)
(b)
TOTAL SPORE BACTERIA (Log_{10} CFU/g)
STORAGE TIME (MONTHS)


(c)
TOTAL SPORE FORMING BACTERIA (Log_{10} CFU/g)
STORAGE TIME (MONTHS)
(d)
TOTAL SPORE FORMING BACTERIA (Log_{10} CFU/g)
STORAGE TIME (MONTHS)

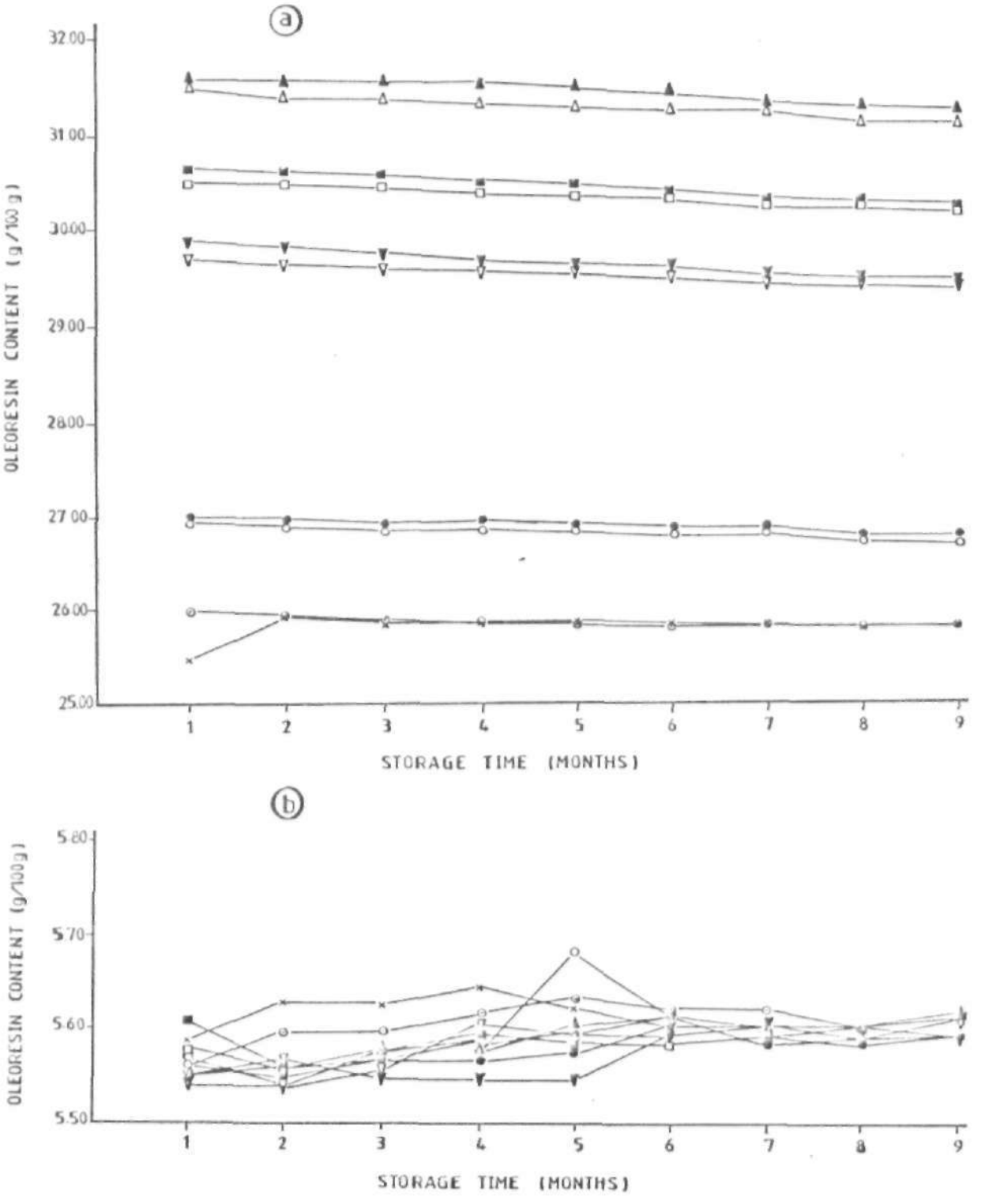
treated (5, 7.5 and 10 kGy) sample were *Clostridia* and *Bacillus*, with *Clostridia* dominating. A similar observation had been reported by Hanis, *et al.* (1988) who investigated the effect of gamma irradiation on survival of natural microflora and some nutrients in cereal meals. They observed that 1-10 CFU/g of *Enterococcus* and *Clostridium* survived in corn meal after a 10 kGy gamma irradiation.

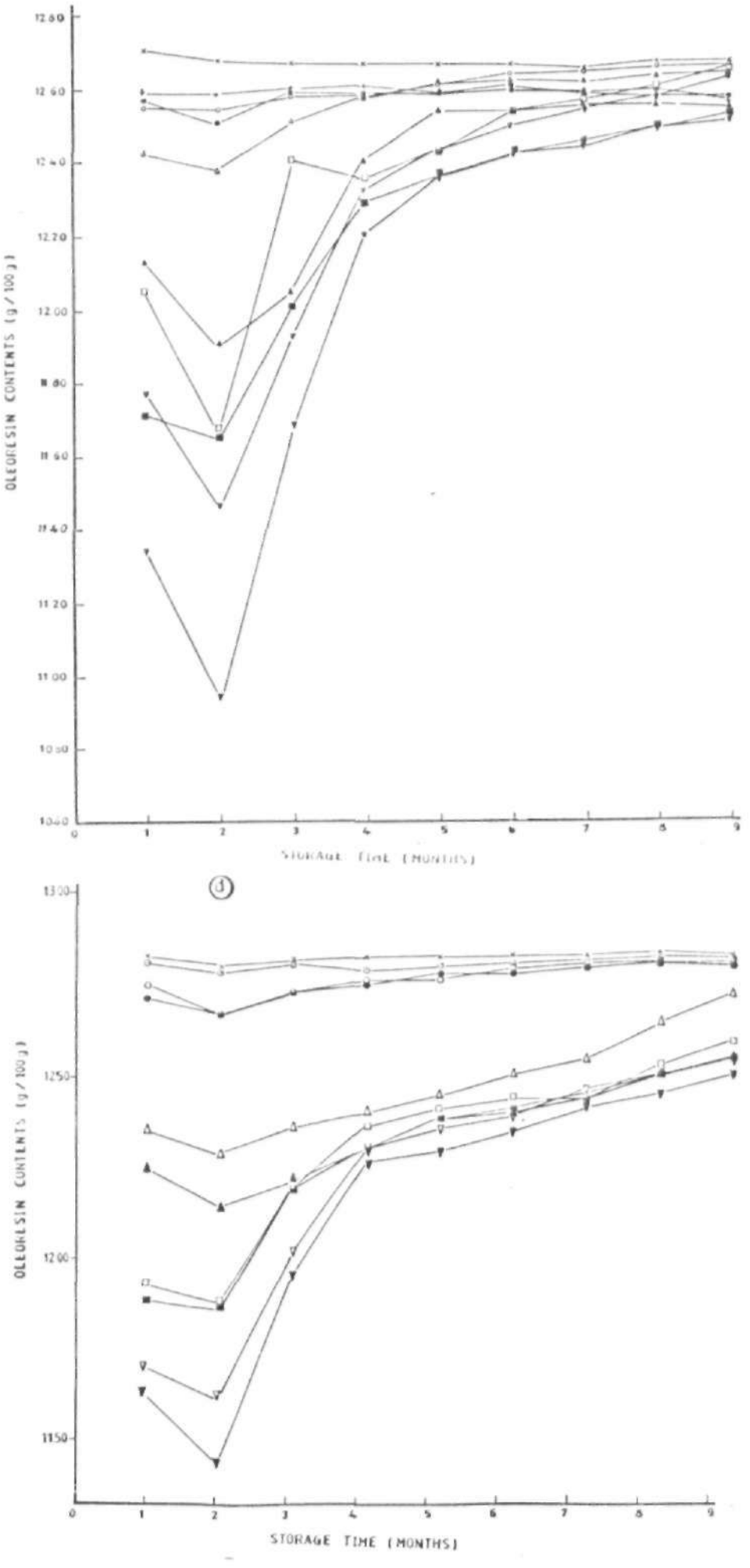
Except in whole capsicum, 10 kGy sterilized all the spices. similar to the observed effect of 2.5 kGy on the fungi population, there was no significant ($P > 0.05$) increase in bacterial count after the 4th month post-irradiation storage and this could still be explained by injury recovery and growth of some sublethally injured microorganisms (Dymsza, *et al.*, 1990). Generally, time did not significantly ($P > 0.05$) affect the bacterial population except in the 7.5 kGy treated samples where prolonged storage enhanced significanthy ($P < 0.05$) bacterial load reduction. This observed trend could be attributed to inability of the initially sublethally injured bacteria to recover and they die with time.

4.2 CHEMICAL ANALYSIS

4.2.1 Oleoresin Content

Investigation of effect of irradiation on the oleoresin content of the spices, showed that the effect varies from spice to spice (Fig 4.4). Capsicum (Fig. 4.4a) showed increase in oleoresin content with increase in radiation dose with the highest oleoresin content (25.98 - 31.6g/100 g) observed with 5 kGy dose However this value did not differ significantly ($P > 0.05$) from those of 7.5 and 10.0 kGy. The increase in oleoresin could mean increased extractability of the oleoresin constituent. Radiolysis of triglycerides had been shown (Nawar, 1977) to provide hydrocarbons and aldehydes as well as a number of low molecular weight products which include alkanes, alkenes, free fatty and, esters, ketones, lactones, alcohols, etc. Some of these products are known to be soluble in the extractant (methanol). Form did not significantly ($P > 0.05$) affect the oleoresin content of capsicum.


(a)
OLEORESIN CONTENT (g/100g)
32.00
31.00
30.00
29.00
28.00
27.00
26.00
25.00
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
(b)
OLEORESIN CONTENT (g/100g)
5.80
5.70
5.60
5.50
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

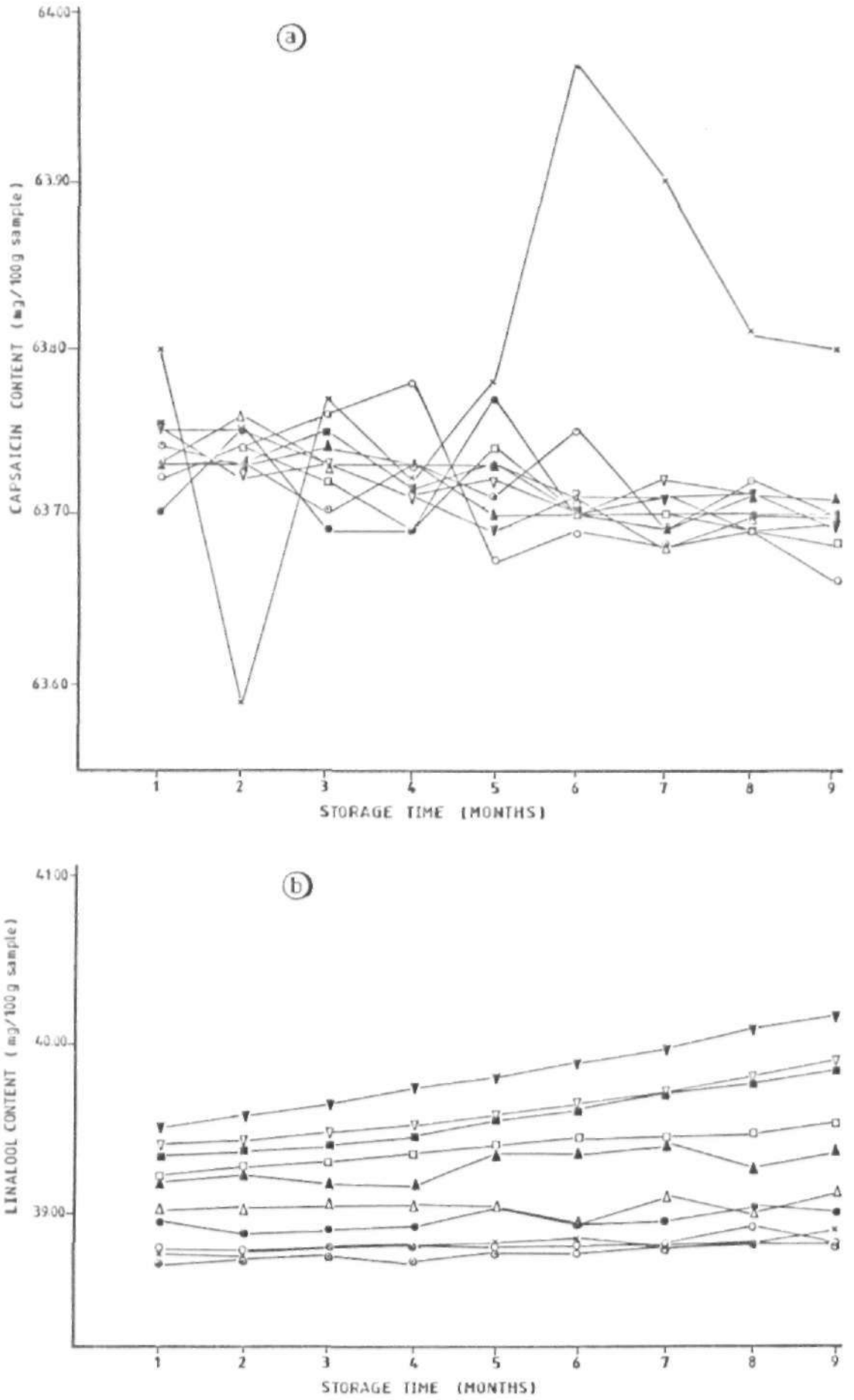

OLEORESIN CONTENTS (g/100g)
12.60
12.40
12.20
12.00
11.80
11.60
11.40
11.20
11.00
10.80
10.60
0
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
(J)
13.00
12.50
12.00
11.50
OLEORESIN CONTENTS (g/100g)
STORAGE TIME (MONTHS)

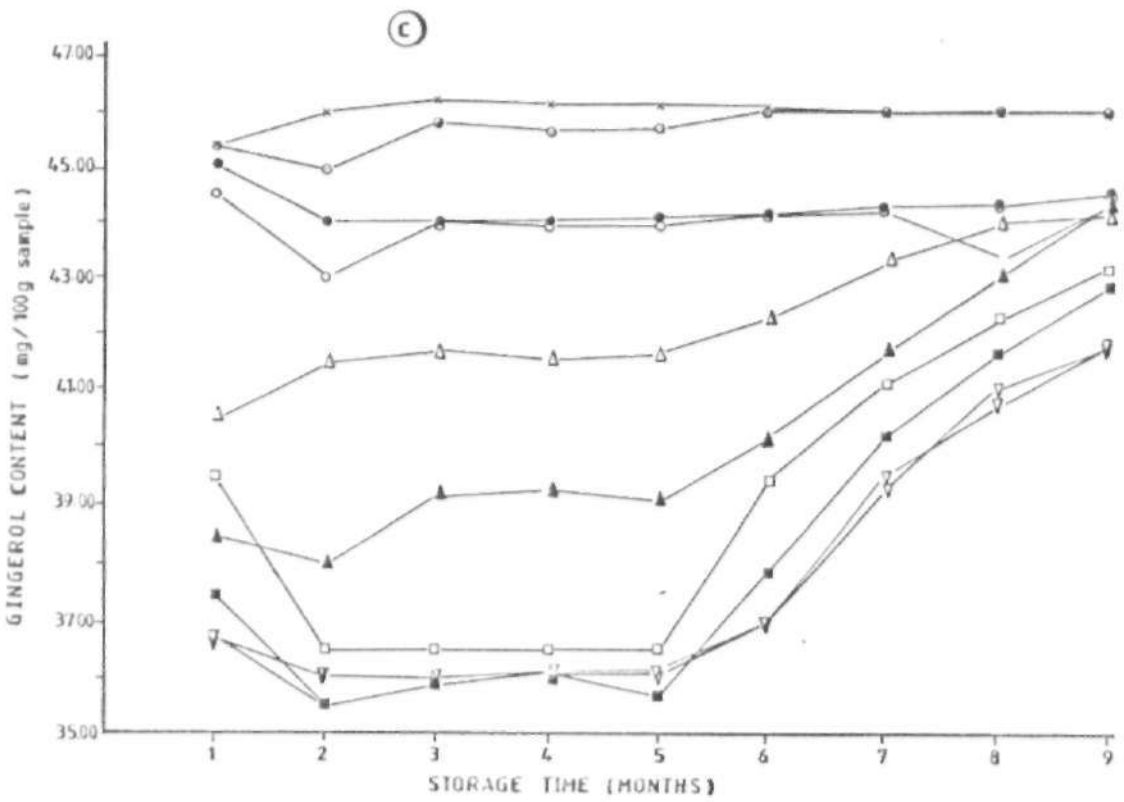
Contrary to the above observations on capsicum, coriander oleoresin content was not significantly ($P > 0.05$) affected by irradiation (Fig 4.4b). Similar to earlier observation with capsicum, time and form had no effect on the oleoresin content.

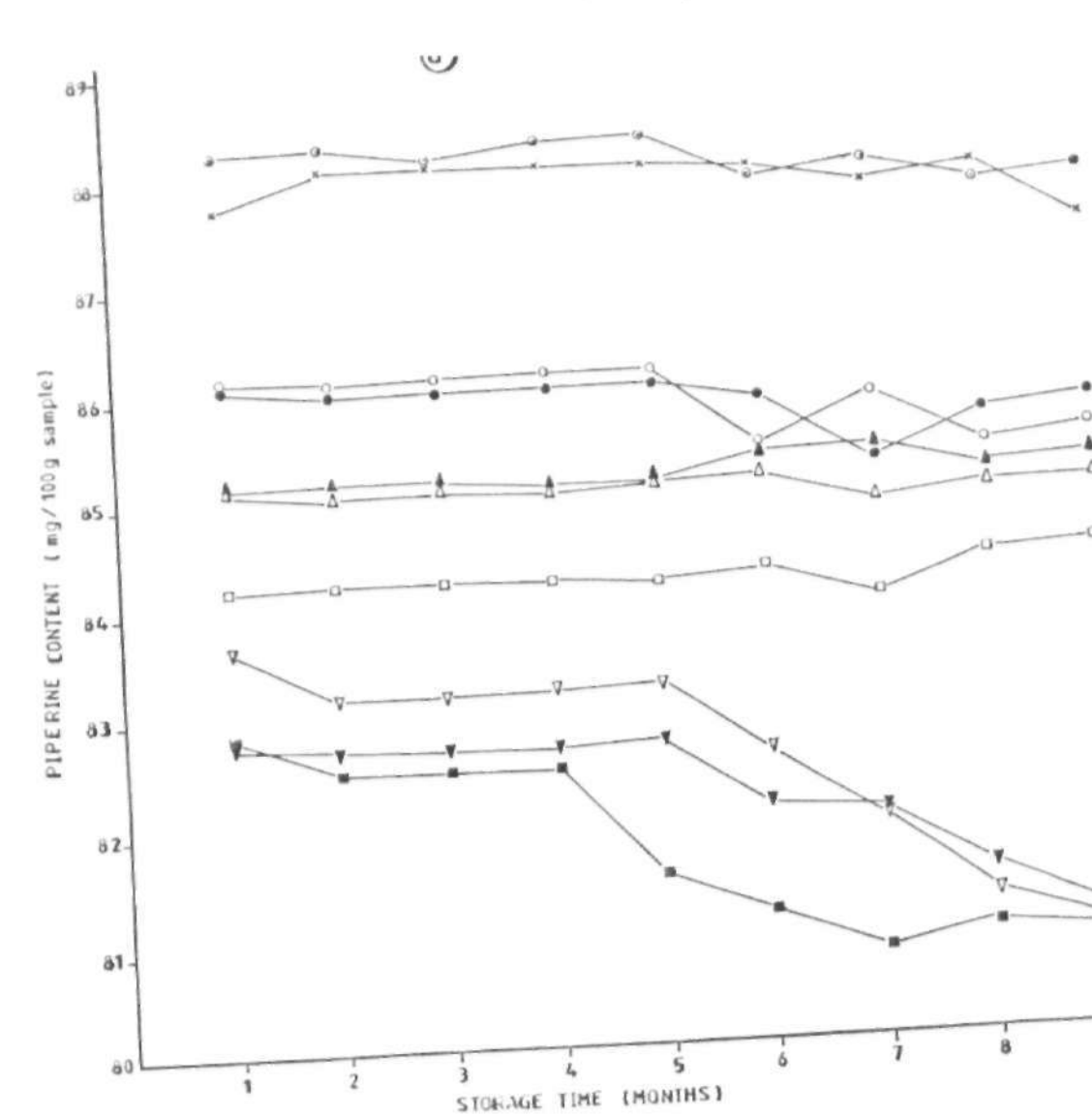
The results, of the oleoresin content of ginger and Ashanti pepper (Fig. 4.4c and 4.4d) are very similar. Radiation treatment of the spices affected the oleoresin content sightly as the dose was increased from 12.71 to 11.77 g/100g and 12.59 to 11.34 g/100g for the whole and ground ginger respectively giving 7.40 and 9.93% decrease in the oleoresin content . The effect of gamma irradiation on whole Ashanti pepper was slightly higher than that observed for whole ginger. A decrease of 8.89% (12.83 - 11.69 g/100g) was observed for the 10 kGy treated sample. For the ground sample irradiated with 10 kGy radiation dose a significant ($P < 0.05$) decrease of 9.29% was observed. The form of the irradiated sample affected the response to irradiation. Although insignificantly ($P > 0.05$) ground sample were more sensitive to irradiation. Storage time affected the oleoresin content of the two spices negatively in the first few months (1-3 months) post irradiation, However it increased steadily with time toward the end of the monitoring period (5-9 months) the values showed no significant difference ($P > 0.05$). This effect of time could be attributed in part to recombination of radiolytic products with time since the moisture content was not high enough (Fig 4.17) to warrant the mobility of the free radicals. According to Conger *et al.* (1968) water provides a medium for movement of radicals, The amount and physiochemical nature of the water present, they opined was of utmost importance. Hence the radiolytes must have been concentrated where they were produced.

4.2.2 Active Principles

The application of radiation for sterilization is justified only if the quality characteristics of the products are not affected. Some spices are taken for their micronutrients, the active ingredient and the aromatic principles, the effect of different doses of gamma radiation on the different active principles were investigated. Figure 4.5 shows the effect of dose form and time on the active


(a)
CAPSAICIN CONTENT (mg/100g sample)
64.00
63.90
63.80
63.70
63.60
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
(b)
LINALOOL CONTENT (mg/100g sample)
41.00
40.00
39.00
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
GINGEROL CONTENT (mg/100g sample)
47.00
45.00
43.00
41.00
39.00
37.00
35.00
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


PIPERINE CONTENT (mg/100g sample)
88
87
86
85
84
83
82
81
80
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

principles in coriander (linalool) and the pungent principles of capsicum (capsaicin) ginger (gingerol) and Ashanti pepper (piperine).

The capsaicin content (Fig. 4.5a) of the capsicum did not change even after treatment with 10 kGy. A previous study (Farkas *et al.*, 1973) on the feasibility of irradiation of spices with special reference to paprika showed that treatment of pungent paprika with 16 kGy did not change the capsaicin content. This is indicative that capsaicin is radioresistant and the observed increase in capsicum oleoresin did not result to concomitant increase in capsaicin.

The major flavour component of coriander has been identified as linalool which constitutes about 60-70% of the seed oil (Macleod and Islam, 1976). Linalool constituted about 0.04% of the seed. The quantitative values for linalool in samples irradiated at different doses (Fig. 4.5b) show trends that are interesting. Irradiation of coriander up to a dose of 10 kGy caused a significant ($P < 0.05$) increase of 2.01% in the linalool content.

The slight increase was observed to be dose dependent and was also affected by the form of the sample. Although the nature of the sample affected the linalool content, there was no significant ($P > 0.05$) difference between 10 kGy dosed samples (39.59) whole and ground samples 39.80 mg/100g respectively. Rao, *et al.* (1978a) reported an increase (63.64%) in butanol content of volatile flavour components of bread irradiated at 10 kGy. Although in the same study a decrease in ethanol and methanol (low molecular alcohols) was observed, which implies that the effect of irradiation on alcohols cannot be generalized.

The gingerol content of irradiated ginger decreased with increasing radiation dose and tended to decrease during the storage period showing some fluctuations (Fig. 4.5c). Paull, *et al.* (1988) observed that storing ginger rhizomes at 22°C for 20 weeks resulted to increase in pungency measured as gingerol content. However they observed that after this, the gingerol content depreciated significantly. The result of the present study to a certain extent agrees with the observation of Paull, *et al.* (1988). Although the increase with time were not significant ($P > 0.05$), the gingerol content decreased gradually after reaching, the peak 88.09 mg/100g (for the whole

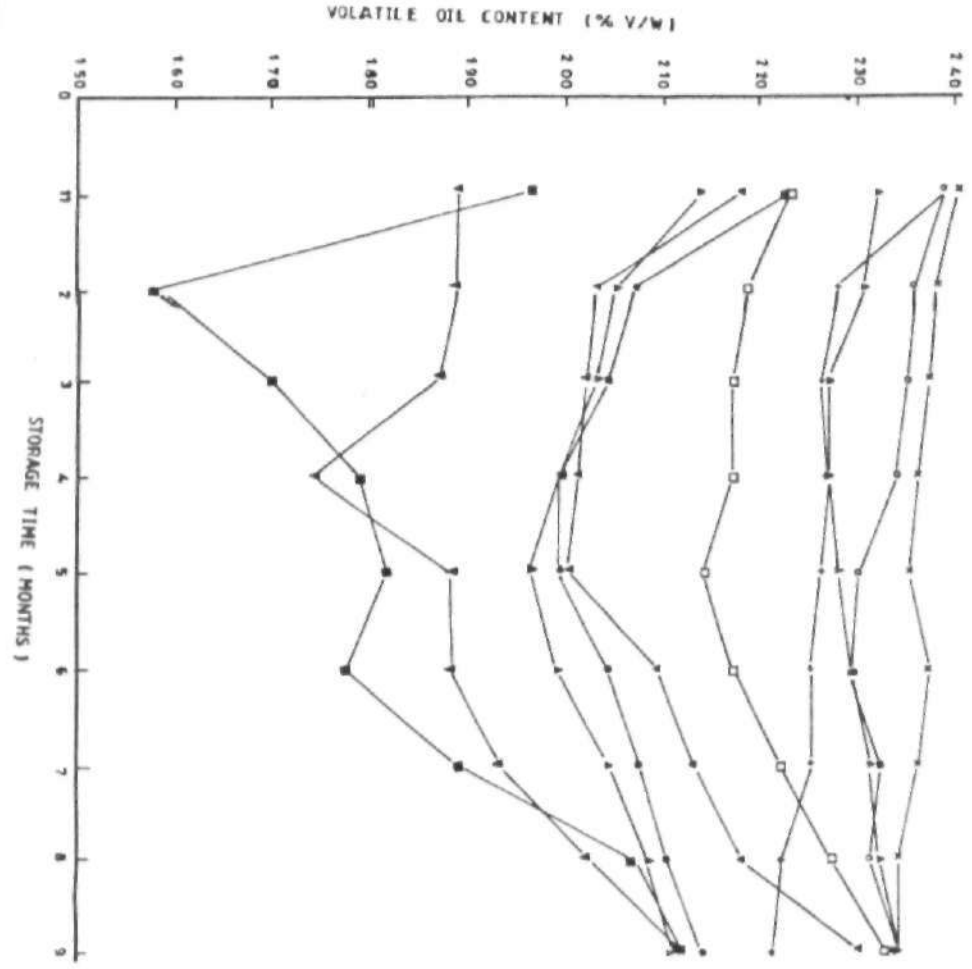
control) at the 3rd month. Similar trends were observed with respect to the irradiated samples. The dose dependent decrease may mean that irradiation may have led to dehydration or degradation of the principle.

Quantitative analysis of the piperine is shown in Fig.4.5d. There was a gradual significant ($P < 0.05$) decreases in the piperine content from 46 to 37.49 mg/100g for the whole control and 10 kGy dose sample respectively. Nature of sample did not cause any measurable change in the piperine. Irradiation, of black pepper had been shown (Uchman, *et al.*, 1983) to have a negative influence on its sensory quality. The decrease in the piperine content could in part be due to the instability of the alkaloid (Purseglove, *et al.*, 1981). The result of this work is at variance with the observation of Zehnder (1980) with black pepper. He reported that in irradiated black pepper, the pungent principle which is piperine, was not significantly different from the control. Although the two spices black pepper (*Piper nigrum*) and Ashanti pepper (*Piper guineense*) belong to the same family *Piperaceae*, their constituents especially the essential oil components differ (Ekundayo, *et al.*, 1988). The phenylpropanoid composition of *P. guineense* oil according to Ekundayo, *et al.* (1988) differ considerably from that of black pepper. Hence the effect may likely be due to species difference. The quantitative variance with time in piperine content of the high dose (5 -10 kGy) irradiated samples could be associated with increased extractability of the oleoresin which contains the piperine.

4.2.3 Volatile (Essential) Oil.

The volatile oil content of ginger and Ashanti pepper were affected by irradiation (Fig 4.6). This effect on the ground samples were more pronounced.

The 10 kGy dose treated whole sample quantitatively (8.99% v/w) differ ($P < 0.05$) from the control (whole) - 9.45% v/w. This result agrees with an earlier observation of Uchman, *et al.* (1983). They reported that irradiation of black pepper led to dose dependent decrease of the relative oil content. However, the ground samples volatile oil content varied ($P < 0.01$) from that of the whole sample - both control and irradiated (Fig. 4.6b). This decrease may apparently be attributed to


VOLATILE OIL CONTENT (% V/W)
150
160
170
180
190
200
210
220
240
0
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

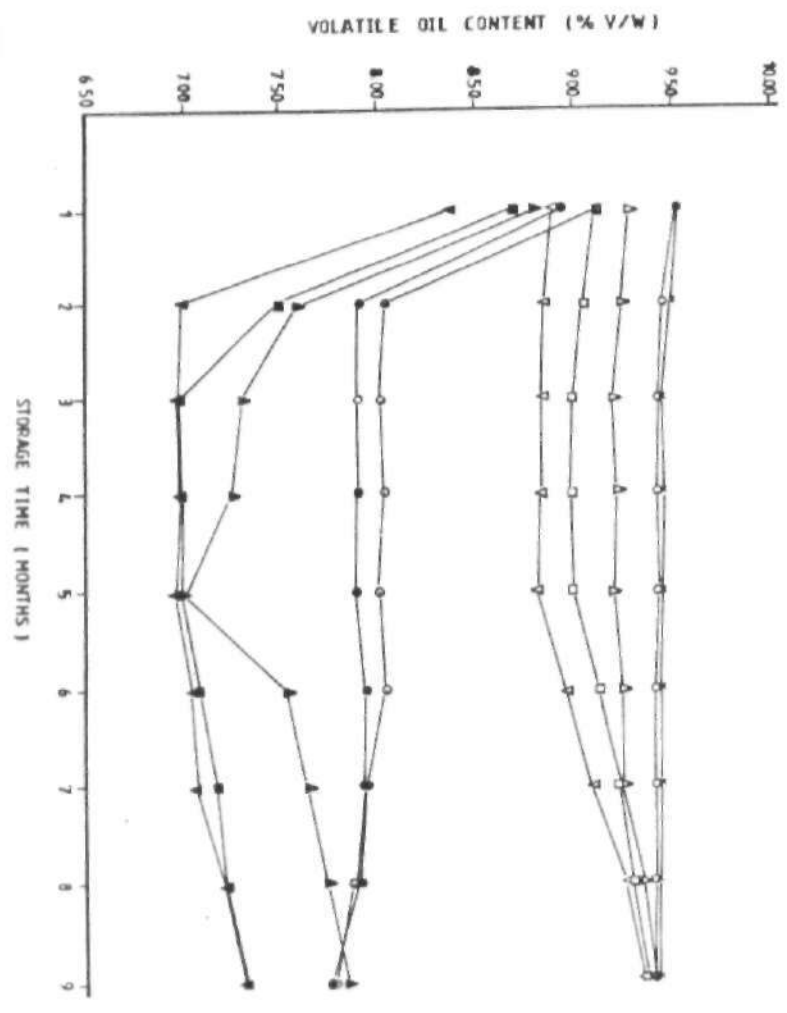

VOLATILE OIL CONTENT (% V/W)
650
700
750
800
850
900
950
1000
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

Table 4.3 Summary of the oil constituents according to functional groups found on the 0 and 10 kGy dose-treated samples of Ashanti pepper.

Constituent	0.0 kg		10.0 kGy	
	Ground	Whole	Ground	Whole
Monoterpenes	9.62	8.00	10.399	8.644
Sesquiterpenes	63.87	60.69	54.878	62.113
Alcohols	10.587	9.53	11.185	9.914
Oxides	2.41	1.84	2.553	2.029
Ketones	0.062	0.061	0.078	0.058
Phenols	0.193	0.128	0.204	0.200

Values represent the sum of the identified constituent of the oil in percent of the total oil.

grinding process. During grinding the glands containing the volatile oils (Anzaldo, *et al.*, 1986) were erupted thereby releasing the components. Another reason that could be advanced is that there is the possibility that during grinding a substantial amount of oxygen must have been incorporated into the samples thereby increasing the effect of radiation. The values of different classes of the essential oil components are shown in Table 4.3

About 80% of the components were identified, no appreciable difference was observed between the doses or the forms. However analyses of the constituents individually (Table 4.4) showed that Germacrene D, a major constituent of Ashanti pepper was significantly ($P < 0.05$) affected by irradiation. A positive effect was recorded. The nature of the sample affected yield of the constituents, higher values were obtained with whole samples than ground samples.

The effect of irradiation on ginger volatile oil content (Fig 4.6a) was very similar to that of Ashanti pepper but not as pronounced. Surprisingly the ground samples irradiated with a dose of 7.5 kGy showed a more pronounced radiation sensitivity. The result of this work is not at variance with earlier result obtained for cardamom a member of the *Zingiberaceae* family and caraway by Bachman, *et al.* (1978). It then implies that the yield and quality of the essential oil of the spices is influenced more by the form of the plant material than by irradiation. The major observed effect of irradiation seems to be its effect on extractability of the oil. In all cases a gradual decrease in volatile content which later increased was observed. There was no significant ($P > 0.05$) difference between the whole samples at the 9th month post irradiation. The influence of form manifested more prominently when the composition of the volatile oil are considered (Table 4.5) Gas chromatographic analyses of the ginger oil confirmed the assertion that grinding must have increased the oxygen content of the samples. Thermodynamically, molecular oxygen has high reduction potential which makes it an extremely good oxidizing agent (Roberfoid, 1987). Hence higher oxygenated compounds found in ginger oil. For example the total alcohol content of the ground control is 9.53% higher than that of whole ginger (control). Irradiation further widened this disparity to about 48%. The effect on the total aldehyde was more pronounced, an increase of 170% was observed. However in

Table 4.4 The composition of the volatile oil of Ashanti pepper in percent (V/V)

Constituent	0.0 kGy		10.0 kGy	
	Whole	Ground	Whole	Ground
α Pinene	1.180	0.766	1.162	0.854
Camphene	0.093	0.067	0.090	0.075
β Pinene	1.991	1.421	2.010	1.531
Sabinene	0.278	0.211	0.203	0.265
Myrcene	2.593	2.007	2.611	2.133
Limonene	3.743	3.132	3.722	3.202
Phellandrene	0.160	0.157	0.109	0.168
1,8-Cineole	0.026	0.028	0.019	0.034
Ocimene	0.021	0.006	0.015	0.010
γ-terpinene	0.030	0.052	0.040	0.067
β-Cymene	0.346	0.284	0.301	0.201
Terpinolene	0.084	0.093	0.096	0.078
cis linalool oxide	0.011	0.006	0.020	0.010
α Cubebene	0.655	0.793	0.605	0.708
δ Elemene	0.702	ni	0.754	0.101
α-Ylangene	5.027	5.741	5.372	6.008
Camphor	0.062	0.061	0.078	0.058
Linalool	2.067	2.297	2.181	2.341
Gurjunene	1.579	0.783	1.599	0.850
β-Caryophyllene	14.075	16.070	14.300	15.910
γ-Elemene	0.368	0.375	0.80	0.401
Cadrene	0.045	0.070	0.059	0.080
Epi β-Farnesene	0.113	0.152	0.098	0.183
(Z)-β-Farnesene	1.459	ni	1.512	
α Humulene	3.449	3.617	3.541	3.001
(E)-β-Farnesene	0.309	1.623	0.481	1.598
Germacrene D	9.619	14.737	10.214	15.080
Zingiberene	1.882	2.842	2.009	3.010
Humachalene	3.167	2.842	3.270	2.341
β-Selinene	1.281	1.031	1.165	0.989
Bicyclogermacrene	0.765	0.931	0.812	1.004
δ-Cadinene	1.314	1.386	1.308	1.410
Sesquiphellandrene	1.427	1.982	1.512	2.030
Cadina-1,4-diene	0.205	0.210	0.301	0.245
Calamenene	1.044	1.162	1.121	1.204
P-cymen-ol	0.004	0.005	0.009	0.019
Calamenene	0.047	ni	0.058	ni
Caryophyllen-oxide	0.217	0.150	0.303	0.240
α-Calacorene	0.048	0.042	0.057	0.060
Caryophyllen oxide	2.159	1.695	2.219	1.745
Methyl eugenol	0.193	0.128	0.204	0.200
Nerolidol	2.111	2.04	2.009	2.141
Elemol	1.674	1.373	1.600	1.284
Guaiol	1.0388	0.871	1.400	0.921
γ-Cadinol	0.434	0.481	0.501	0.453
Bisabolol	2.410	1.806	2.521	1.913
β-Eudesmol	0.849	0.718	0.964	0.842

ni- not identified

Table 4.5: Summary of the oil constituents according to functional groups found in the experimental samples of Ginger.

Constituent	0.0 kGy		10.0 kGy	
	Ground	Whole	Ground	Whole
Hydrocarbons	0.032	0.025	0.047	0.027
Monoterpenes	1.792	1.483	0.610	3.257
Sesquiterpenes	60.592	70.387	54.816	65.455
Alcohols	6.07	5.542	10.909	7.332
Carboxylic acids	ni	0.271	ni	ni
Oxides	0.586	1.131	0.991	0.048
Ketones	0.456	0.643	0.688	0.658
Aldehydes	9.503	3.514	8.791	2.969
Esters	0.670	0.764	1.114	0.057
Phenols	0.074	0.056	0.207	0.057

ni - not identified

Values represent the sum of the identified constituents of the oil in percent of the total oil.

both whole and ground samples the data showed that irradiation had a negative influence on the total aldehyde content of the oil. The total aldehyde content of the ground samples decreased from 9.5 to 8.8% for the control and 10 kGy treated sample respectively.

According to Bednarczyk and Krammer, (1975) α-terpineol, neral, geranial, β-sesquiphellandrene, arcurcumene, nerolidol and cis-β-sesquiphellandrol accounted for 85% of the flavour of ginger, they then opined that a mixture of these compounds in the correct proportion could pass as suitable imitation of ginger. Therefore the effect of irradiation on these components could be used as an index. It was found that irradiation had little or no effect on these essential oil components, (Table 4.6). Instead grinding was found to affect the composition of these flavour constituents quantitatively, this effect of grinding may be due to isomerization of the components, for example the least quantity of neral corresponds to the highest value of geranial which is a stereoisomer of neral. The most affected by this factor seems to be farnesene. The GC-MS results (Table 4.7) show the presence of geometrical isomers of α and β- farnesene in the irradiated samples especially the ground. Courtney and McDonald (1969) observed that α and β-farnesene are affected by irradiation however the effect differ. According to their findings α-farnesene simply undergoes cis-trans isomerization whereas irradiation of β-farnesene yields a variety of compounds amongst them were bicyclohexame, cyclobutene and β-bergamotene.

Table 4.6: The composition of the volatile oil of Ginger in percent (V/V) of oil sample.

Dose	0.0 kGy		10.0 kGy	
Treatment	Whole	Ground	Whole	Ground
Constituent				
α-Pinene	0.211	0.132	0.263	0.076
Toluene	0.025	0.032	0.027	0.047
Camphene	0.613	0.438	1.012	0.167
n-Hexanal	0.043	0.022	0.004	0.004
β-Pinene	0.053	0.009	0.047	0.068
Myrcene	0.105	0.069	0.099	0.133
α-Phellandrene	0.033	0.039	0.030	0.031
Limonene	0.337	0.158	0.143	0.245
β-Phellandrene	0.951	0.201	1.593	0.097
1,8-Cineole	0.405	0.540	0.006	0.134
γ Terpinene	0.008	0.010	ni	ni
ρ Cymene	0.024	0.020	0.011	0.054
Terpinolene	0.091	0.048	0.070	ni
n Heptan-2-ol	0.016	0.025	ni	ni
2-methyl-2-hepten-6-0-ne	0.092	0.085	0.131	0.146
2,6-Dimethyl-5-hepten-1-al	0.009	0.009	ni	ni
Methyl n-heptyl ketone	0.031	0.024	0.044	ni
trans-2-octenal	ni	0.010	ni	ni
Citronellal	ni	0.141	0.009	ni
α Ylangene	0.547	0.407	0.264	0.406
Camphor	0.060	0.048	0.078	0.029
α Gurjunene	ni	0.006	ni	ni
Linalool	0.397	0.303	0.484	0.402
Isobornyl acetate	0.026	0.166	0.038	0.158
α-Bergamotene	0.228	0.075	0.249	ni
β Elemene	1.143	0.786	1.128	0.754
Methyl n -nonyl ketone	0.031	0.507	0.357	0.717
Eremophyllene	0.089	0.105	0.162	ni
β-caryophyllene	0.348	0.507	0.357	0.717
γ Elemene	0.115	0.192	0.048	0.327
Citronelly acetate	0.392	0.504	0.670	0.327
(E)-β-Farnesene	0.730	0.794	0.934	0.699
Neral	2.502	2.389	2.894	1.079
α Humulene	0.221	0.168	0.266	0.112
Borneol	1.274	1.272	2.730	0.973
Germacrene D	3.577	3.242	0.952	
Zingiberene	18.677	29.541	22.398	13.480
Geranial	3.462	6.941	6.153	7.702
Citronellol	ni	ni	0.721	0.764
α Farnesene	0.458	7.123	0.800	5.767
Curcumene	18.677	24	12.85	21.456
β Sesquiphellandrene	18.677	17.793	16.688	ni
Mithyl-n-undecyl ketone	0.093	0.067	0.063	0.078
Geraniol	0.771	1.253	1.165	1.134
Caryophyllen oxide	0.181	0.046	0.028	0.759
Nerolidol	0.536	0.896	0.578	1.719
Elemol	0.363	0.639	0.471	1.229
α-Eudesmol	0.100	0.162	0.116	0.514
β Eudesmol	0.359	0.773	0.424	1.850
Sesquiphellandrol	0.341	0.738	0.369	1.550
γ-Muurolol	0.139	ni	0.163	0.126
α-Himachallene	ni	ni	0.251	ni
Trans Isoeuginol	0.056	ni	0.057	0.207
α Cubebene	ni	ni	0.040	0.062
α Calacorene	0.011	ni	0.014	ni
α Terpineol	0.008	0.666	0.948	0.648
δ Elememe	ni	ni	0.186	n

* ni - not identified

Table 4.7 Compounds Identified in the Volatile Oil of Ginger

		GW_0	GW_{10}	GG 10
α Pinene	GEMS	GCMS	GCMS	GCMS
Toluene	GCMS	GCMS		
Camphene	GCMS	GCMS	GCMS	
n-Hexanal	GCMS	GCMS	GCMS	GCMS
β-Pinene	GCMS	GCMS	GCMS	GCMS
Myrcene	GCMS	GCMS	GCMS	GC
α Phellandrene	GCMS	GC		GC
1,8 Cineole	GCMS	GCMS	GC	GCMS
γ Terpinene	GCMS	GC		
ρ Cymene	GCMS	GCMS	MS	GCMS
Terpinolene	GCMS	GC		
n-Heptan-2-ol				
2-Methyl-2-hepten-6-one	GCMS	MS	GCMS	
2,6-Dimethyl-hepten-1-ol	GCMS	GC	MS	
Methyl n-hepty ketone		GC		
trans-2-octenal				
Citonelal	GCMS	GCMS		
αYlangene		GCMS	GC	GCMS
Camphor	GCMS	GCMS	GCMS	GCMS
α Gurjunene	GCMS	GCMS		
Linalool		GCMS	GCMS	GCMS
Iso Bornylacetate		GCMS	GCMS	GCMS
α Bergamotene		GCMS	MS	GCMS
Acetone	MS	GCMS		
Sabinene		GCMS	GCMS	
Linalool oxide	MS	GCMS		
δ-Elemene		GCMS	MS	
n-Butylaldehyde	GCMS			
Isovaleraldehyde	GCMS		GCMS	
2-Pentanone	GCMS			
Cadinol				
Lauric acid				GCMS
α-Terpineol	MS	GCMS	GCMS	
α-Calacorene		GC		
γ-Calacorene		GC		
β-Elemene	GCMS	GCMS	GCMS	
Methyl-nonylketone		GC	GCMS	
β-Caryophyllene		GC	GCMS	
Eremophyllene		GC	GCMS	
γ-Elemene		GC	GCMS	
Citronelly acetate		GC	GCMS	GCMS
(E)-β-Farnesene		GC	GCMS	
Neral		GC	GCMS	GCMS
α-Humulene	GCMS	GC	GC	GC
Borneol		GC	GCMS	
Germacrene D		GC	GCMS	
Zingiberene	GCMS	GC	GC	
Geranial	GCMS	GC	GC	
α-Farnesene	GCMS			
β-Sesquiphellandrene	GCMS	GC		
Methyl n- undecylketone		GC	GC	MS
Geraniol	GCMS	GCMS	GCMS	GCMS
Caryophyllen oxide	GCMS	GC	GC	
Nerolidol		GC	GC	

Table 4.7 (contd)

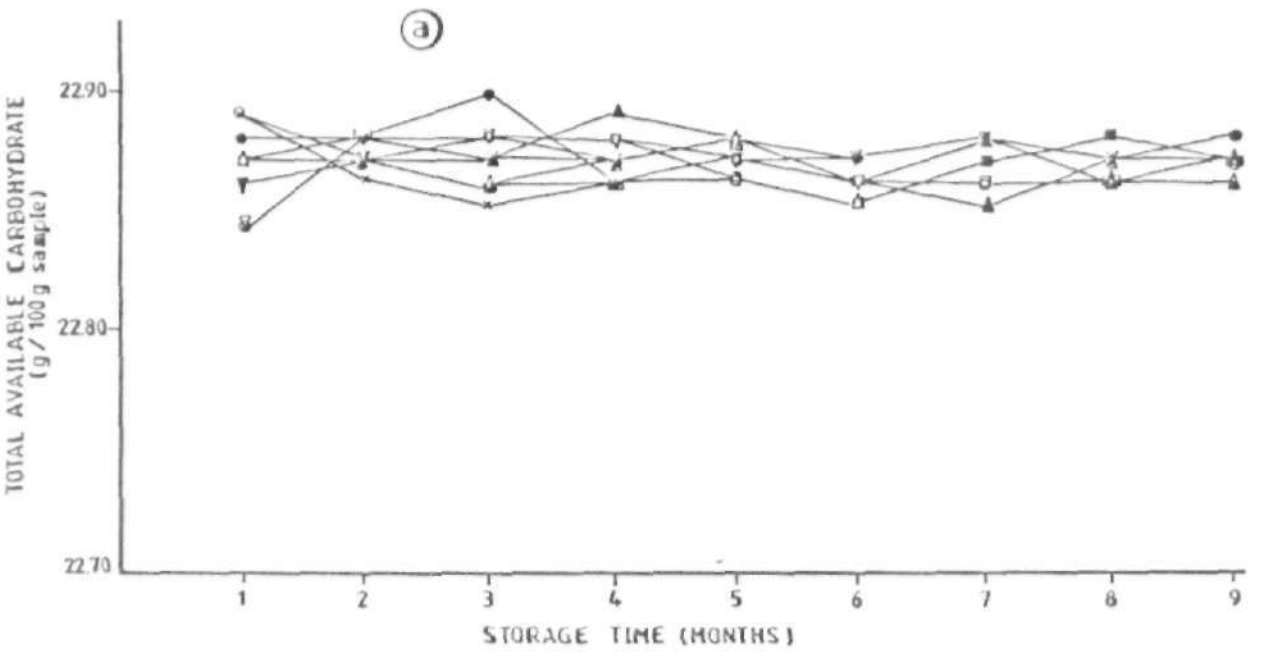
	GGo	GW_o	GW_{10}	GG_{10}
Elemol		GC	GCMS	GCMS
α-Eudesmol	GCMS	GCMS	GC	
β-Eudesmol	GCMS	GCMS	GC	
Sesquiphellandrol		GC	GC	
T-Muurolol	MS	GC		
α-Himachallene		GCMS		
α-Cubebene	MS	GCMS	MS	MS
α-Copaene		GCMS	MS	MS
Muurolene				MS
Geranylacetone				MS
Vetivinene				MS
Trans isoeugenol		GCMS	GC	
Eugenol α	MS			
2-Methylbutanal	MS			
Limonene	GCMS	GCMS	MS	MS
β-Phellandrene	GCMS	GCMS		
Acetic acid	MS			
Pinanol	MS			
Alloaromadendrene	MS		MS	MS
(-) α-Bisabolol	MS			
$C_9H_{20}O$	MS			
Perillene		MS		
2-Ethyl hexanol		MS		
Acetyl Furan		MS		
α Santalene		MS		
(Z)-β-Farnesene		MS		
Citronellol+α	GCMS			MS
Geranyl acetate				MS
Geranyl propionate	MS			
Geranoic acid	MS			
E,E-α-Farnesene	GCMS			
E,β-farnesene	GCMS			
n-Methyl pyrrole	MS			
4-iso propyl-2-cyclohexen-1-one				MS
Neryl acetate			MS	
Calamenene			MS	
Limonen-10-ol			MS	
Bisabolol			MS	MS
Geranic acid	GCMS			
2-Pentanal				MS
α-Cadrene				MS
Bornyl formate				GCMS
Citronellyl formate				MS
Cedrol				MS

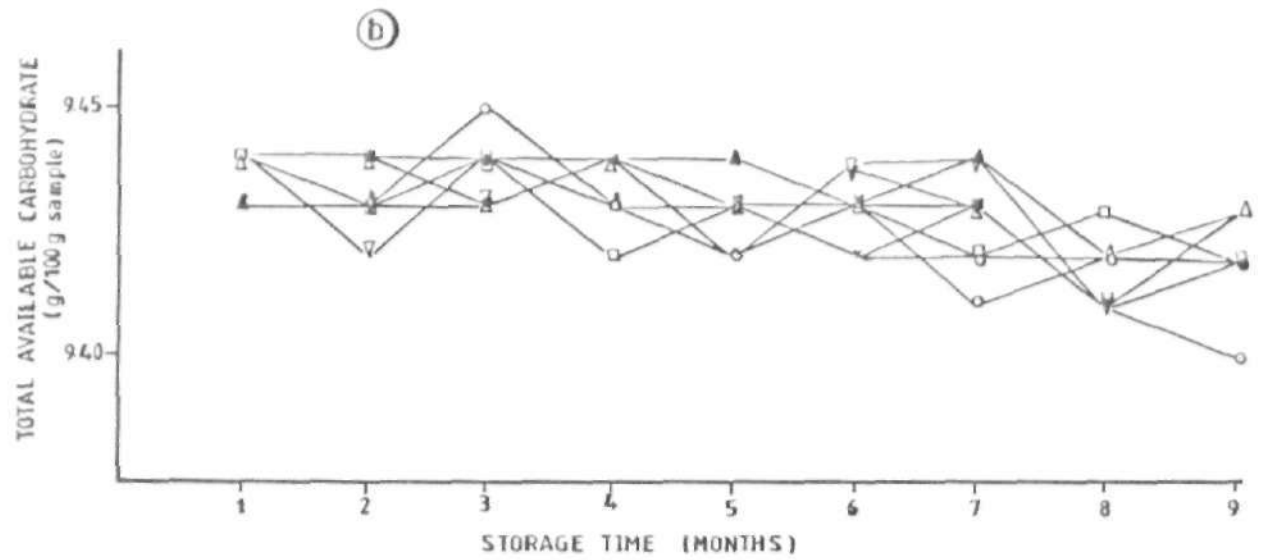
4.2.4 Carbohydrates.

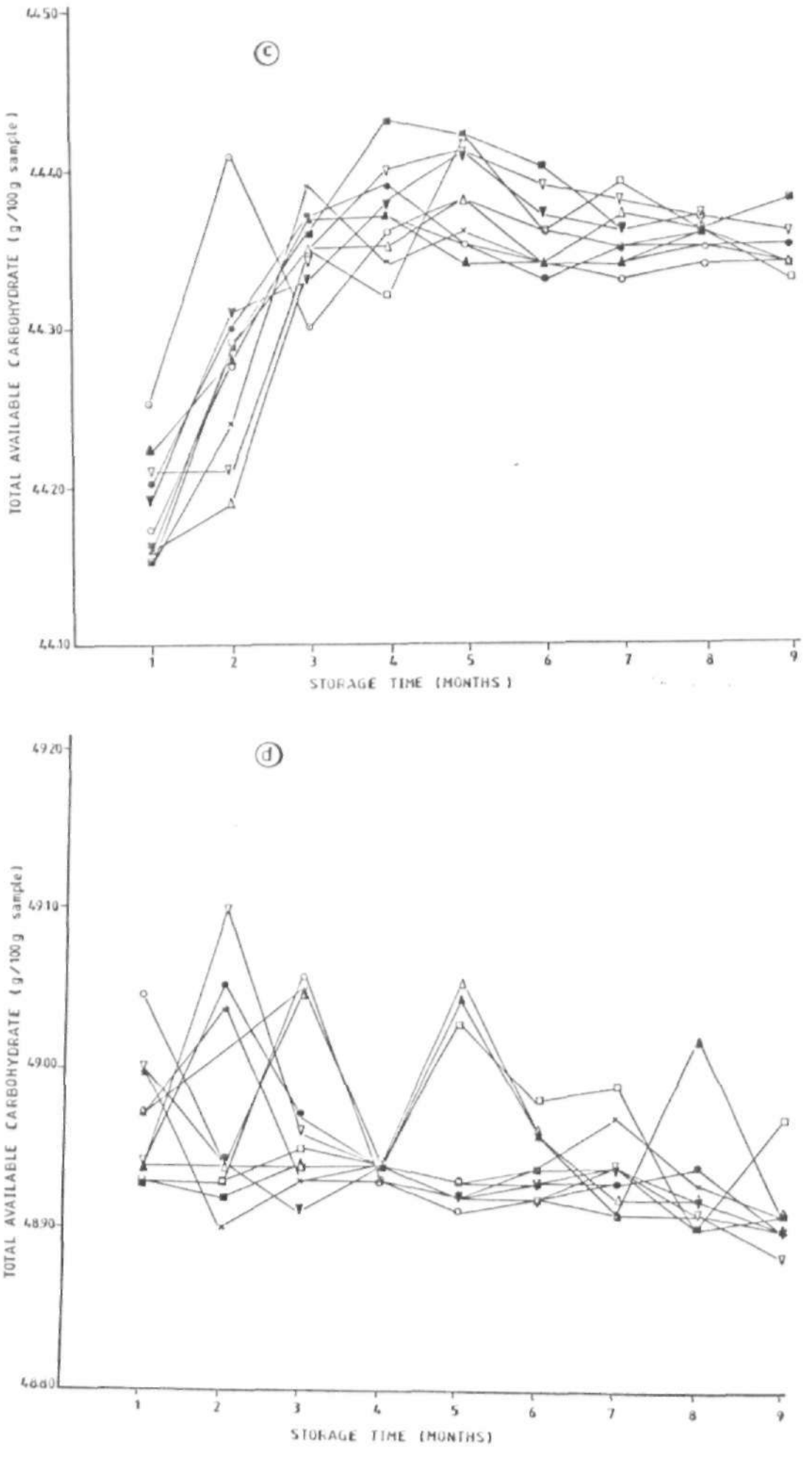
The total available carbohydrate (TAC) of the spices varied from one to the other (Fig. 4.7). The Ashanti pepper topped the list with a mean of about 49% and coriander the least with a mean of about 9.42%. The results showed that there is no effect ($P > 0.05$) of irradiation dose on the total available carbohydrates. Time did not affect ($P > 0.05$) the TAC content either. However, since this is a measure of all the digestible carbohydrates present in the samples, it then indicates that there is no destruction or degradation of the carbohydrates into nondigestible carbohydrates. Similarly, it may mean that no non-degestible carbohydrates was degraded to digestible form. Less work has yet been done on the effect of irradiation on polysaccharides like pectin and cellulose, however, Diehl, *et al.* (1978) suggested that these polysaccharide may be resistant to irradiation.

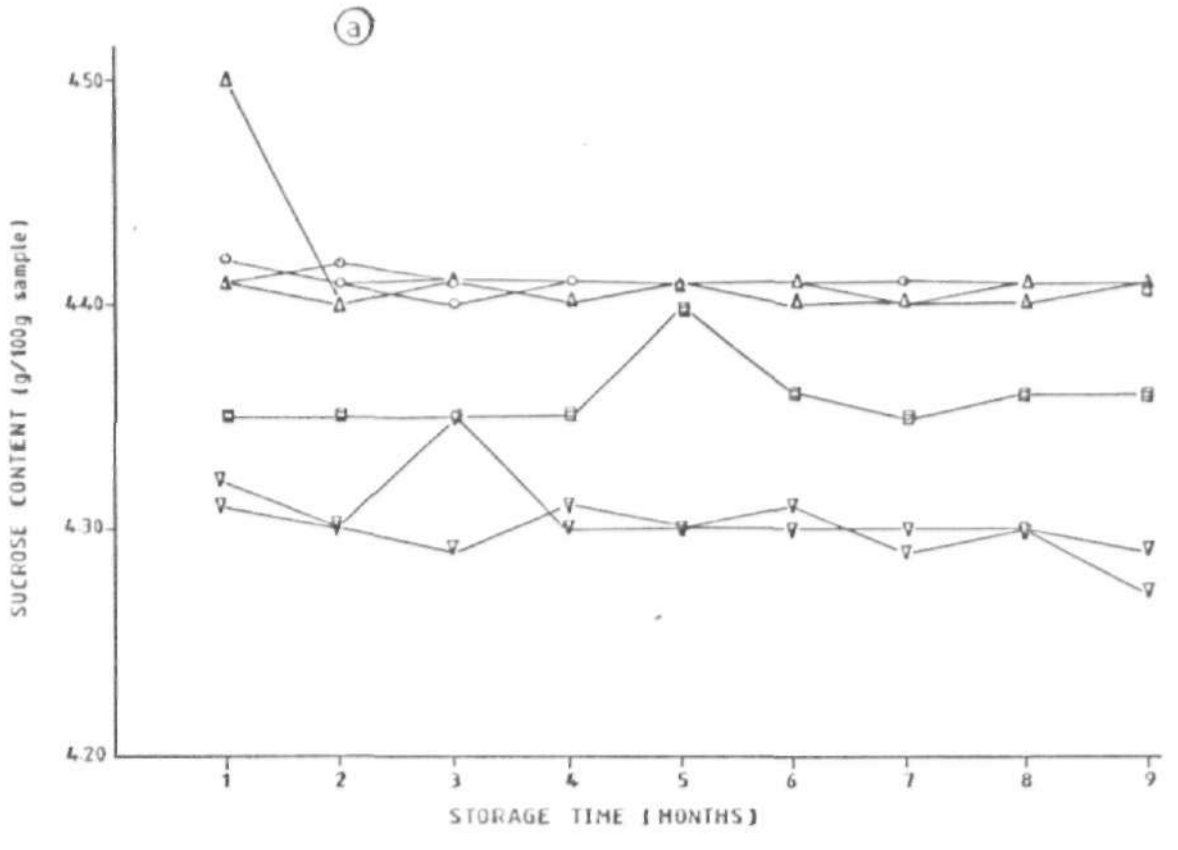
However a gradual decrease in sucrose content, with increasing radiation dose, although insignificant ($P > 0.05$) was observed with capsicum and Ashanti pepper (Fig. 4.8a and d). These two spices have higher sucrose content 4.40% than the other two - coriander and ginger (1.34 and 0.41% respectively) which implies that if the percentage decrease is considered which about 0.023% (that is about 0.66 μmoles/g) any decrease in these two could not have been detected in with the method used. Berger, *et al.* (1973) reported that lower molecular weight sugars such as glucose, maltose, erythrose, ribose and mannose are formed in dose dependent yield from polysaccharides. This observed effect could also be applicable to disaccharides. The apparent effect observed was not selective, that is, it was not dependent on the form of the spices. The decrease with dose used from 4.42 and 4.37 for the control sample to 4.31 and 4.24% after irradiation with 10 kGy does with respect to capsicum and Ashanti pepper had earlier been noticed by Bachman, *et al* (1978) with cardamom.

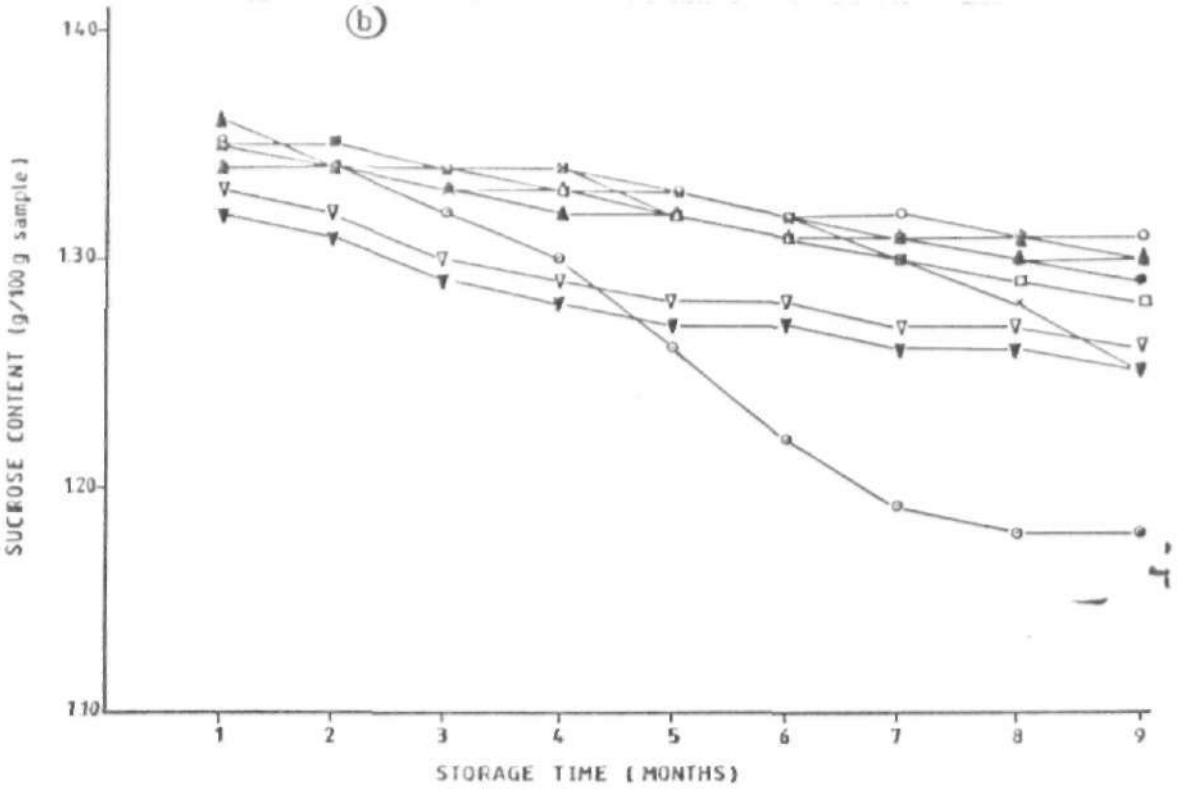
Sugars are important constituents (13.6, 3.24, 9.74 and 9.42%) of ginger coriander, Ashanti pepper and capsicum respectively. In aqueous extracts of the spices the content of total reducing sugars content was estimated (Fig 4.9). A slight increase in reducing sugar was observed. The observed effect increased significantly ($P < 0.05$) as the dose was

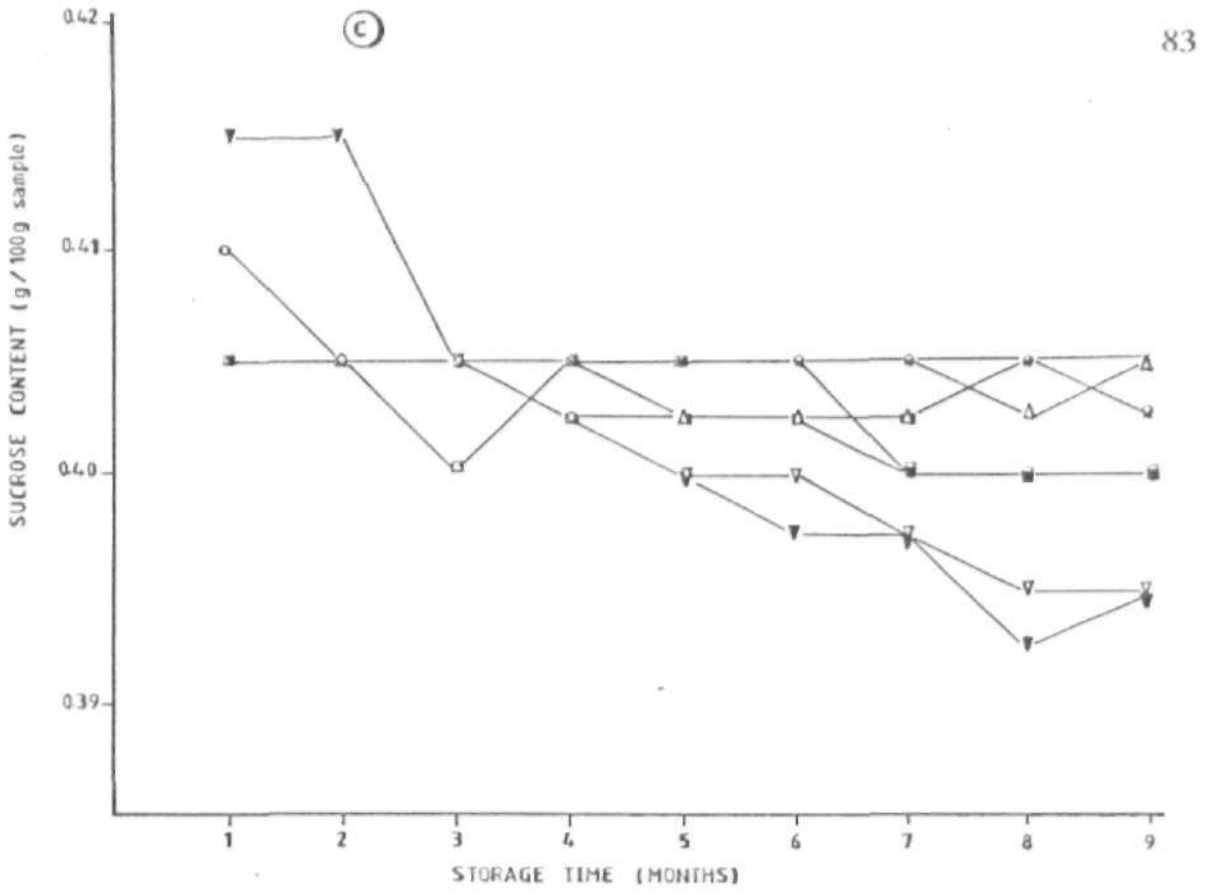

(a)
TOTAL AVAILABLE CARBOHYDRATE (g/100 g sample)
22.90
22.80
22.70
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

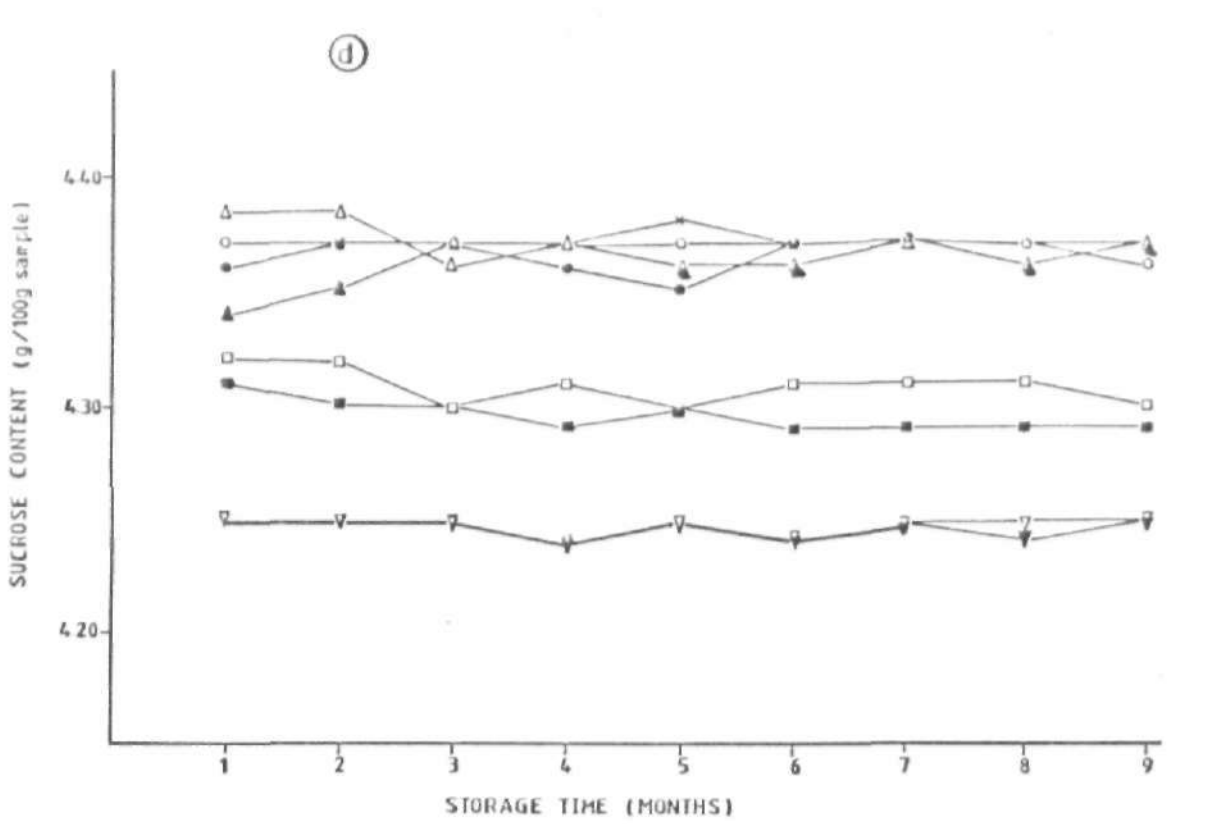

(b)
TOTAL AVAILABLE CARBOHYDRATE (g/100 g sample)
9.45
9.40
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

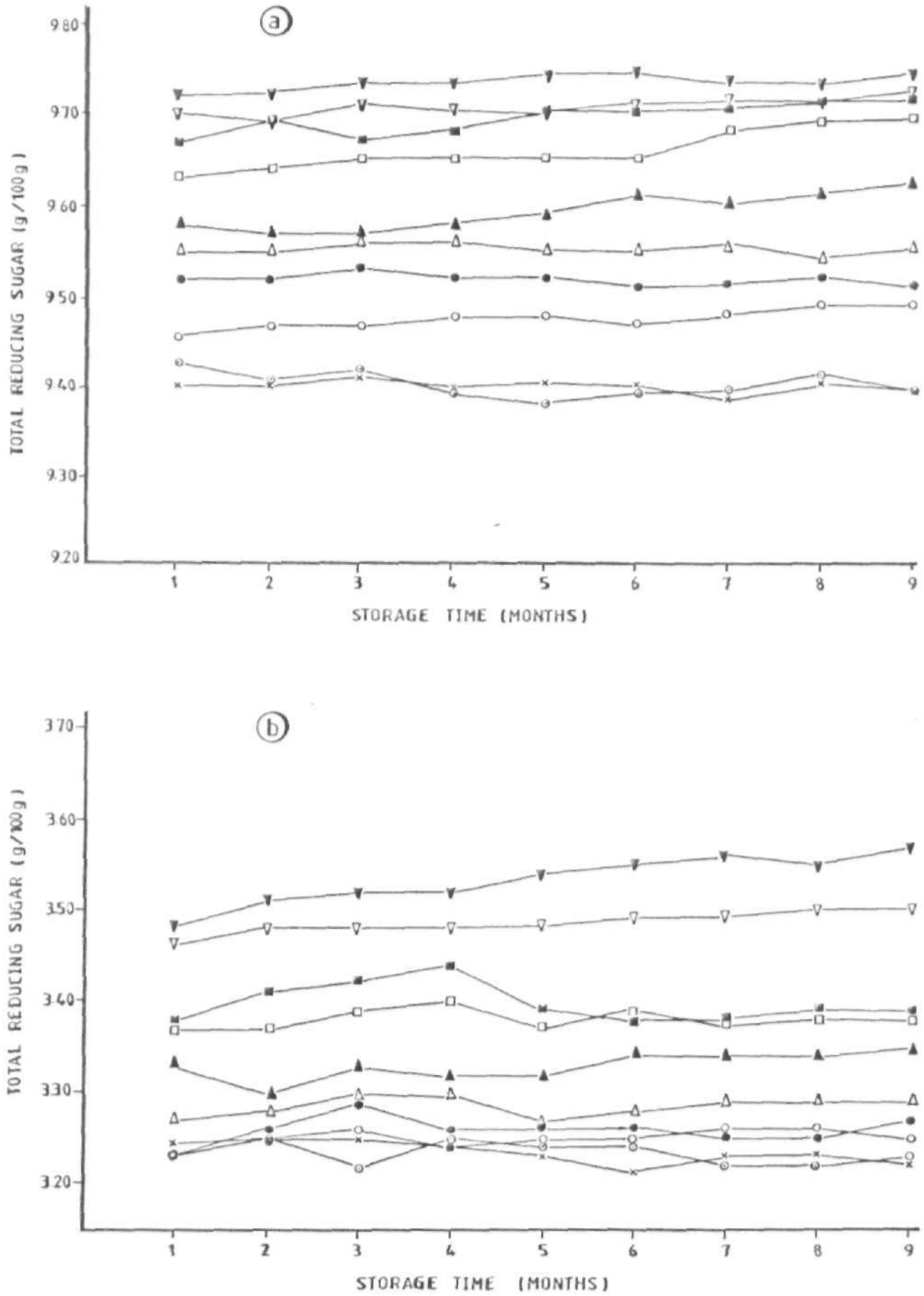

(c)
TOTAL AVAILABLE CARBOHYDRATE (g/100g sample)
44.50
44.40
44.30
44.20
44.10
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
(d)
TOTAL AVAILABLE CARBOHYDRATE (g/100g sample)
49.20
49.10
49.00
48.90
48.80
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

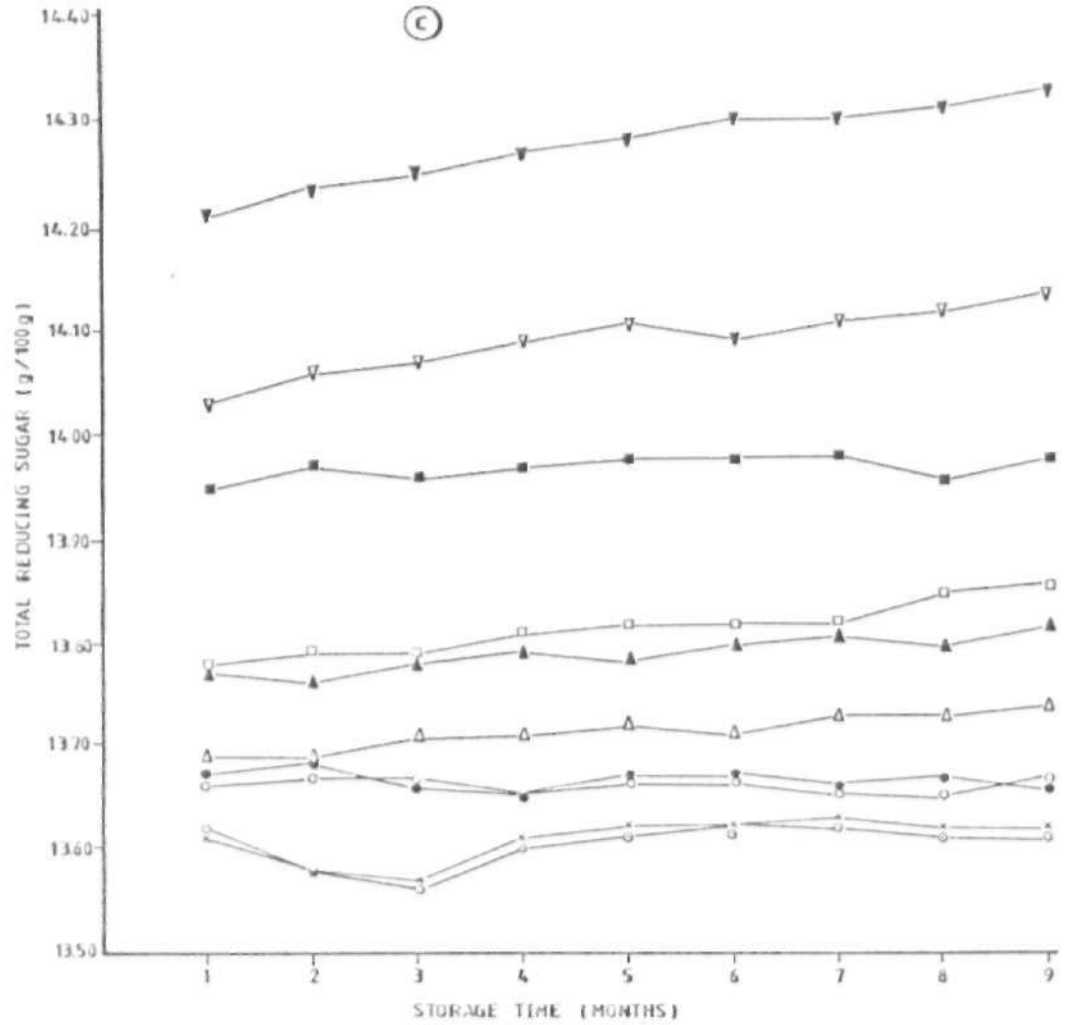

(a)
SUCROSE CONTENT (g/100g sample)
4.50
4.40
4.30
4.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

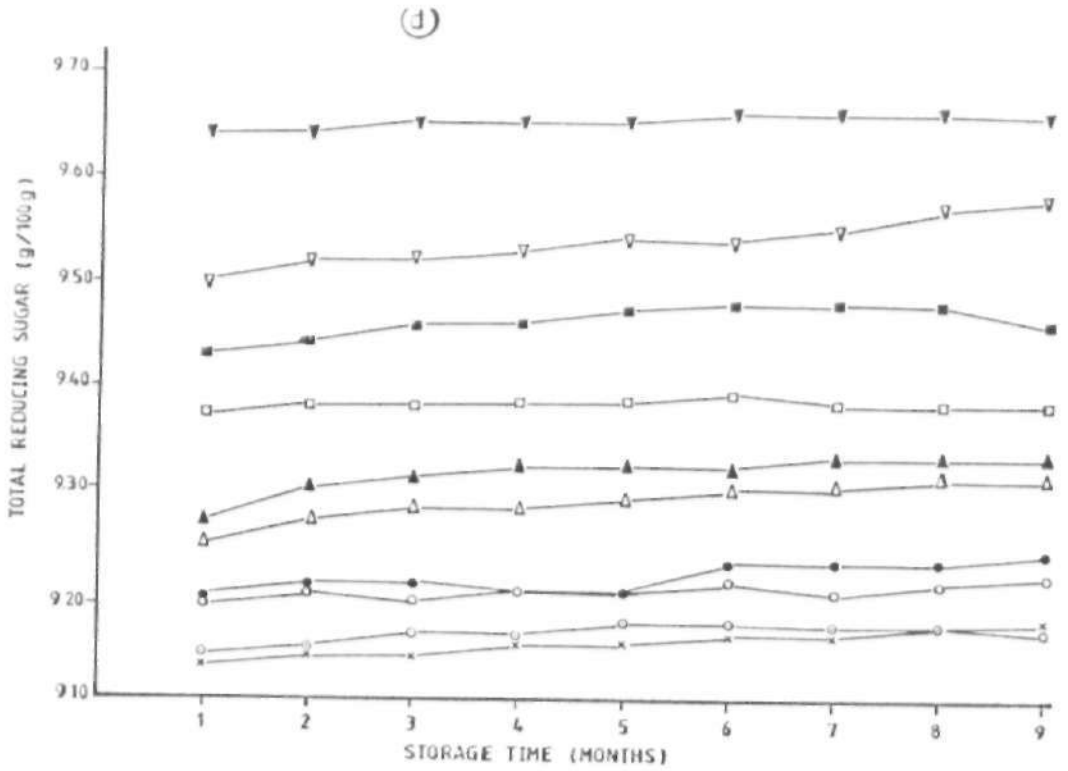

(b)
SUCROSE CONTENT (g/100 g sample)
140
130
120
110
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
SUCROSE CONTENT (g/100g sample)
0.42
0.41
0.40
0.39
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(d)
SUCROSE CONTENT (g/100g sample)
4.40
4.30
4.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


a
TOTAL REDUCING SUGAR (g/100g)
9.80
9.70
9.60
9.50
9.40
9.30
9.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
b
TOTAL REDUCING SUGAR (g/100g)
3.70
3.60
3.50
3.40
3.30
3.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
TOTAL REDUCING SUGAR (g/100g)
14.40
14.30
14.20
14.10
14.00
13.90
13.80
13.70
13.60
13.50
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

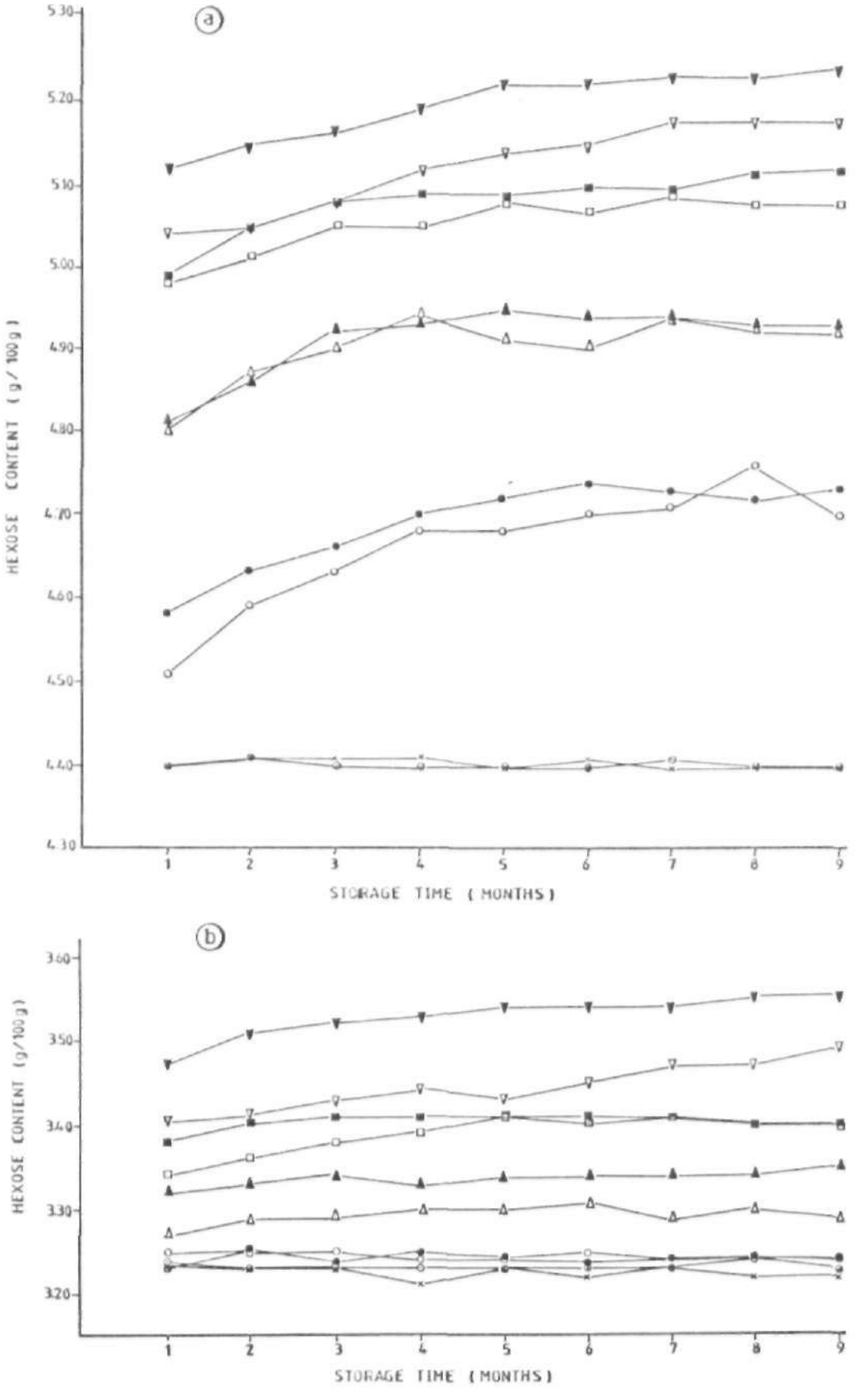

(d)
TOTAL REDUCING SUGAR (g/100g)
9.70
9.60
9.50
9.40
9.30
9.20
9.10
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

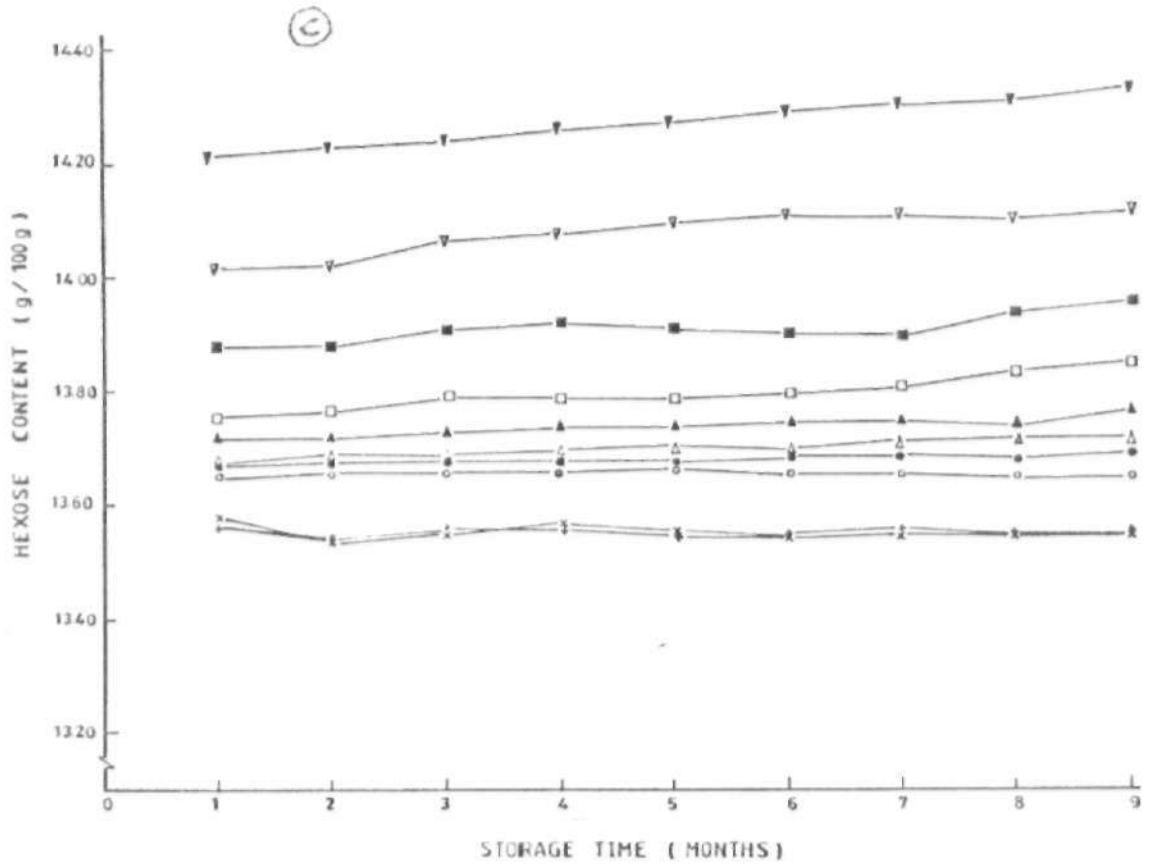
increased. A higher effect was observed with Ashanti pepper where the difference between the control and highest dose-treated sample was about 5.58%. Similar observations had been reported by Bachman, *et al.* (1978) on caraway. The increase in reducing sugar content they opined, showed polysaccaharide degradation under the action of radiation. The same year, Rao, *et al.* (1978) reported an overall increase in initial total reducing sugars in irradiated wheat flour which according to Ananthaswany, *et al.* (1970) have risen from stepwise and random degradation of starch. The most important action of irradiation as reported by Galetto, *et al.* (1979) is the splitting of the external glycosidic linkages which connect the single monosaccharides to chain molecules.

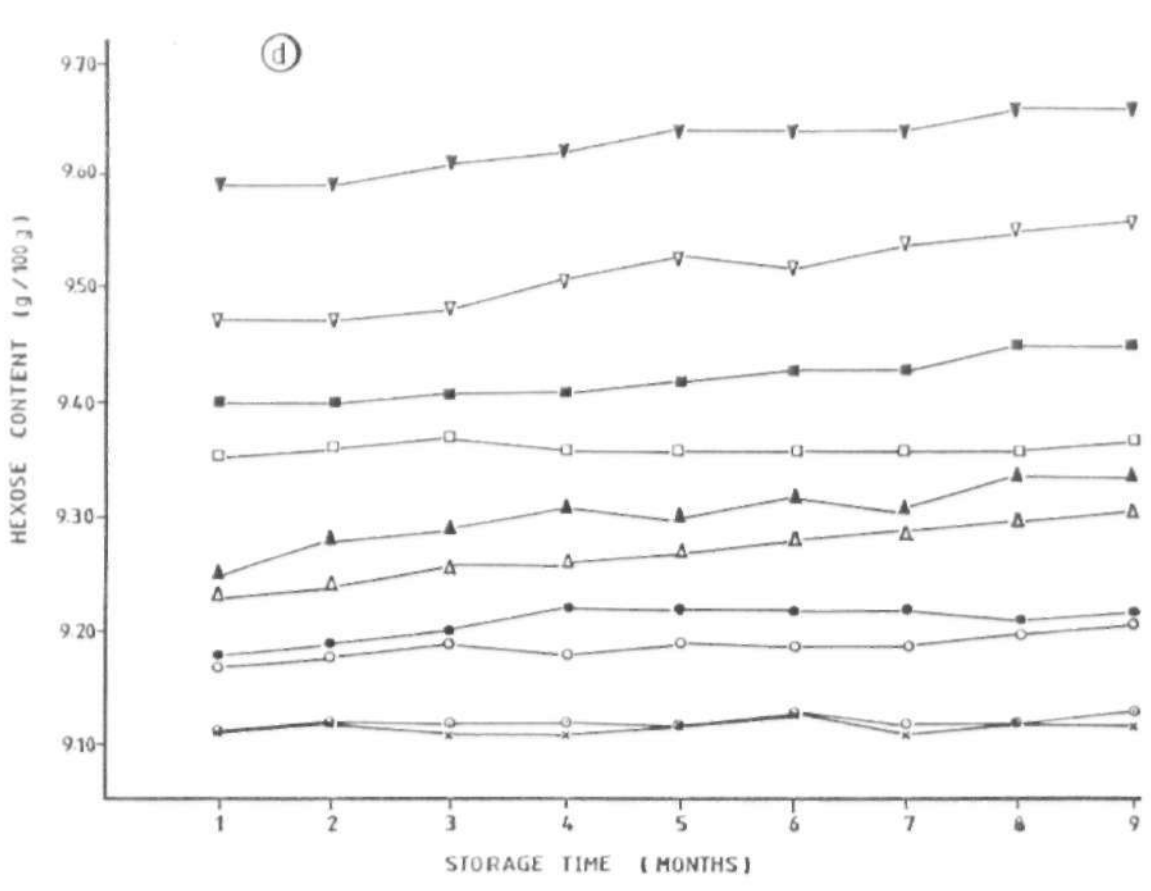
Byun, *et al.* (1984) worked on the effect of irradiation on the sterilization of black pepper powder and observed that irradiation at 3, 6 and 9 kGy slightly increased the total reducing sugar content of the spice. The result showed that the effect of irradiation on the reducing sugar content depended on the form of the sample. In all the doses used in this study the whole samples were less sensitive to radiation treatment. This radiosensitivity of the ground samples would have arisen from the fact that during grinding natural structures of carbohydrate polymers may have been disrupted thereby exposing them further to radiation attack. A similar observation has been reported by Urbain (1978) with protein. Another possible explanation for the increase in reducing sugars may be as a result of loosening of the tissue in the irradiated raw material hence the better extraction of carbohydrate dissolved in aqueous medium as observed by caraway (Bachman, *et al.*, 1978).

A marginal increase in reducing sugar content was observed as the storage time progressed with the high dose (5 - 10 kGy) treated samples. This effect had been attributed to after effect of ionizing radiation especially in dry material.

In order to ascertain whether the increase in reducing sugars was due to other carbohydrates other them the common sugars. The total hexose content was analysed. The results (Fig 4.10) show that there was no difference ($P > 0.05$) between the hexose and reducing sugar contents indicating that the observed reducing sugars may be composed of mainly hexose sugars.


a
HEXOSE CONTENT (g/ 100 g)
5.30
5.20
5.10
5.00
4.90
4.80
4.70
4.60
4.50
4.40
4.30
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
b
HEXOSE CONTENT (g/100g)
3.60
3.50
3.40
3.30
3.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
HEXOSE CONTENT (g / 100 g)
14.40
14.20
14.00
13.80
13.60
13.40
13.20
0
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

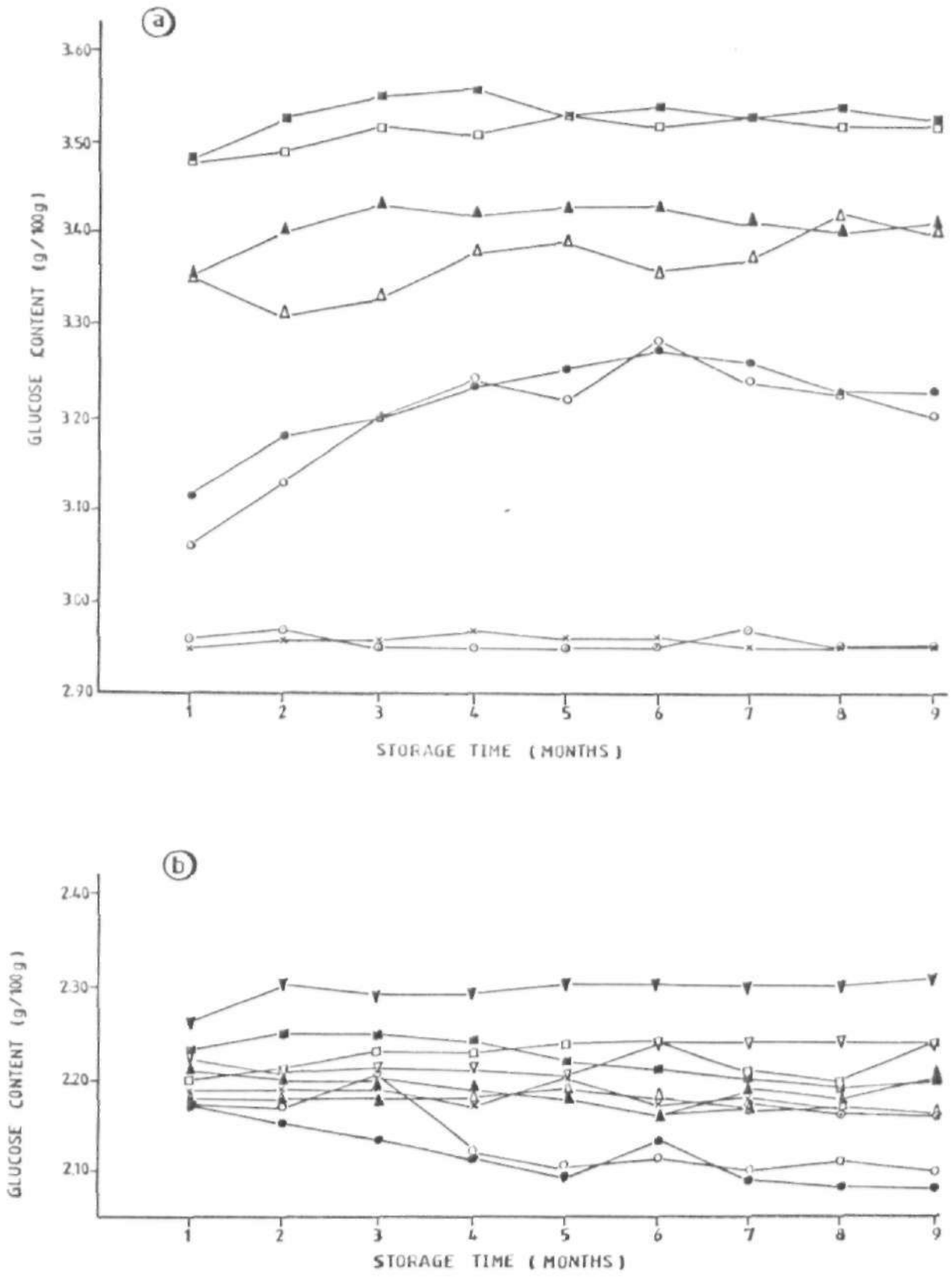

(d)
HEXOSE CONTENT (g/100 g)
9.70
9.60
9.50
9.40
9.30
9.20
9.10
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

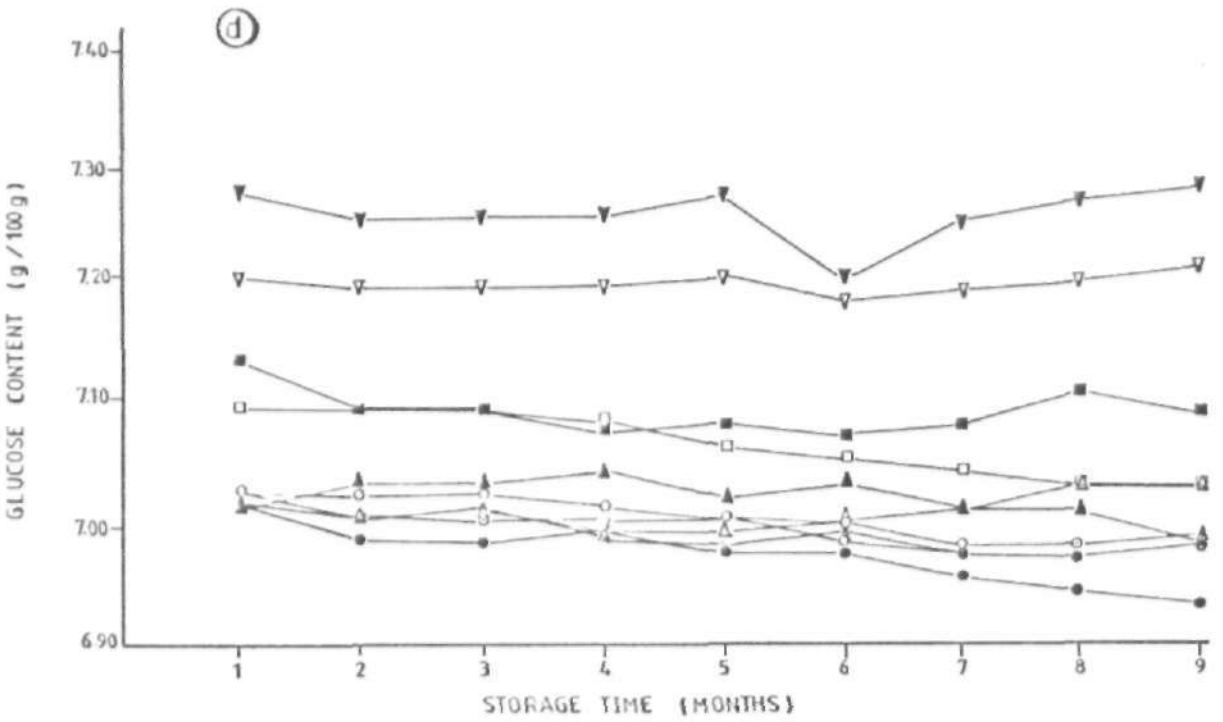
Gamma irradiation of rice increased the soluble starch content of residual cooking water with increase in dose levels suggesting degradation of the starch grain structure (Sabularse, *et al.* 1991). Depolymerization of starch chain had been suggested (Deschreider 1960) to be one of the actions of irradiation. MacArthur and D'Applolonia (1984) attributed the increase in wheat starch solubility on irradiation to losses of molecular weight components formed by starch degradation. Since starch is a glucose polymer it implies that the observed significant ($P < 0.05$) increase in glucose content (Fig 4.11) could be attributed to degradation of starch. A similar observation had been reported (Bachman, *et al.*, 1978) for cardamom. They observed decrease in pentose and sucrose with the dose used from 5.2% for the control sample to 3.0% after irradiation with 15 kGy dose as will as some increases in fructose and sucrose content.

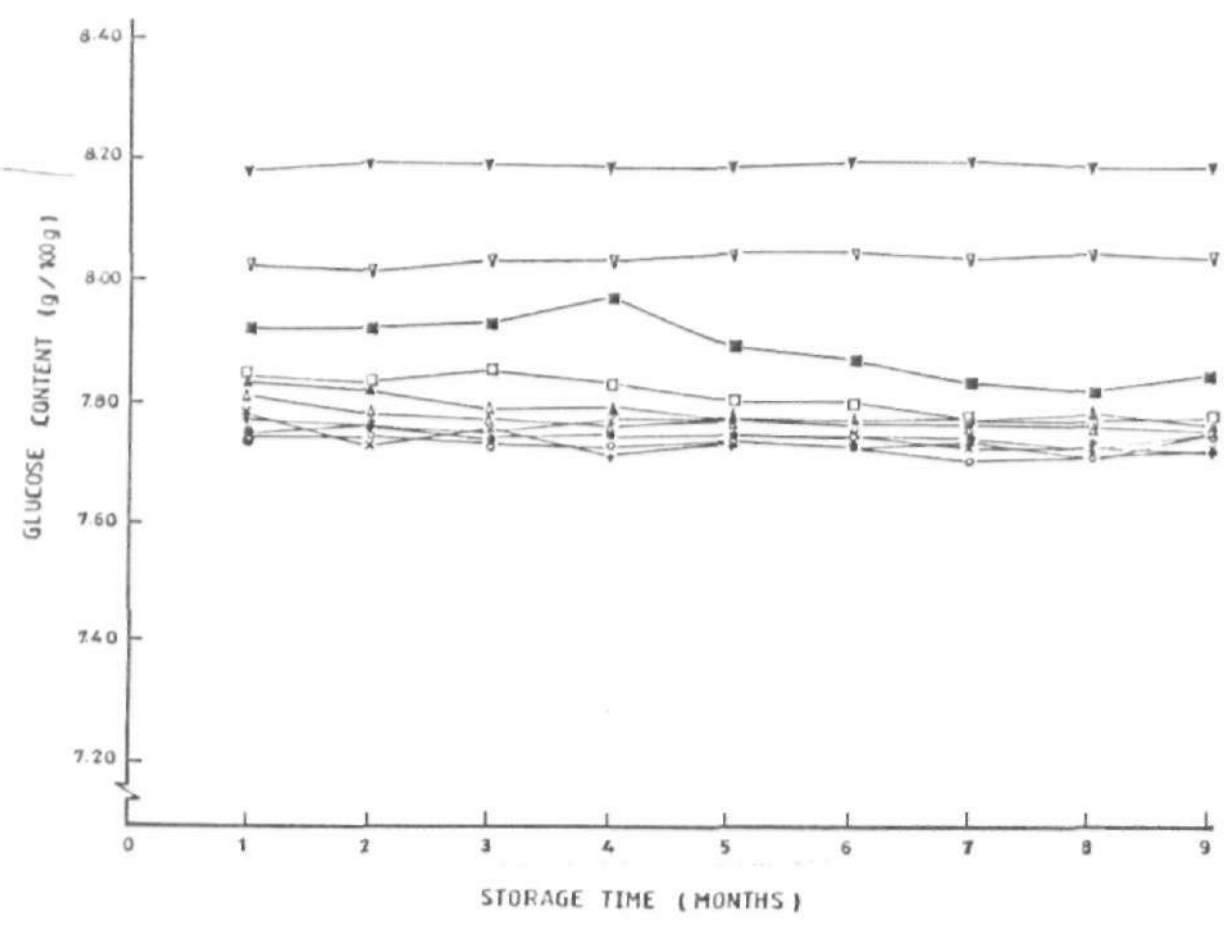
As observed with reducing sugar content, the state of the sample rather than time of storage affected the response to irradiation. Although statistically negligible ($P > 0.05$) at lower doses but significant ($P < 0.05$) at 10 kGy, the ground samples showed lesser resistance to irradiation than the whole samples. An insignificant ($P > 0.05$) decrease in glucose content was observed with 2.5 kGy does treated samples.

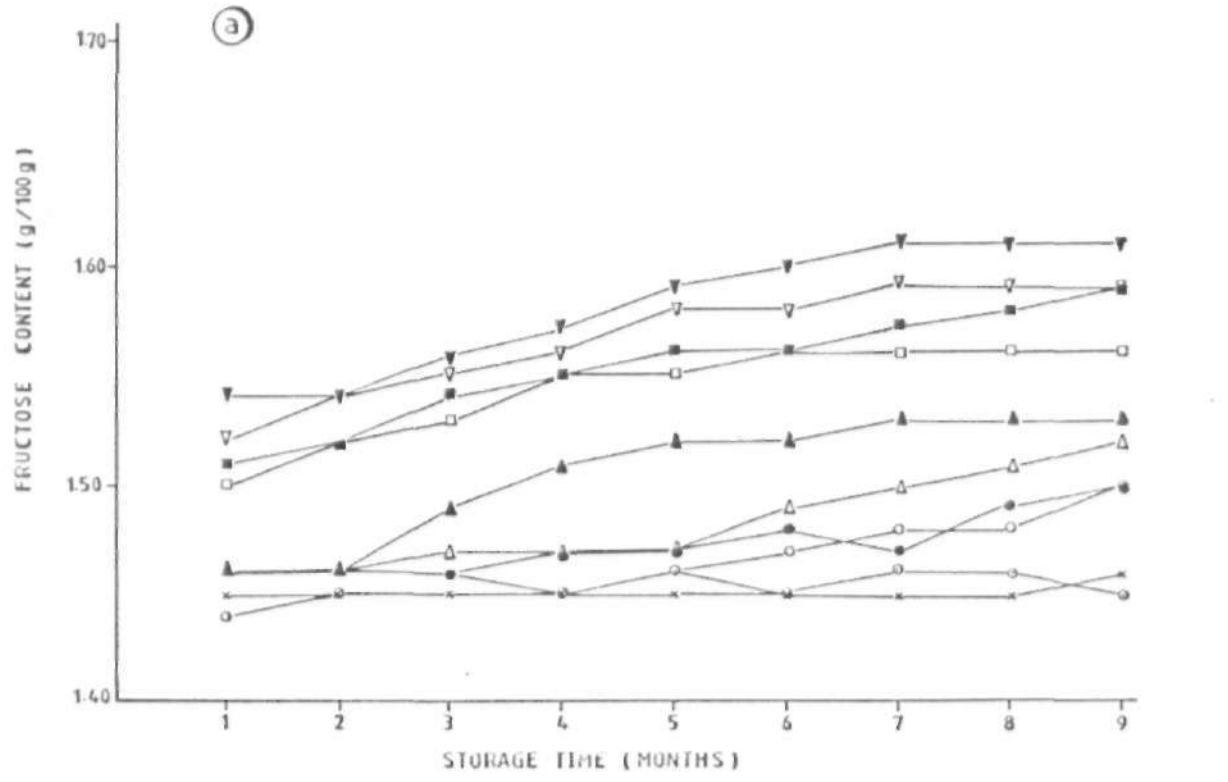
4.2.5 Protein

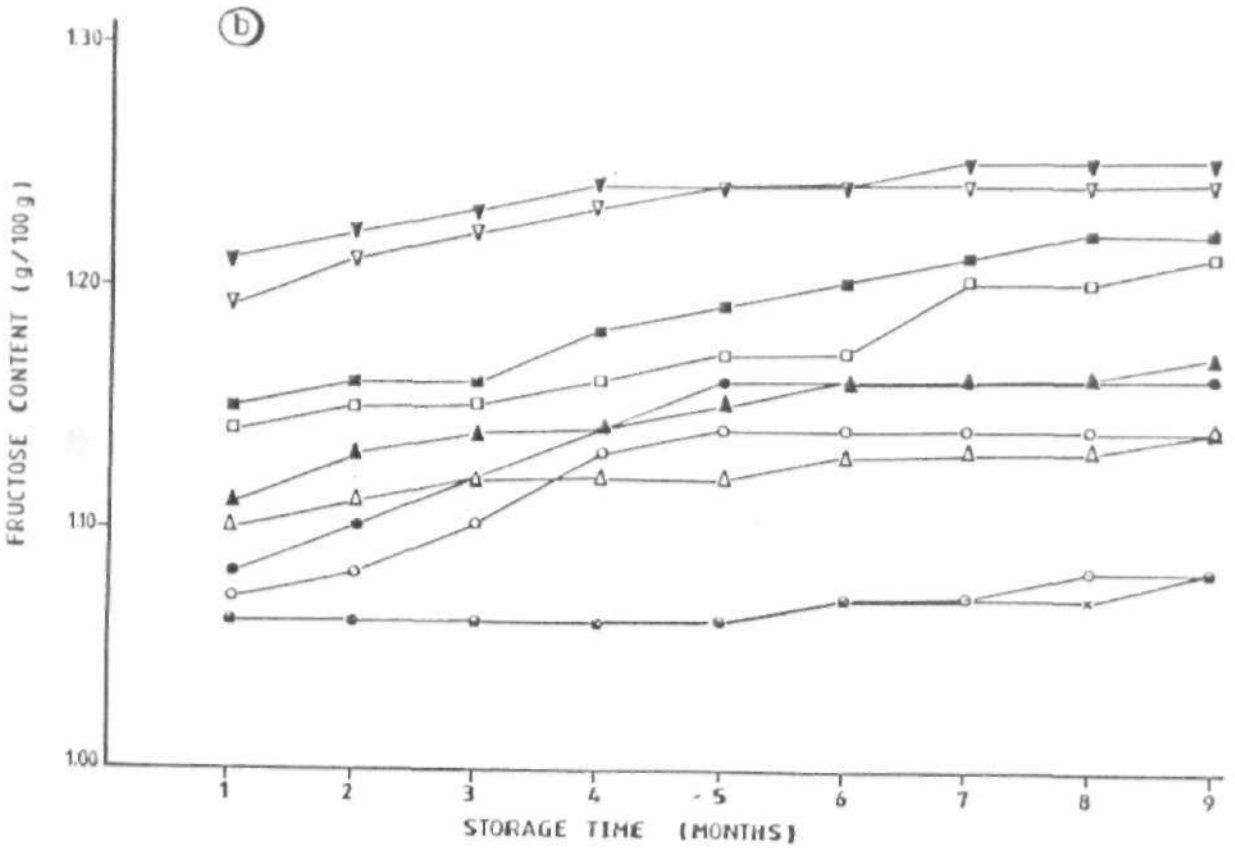
The protein contents of the spices is shown in Fig. 4.13. The spices contain different amounts of protein. Coriander had the highest protein content of about 25.18% indicating that could be a good source of protein (the biological value not withstanding) and ginger the least (approximately 12.0%) on dry weight bases. In all the spices neither radiation dose, time nor form had any influence on the protein content. ($P > 0.05$). Radiation-induced degradation of pure proteins in the dry state should almost entirely be due to the direct action of radiation (Garrison, 1979).

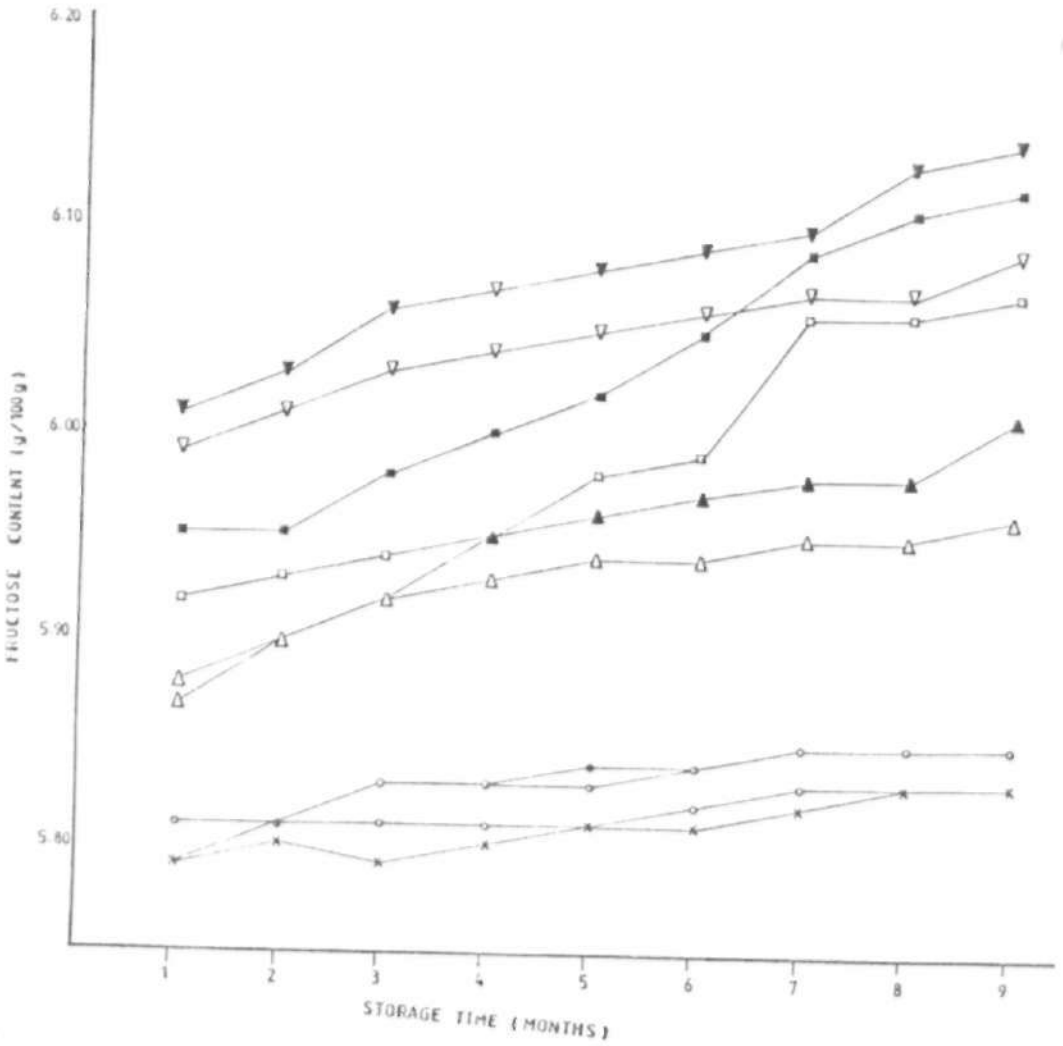

a
GLUCOSE CONTENT (g/100g)
3.60
3.50
3.40
3.30
3.20
3.10
3.00
2.90
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
b
GLUCOSE CONTENT (g/100g)
2.40
2.30
2.20
2.10
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

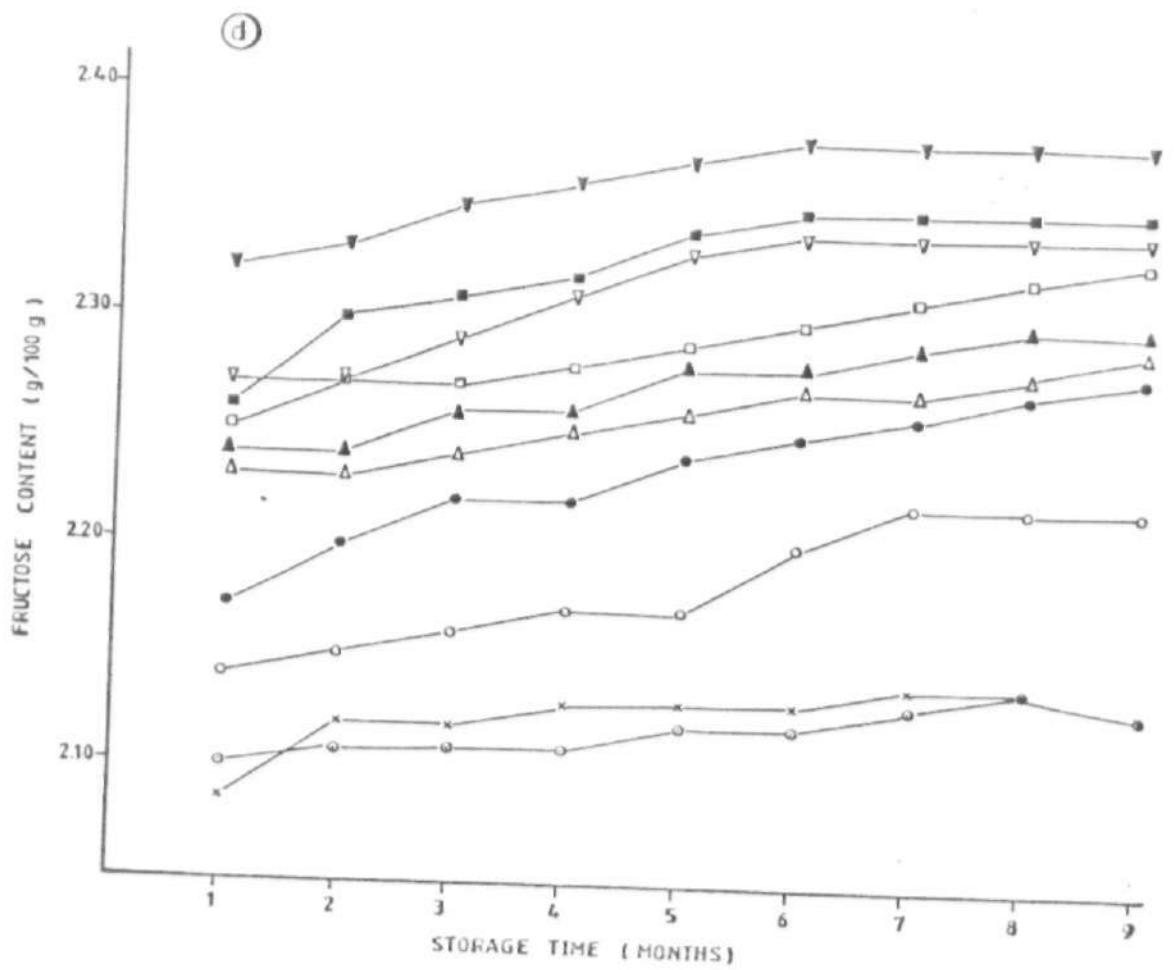

(d)
GLUCOSE CONTENT (g/100g)
7.40
7.30
7.20
7.10
7.00
6.90
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

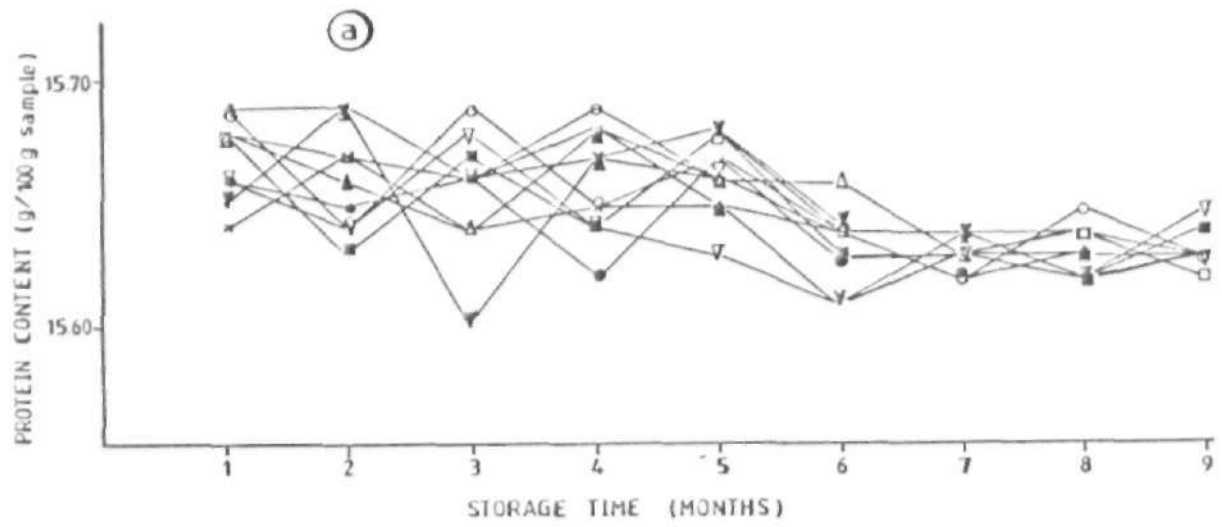

GLUCOSE CONTENT (g/100g)
8.40
8.20
8.00
7.80
7.60
7.40
7.20
0
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

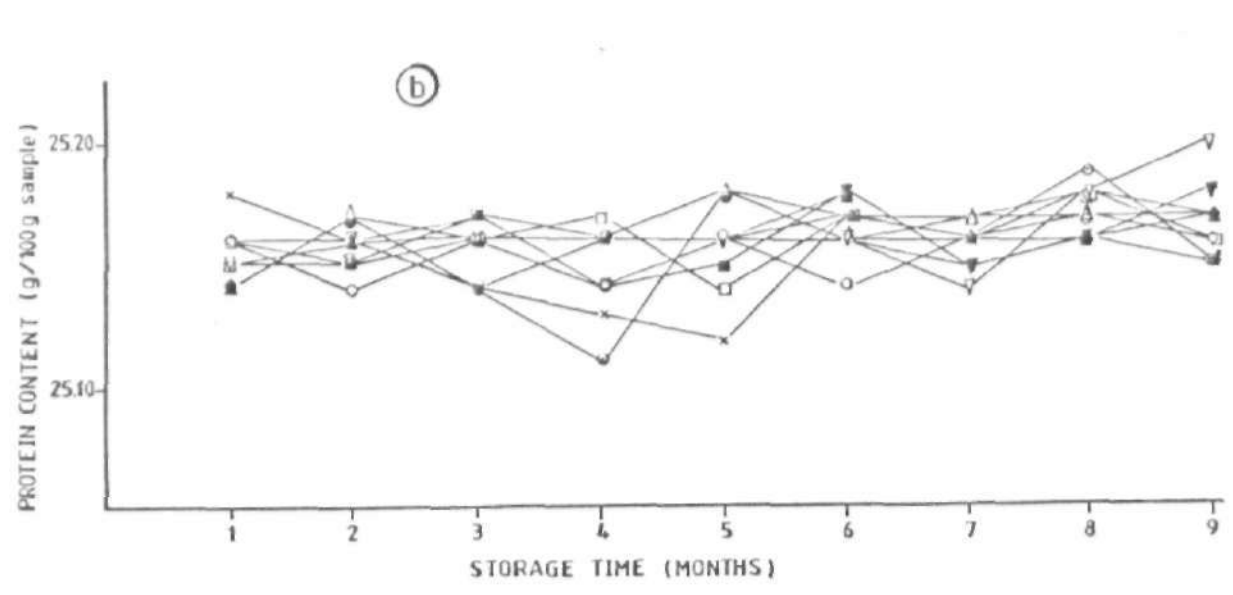

(a)
1.70
1.60
1.50
1.40
FRUCTOSE CONTENT (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

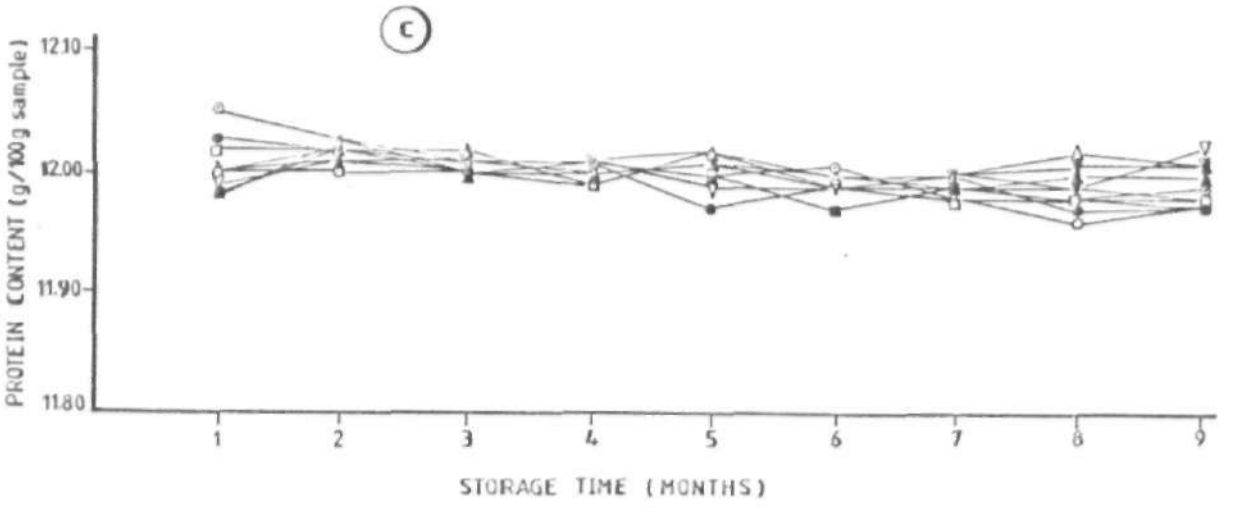

(b)
1.30
1.20
1.10
1.00
FRUCTOSE CONTENT (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

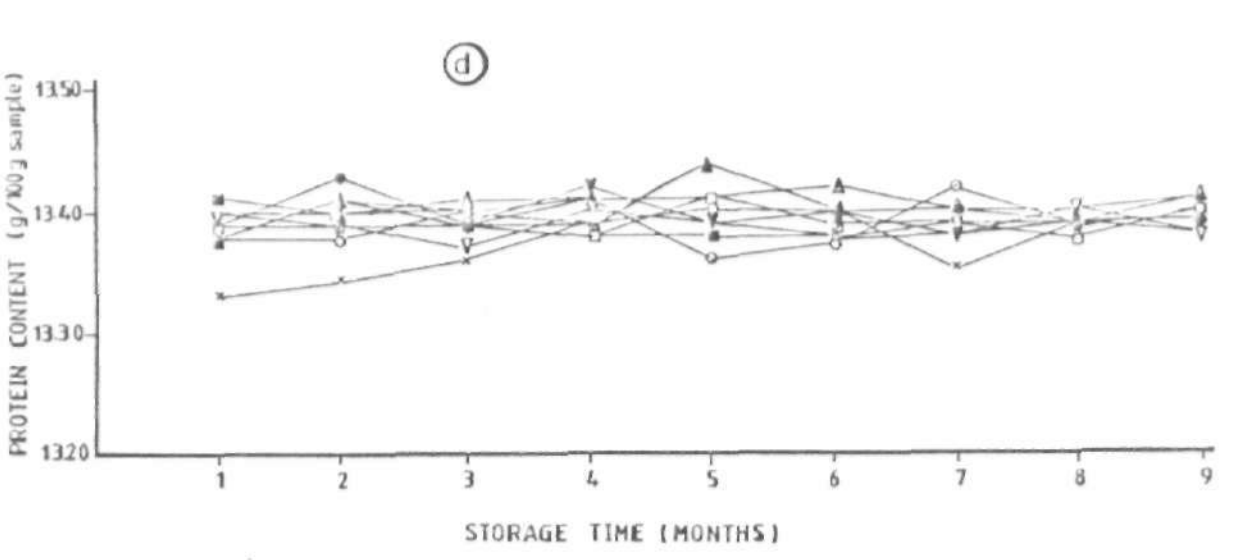

6.20
6.10
6.00
5.90
5.80
FRUCTOSE CONTENT (g/100g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(d)
2.40
2.30
2.20
2.10
FRUCTOSE CONTENT (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(a)
PROTEIN CONTENT (g/100g sample)
15.70
15.60
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(b)
PROTEIN CONTENT (g/100g sample)
25.20
25.10
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


c
PROTEIN CONTENT (g/100g sample)
12.10
12.00
11.90
11.80
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


d
PROTEIN CONTENT (g/100g sample)
13.50
13.40
13.30
13.20
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

4.2.6 Lipid Content

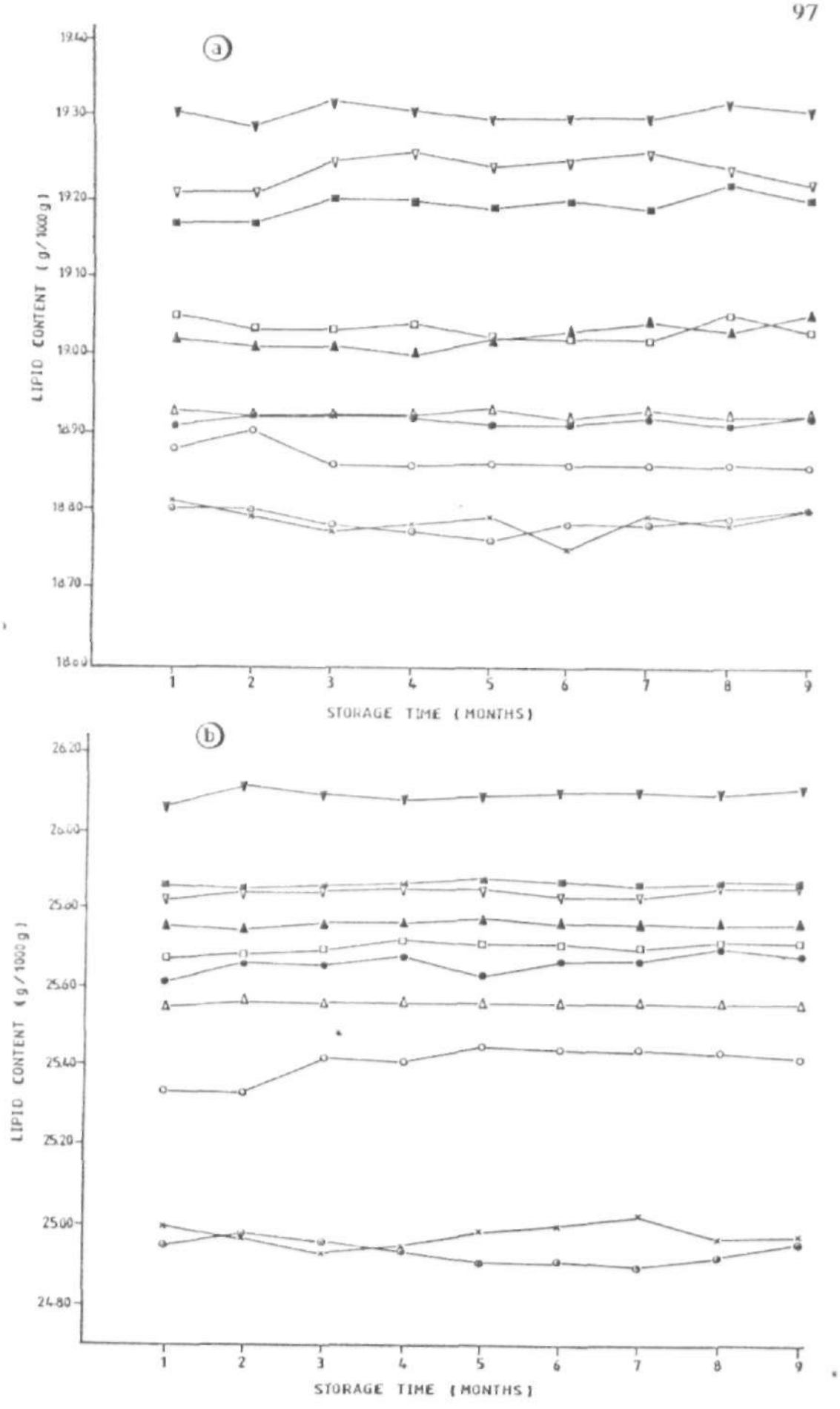
The lipid content of the spices are shown in (Fig. 4.14). In all the cases gradual increase in the lipid fraction as other extract was observed with increase in radiation dose. The ground samples were more susceptible to irradiation effect.

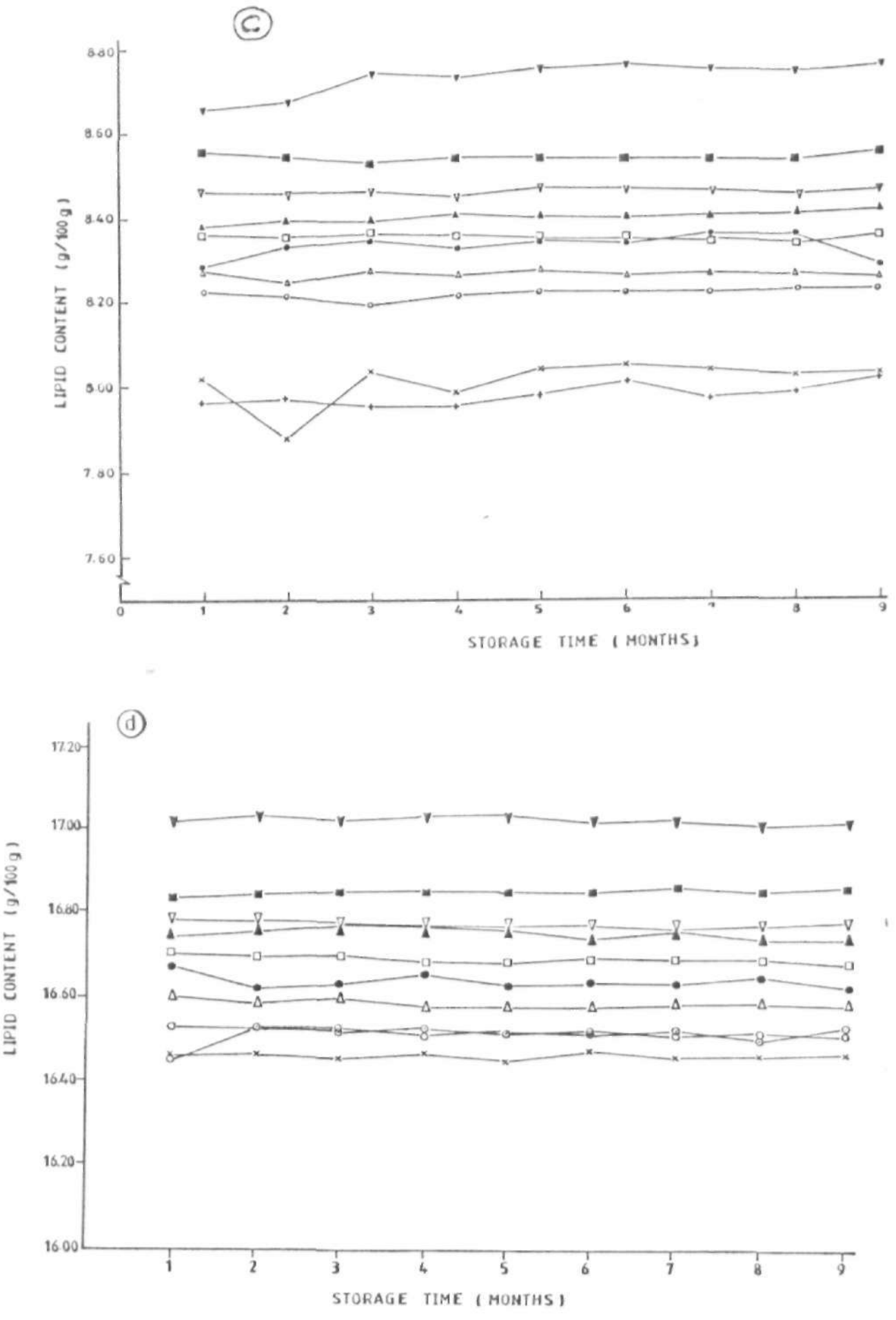
Bachman, *et al.*, (1978) investigated the alteration in the chemical composition of spices and spice mixtures and observed no distinct changes in lipid fraction composition rather a total increase was observed. They attributed this increase in total lipid fraction to improved extractability. Rao, *et al.*, (1978) observed that total lipid content of wheat was not changed due to irradiation, however samples irradiated at 10 kGy were observed to differ positively (30%) from non-irradiated wheat samples in free lipids and negatively (40%) in bound lipid . This actually confirmed the assertion of Bachman, *et al.*, (1978) that irradiation improves the extractabililty of lipid fractions.

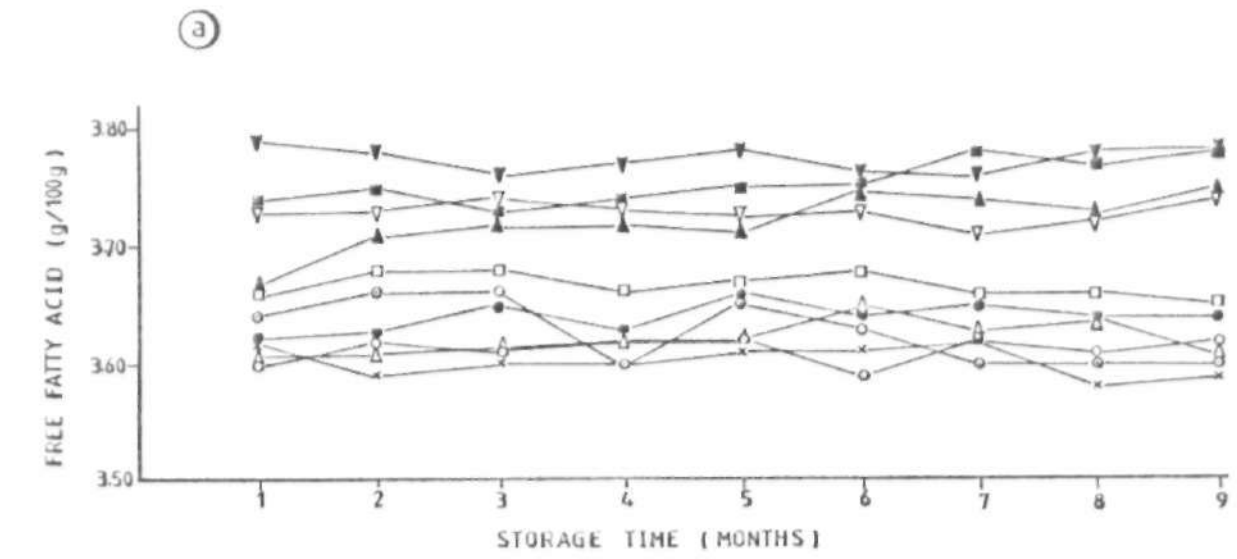
The relatively higher sensitivity shown by coriander may be due to its higher lipid content and/or the presence of other sensitizers. Effect of irradiation on the lipid content of food substance is said to be dependent on a number of variables such as type and composition of the lipid (Hanis and Mnukova, 1985) presence of antioxidants, composition of irradiated food and irradiation conditions (Delincee, 1983; Nawar 1983). This could also explain the increased sensitivity to irradiation shown by the ground samples.

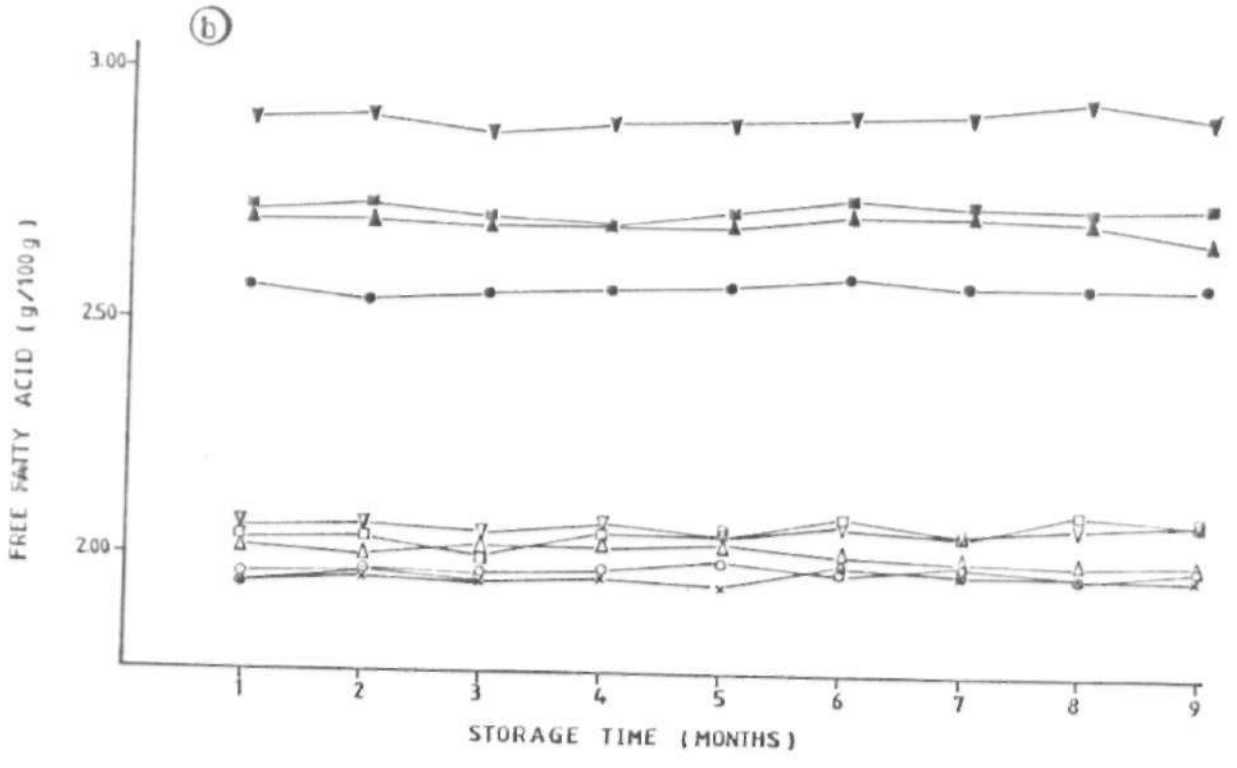
Lipids according to Nawar (1983) belong to the food constituents that are sensitive to irradiation. Irradiation did not significantly ($P > 0.05$) affect the total lipid content at higher radiation doses (7.5 - 10.0 kGy) as shown in Fig. 4.14. Katusin-Razem *et al.* (1989) have shown that radiation decomposed some triglycerides and probably some diglycerides in dried egg so that the fraction of monoglycerides increased with increasing dose. Radiolysis of triglycerides to yield diglycerides leads to concomitant release of free fatty acids, Bachman, *et al.* (1978) observed slight increase in radiation dose.

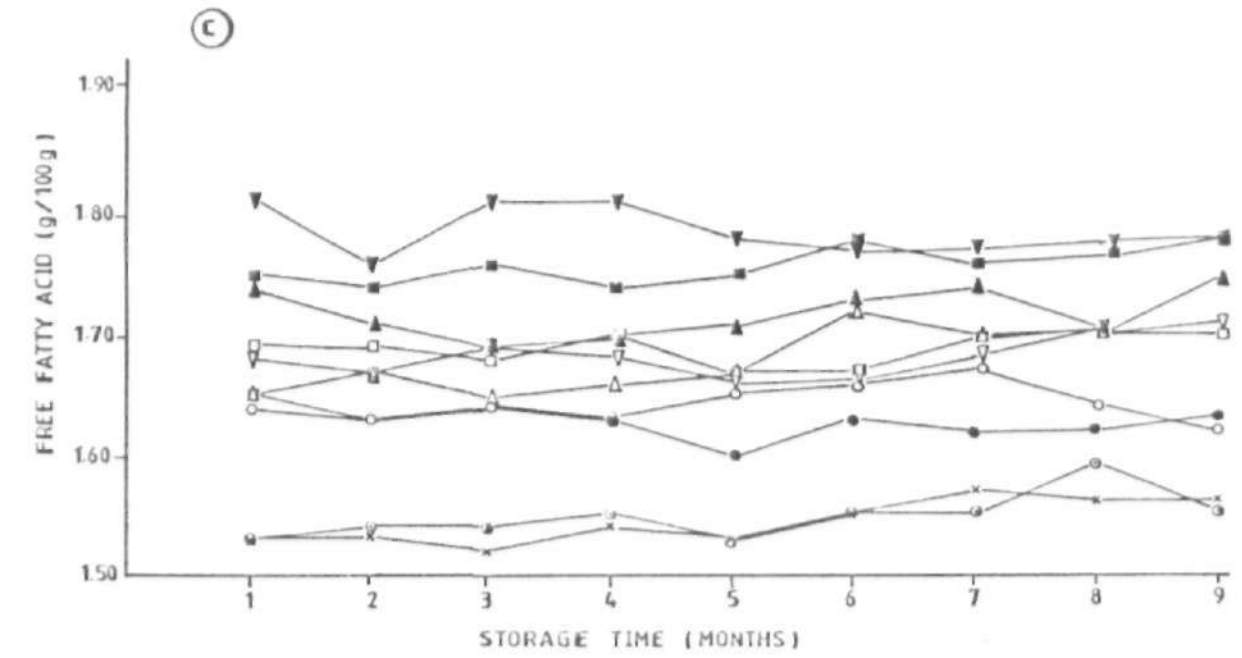
The effect of irradiation on the free fatty acids (Fig 4.15) the spices differed. There was no significant ($P > 0.05$) effect of irradiation on the free fatty acid content

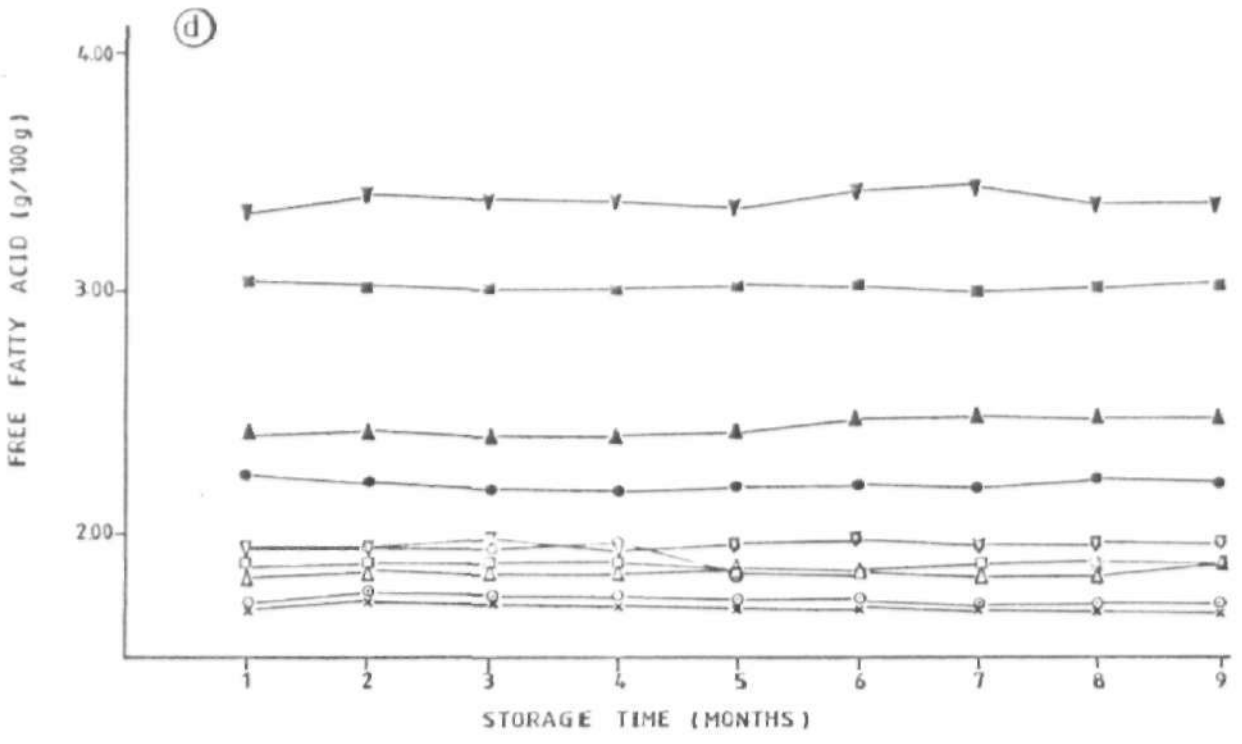

a
LIPID CONTENT (g/1000 g)
19.40
19.30
19.20
19.10
19.00
18.90
18.80
18.70
18.60
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
b
LIPID CONTENT (g/1000 g)
26.20
26.00
25.80
25.60
25.40
25.20
25.00
24.80
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
8.80
8.60
8.40
8.20
8.00
7.80
7.60
LIPID CONTENT (g/100 g)
0
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)
(d)
17.20
17.00
16.80
16.60
16.40
16.20
16.00
LIPID CONTENT (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(a)
FREE FATTY ACID (g/100g)
3.80
3.70
3.60
3.50
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(b)
FREE FATTY ACID (g/100g)
3.00
2.50
2.00
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


c
1.90
1.80
1.70
1.60
1.50
FREE FATTY ACID (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


d
4.00
3.00
2.00
FREE FATTY ACID (g/100 g)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

4469

of capsicum and ginger whereas coriander and Ashanti pepper ground samples showed a significant ($P < 0.05$) increased in free fatty acid content as the radiation dose was increased the whole samples were not affected by the treatment.

4.2.7 Ash Content.

Ash content gives a rough idea of the amount of mineral elements present in a food sample. Although spices are not taken because of their mineral element content, some are known to be rich in some minerals like calcium, phosphorus, and iron (Pellet and Shadarevian, 1970).

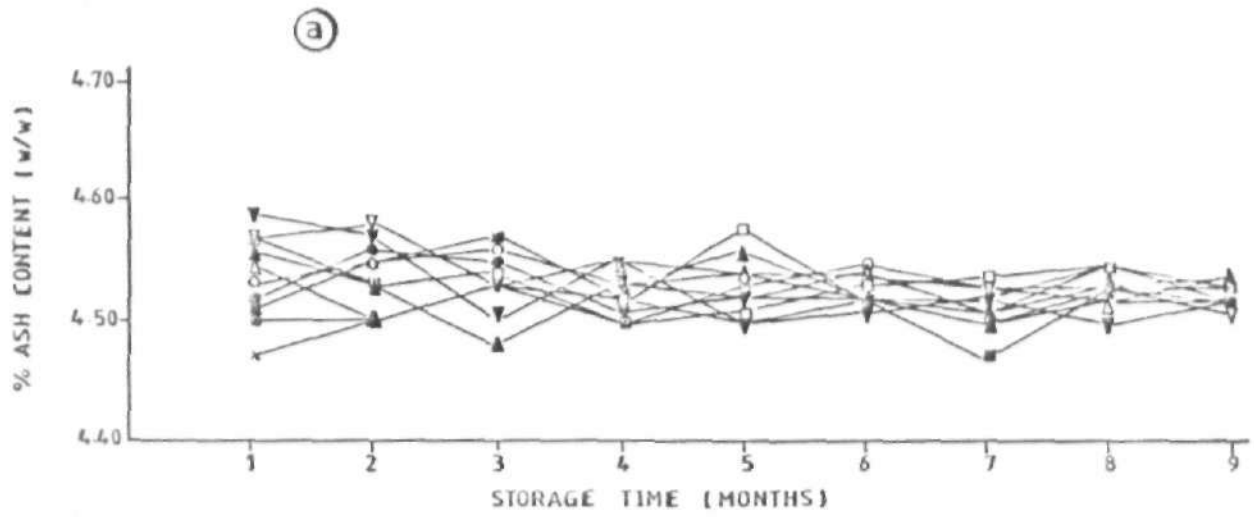
The results of the ash content of both the control and irradiated samples as a function of storage time are shown in Fig 4.16 Ginger had the highest ash content of about 7.55% and capsicum the least (4.50%). The ash content is known to vary between individual food materials and it is often difficult to obtain satisfactory duplicate ash determinations (Josyln, 1970).

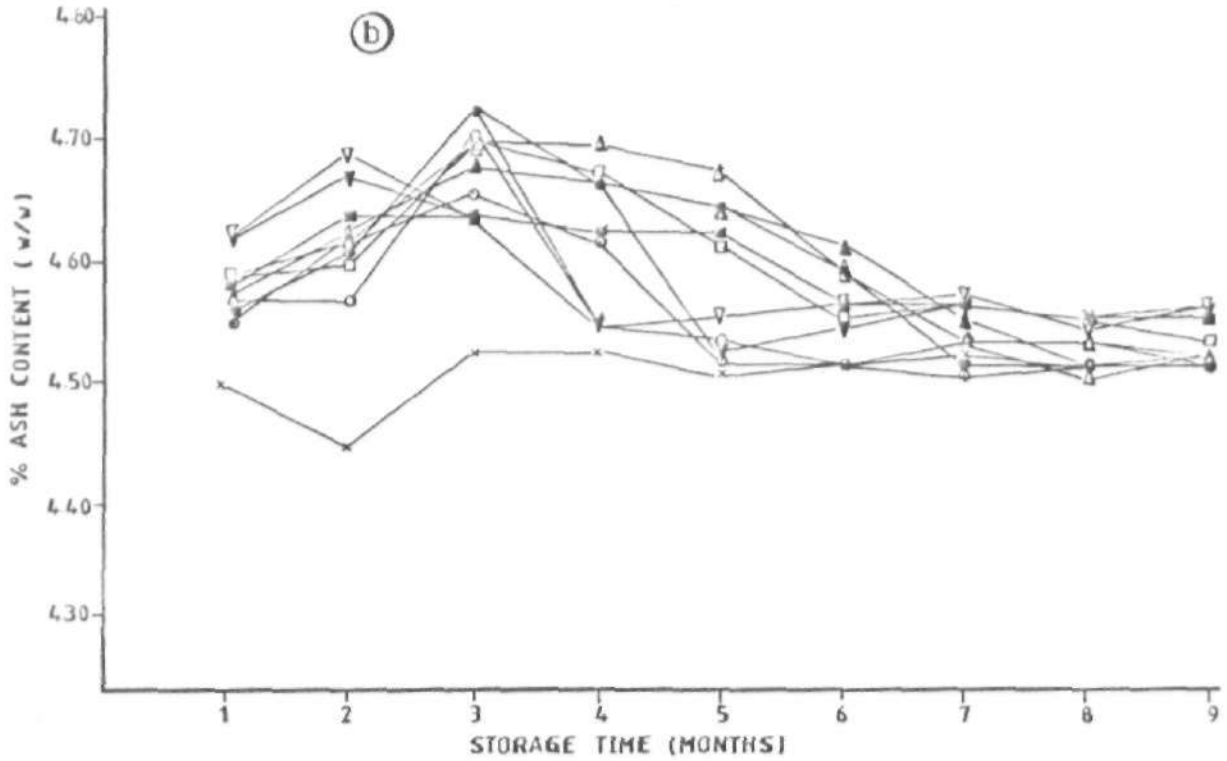
In general, the ash contents were not affected by irradiation dose, form and storage time. The reason for the marginal increase in the ash content of coriander (both control and irradiated) in the second and third months is not very obvious but may be due to very low relative humidity of the period, December and January respectively and these correspond to the periods of low moisture content (relatively).

4.2.8 Moisture Content

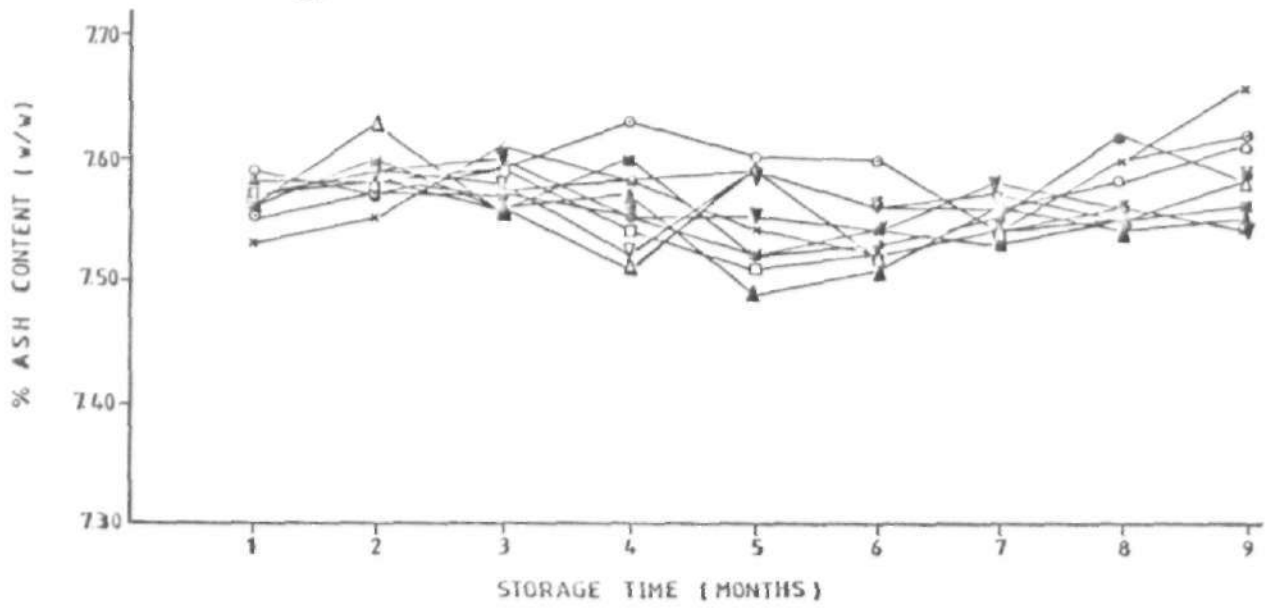
The contents which is inversely related to the dry matter content are shown in Fig. 4.17. The moisture content of the spices ranged from 4.60 to 6.10%. Form and time more than irradiation dose affected the moisture content although negligible ($P > 0.05$). The moisture content of the whole samples were higher than these of the ground samples. This observed effect of grinding may be due to desiccation and loss of very volatile components as could be seen from Fig. 4.17c and d, ginger and Ashanti pepper respectively, the spices of higher volatile oil content were more affected than others. Capsicum known to contain virtually no essential oil is the least affected in this respect.

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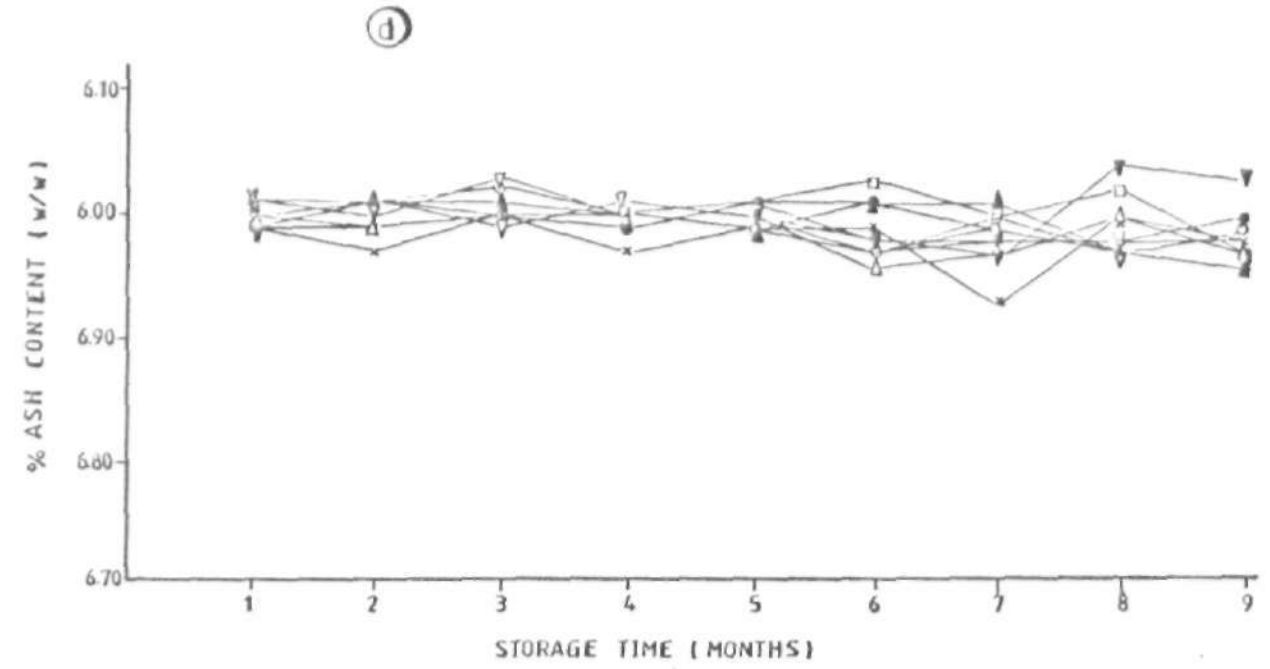

a
4.70
4.60
4.50
4.40
% ASH CONTENT (w/w)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

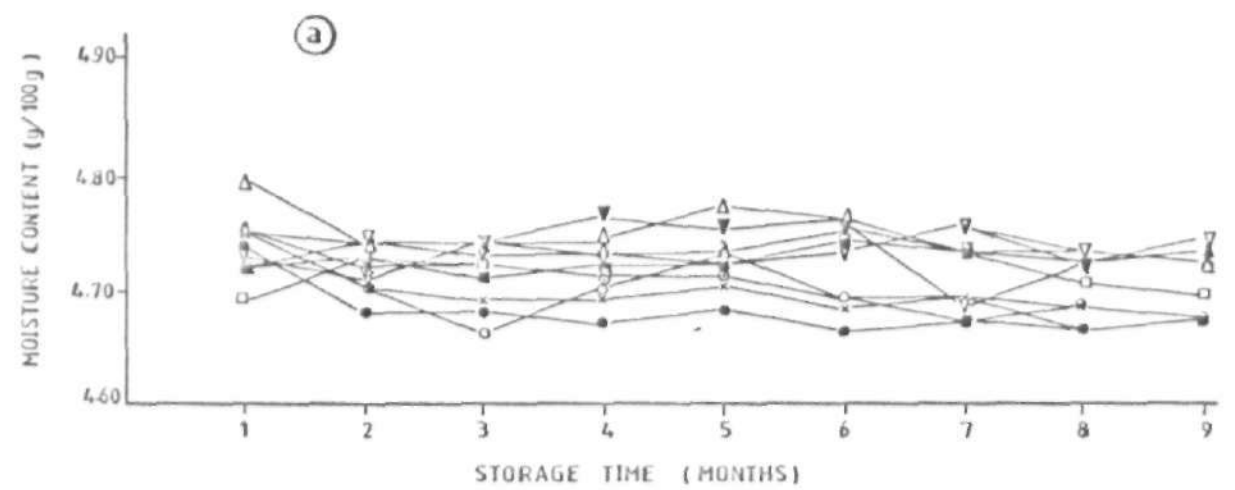

b
4.60
4.70
4.60
4.50
4.40
4.30
% ASH CONTENT (w/w)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

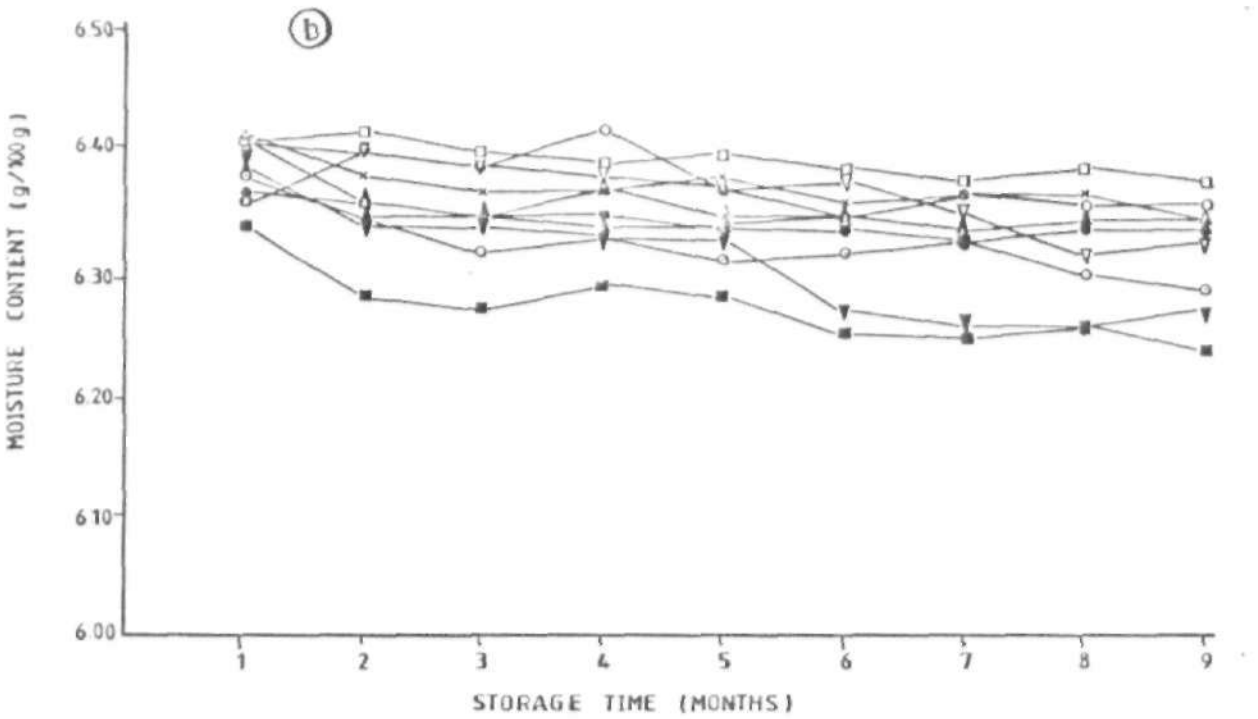
(c)

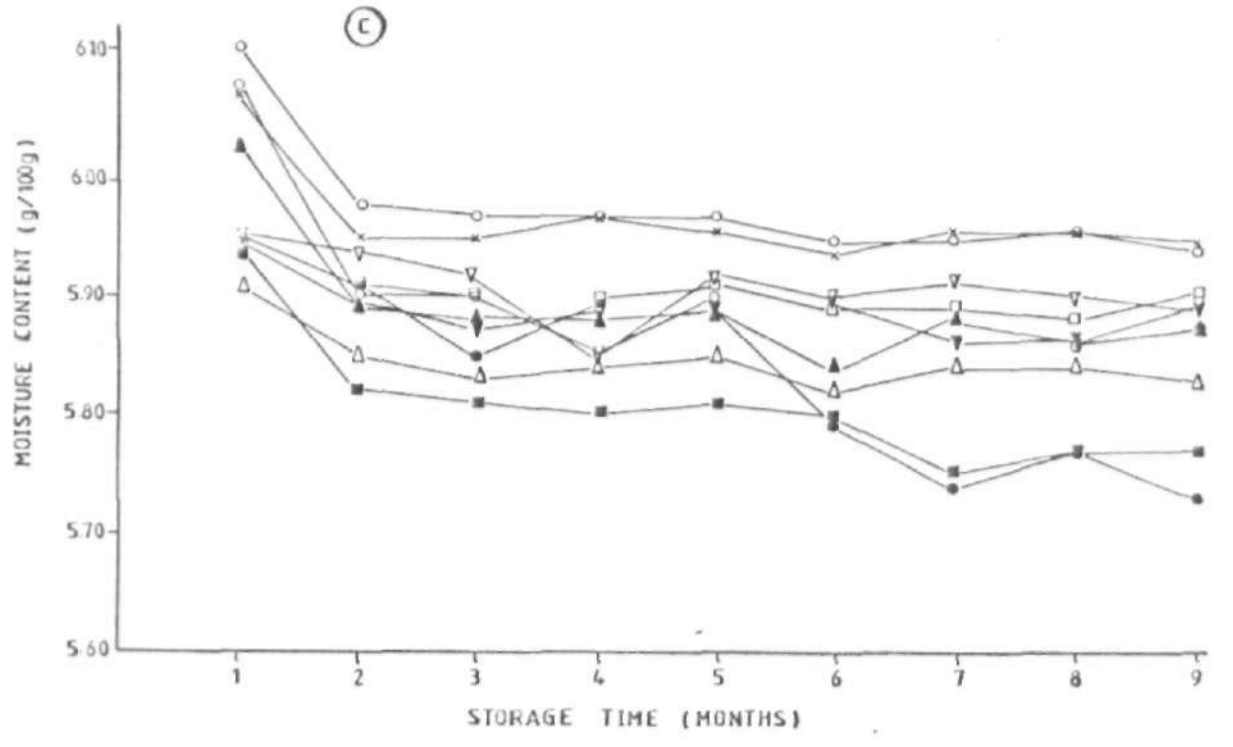

7.70
7.60
7.50
7.40
7.30
% ASH CONTENT (w/w)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

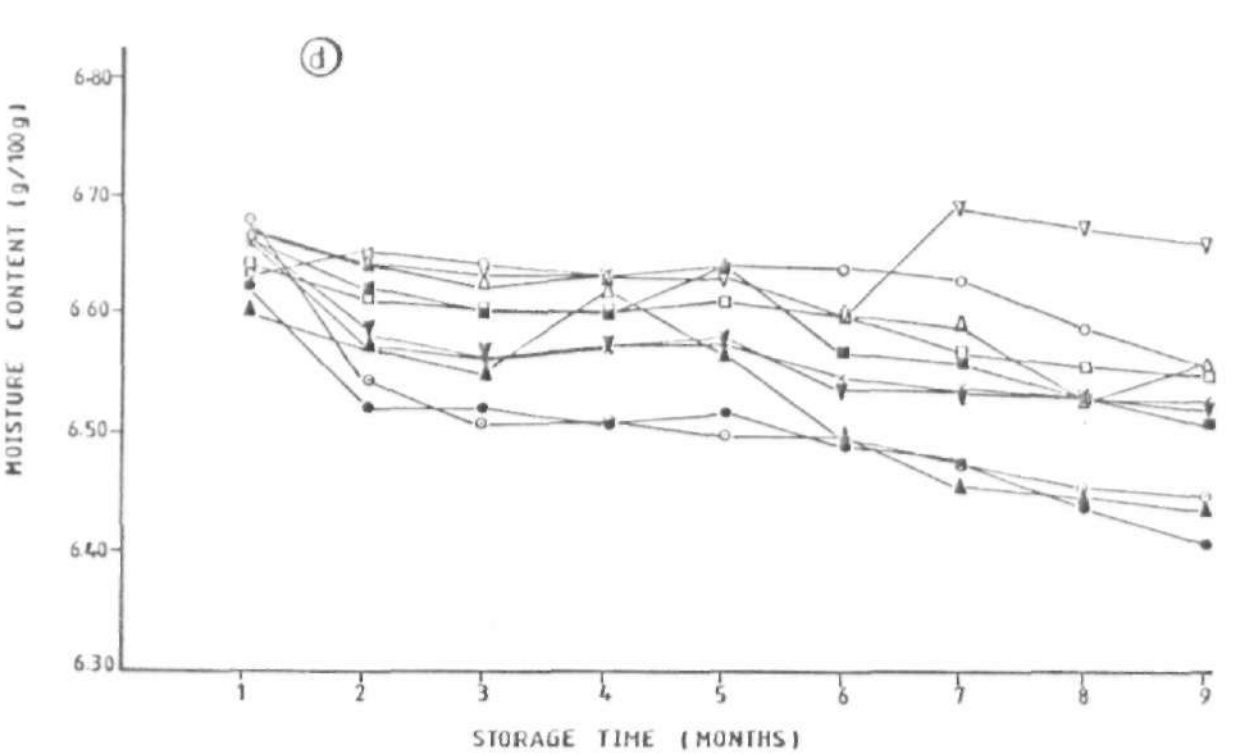
(d)


6.10
6.00
6.90
6.80
6.70
% ASH CONTENT (w/w)
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(a)
MOISTURE CONTENT (g/100g)
4.90
4.80
4.70
4.60
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(b)
MOISTURE CONTENT (g/100g)
6.50
6.40
6.30
6.20
6.10
6.00
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(c)
MOISTURE CONTENT (g/100g)
6.10
6.00
5.90
5.80
5.70
5.60
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)


(d)
MOISTURE CONTENT (g/100g)
6.80
6.70
6.60
6.50
6.40
6.30
1
2
3
4
5
6
7
8
9
STORAGE TIME (MONTHS)

CHAPTER 5

CONCLUSION AND SUGGESTIONS

5.1 CONCLUSION

Contamination of foods by micro-organisms particularly pathogenic sporing bacteria and infection of food by moulds are among the most important public health problems and a major cause of human sufferings throughout the world. Also many dry ingredients such as spices and herbs which are important sources of foreign exchange earning for some developing countries may be highly contaminated by spoilage organisms and to a certain degrees by pathogens. This causes difficulties during further processing into composite food products and creates potential health hazards resulting to decreased foreign exchange earing of that country.

While thermal pasteurization of liquid foods is a well established and satisfactory means of terminal decontamination treatment of such commodities, it does not suit solid foods and dry ingredients (ICGFI 1987). Alternative chemical sanitizing procedures have regulatory limitations and/or pose potential problems of public health, toxic residues and environmental pollution.

The result of this work agrees and confirm earlier reports that spices can be adequately sterilized by irradiation at a dose of 10 kGy. complete elimination of fungi in the samples used in this study was achieved with 5 to 7.5 kGy dose similar to an earlier observation of Ito, *et al.* (1973) that the sterilization dose for spoilage moulds of cereal grains should be 5 to 6 kGy. The highest dose (10 kGy) which is the highest dose recommended as safe eliminated all the bacterial populations of the spices. This dose had been confirmed to pose no toxicological hazard and present no special nutritional or microbial problems (ICGFI-IAEA, 1987).

Sharma, *et al.*, (1984) have also shown that exposure of clove to gamma irradiation in the range of 7.5- 10 kGy was adequate to sterilize all the spices used in their study. Gamma-irradiation, they observed did not affect fungal inhibitory

principle present in clove, though marginal reduction was observed in that of cinnamon. Hence radiation treatment of coriander and Ashanti pepper may not have affected their microbial inhibitory properties.

The observed effect of irradiation on the oleoresin and volatile oil content of ginger and Ashanti pepper which became insignificant ($P > 0.05$) with time poses no problem since the essence of the radiation treatment is to preserve the food materials. Although form ((whether whole or ground) was found to affect the content and composition of the essential oils, a problem that had earlier been identified (Heath and Reineccius, 1986) Ground spices they cautioned are subject to oxidation flavour loss and degradation on storage. Hence when it is necessary to produce ground spices, they should be ground under aseptic conditions after sterilization.

The GC patterns of the whole samples were within experimental error almost identical which is a pointer to the fact that when spices are irradiated whole, the change in flavour constituents are marginal.

Although small change were observed in the sugar contents and free fatty acid content, spices are not consumed because of these macro-nutrients. Moreso, spices are among the food terms that constitutes only a small fraction of the human diet (that is, no more than 0.01 percent of the diet).

The results of this work confirm earlier observations that effect of irradiation is species-dependent and hence as a pionier work on these Nigerian spices, will form the basis for the decontamination of these spices using gamma irradiation.

5.2 SUGGESTIONS

Lack of certain equipments for high precision determination of some of the parameters tend to render some of the results inclusive. For example, changes in the active ingredients may mean that the one been analysed may have been converted to its analogue. It is known that zingerones and shogaols are analogues of gingerol. The active principle of ginger zingerone is a decomposition product of gingerol while shogoal is the dehydration product (Wood, 1987). Shogoal is known to be more

pungent than gingerol (Wood, 1987) Hence there is need for further resolution of the oleoresin using either GC and /or HPLC and determine the different analogues accordingly as used by Chen, *et al.* (1986) and Wood (1987).

There is also the need to analyse volatile oil monthly. This was not possible in the present work because of the limited number of oil samples accepted by the foreign laboratory that did the GCMS analysis. This may further bring out the disparity between the ground and whole samples. However Heath and Reineccius (1986) recommended that ground spices be stored for no longer than three months in manufacturing practice.

One of the commonly asked questions on the sterilization of foods using gamma-irradiation is the effect of the treatment on the toxins of the microorganisms Earlier studies (Mitchell, 1988., Sharma, *et al.*, 1990) have shown that irradiation does not increase aflatoxin production. Once formed, aflatoxins and other toxins are reported to be highly resistant to irradiation (ICGFI, 1987). Therefore the need for decontamination of spices meant for storage before lethal quantities of the toxins are produced is necessary.

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APPENDICES

Appendix 1: Effect of Gamma Irradiation on the Total Fungal Count (Log_{10} CFU/g) Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.43±5.11	6.39±4.60	4.33±2.84	4.27±2.78	3.28±1.96	2.94±1.15	0.84±0.92			
2	6.52±5.33	6.42±4.93	4.30±2.51	4.21±2.72	3.18±0.00	2.86±1.07				
3	6.58±5.39	6.63±4.84	4.29±2.80	4.19±2.70	3.01±1.22	2.83±1.34				
4	6.62±5.30	6.65±5.16	4.20±0.00	4.16±2.37	2.97±1.48	2.81±1.02				
5	6.65±0.00	6.66±0.00	4.26±2.47	4.16±2.37	2.95±1.16	2.79±0.00				
6	6.68±5.19	6.68±4.89	4.33±3.23	4.25±2.76	2.94±1.15	2.77±1.59				
7	6.72±5.23	6.73±4.94	4.34±0.00	4.32±2.53	2.90±0.00	2.73±1.24				
8	6.70±4.91	6.71±4.92	4.29±2.80	4.28±2.79	2.87±1.38	2.68±0.00				
9	6.68±0.00	6.68±4.89	4.25±2.76	4.25±2.76	2.83±1.34	2.62±1.13				

Mean ± SD of replicates per treatment

Appendix 2: Effect of Gamma Irradiation on the Fungal Load (Log_{10} CFU/g) Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	7.27±5.78	7.19±5.98	4.95±3.46	4.92±3.42	2.88±0.00	2.89±1.57				
2	8.33±6.54	7.28±5.96	4.93±0.00	4.91±3.21	2.86±1.07	2.86±1.37				
3	7.42±5.93	7.41±5.92	4.91±3.42	4.88±0.00	2.86±1.33	2.77±0.98				
4	7.53±6.21	7.41±5.62	4.90±3.41	4.89±3.10	2.79±1.30	2.72±1.40				
5	7.56±5.77	7.47±6.15	4.91±3.42	4.91±3.12	2.73±1.64	2.67±1.35				
6	7.58±0.00	7.51±5.72	4.92±3.43	4.92±0.00	2.62±1.30	2.60±0.81				
7	7.62±5.83	7.53±0.00	4.94±3.45	4.93±3.14	2.59±0.80	2.57±1.08				
8	7.60±5.81	7.50±0.00	4.93±3.61	4.91±3.16	2.56±1.07	2.53±0.00				
9	7.57±6.25	7.48±5.67	4.90±3.11	4.88±3.09	2.53±0.74	2.56±0.73				

Mean ± SD of replicates per treatment

Appendix 3: Effect of Gamma Irradiation on the Fungal Load (Log_{10} CFU/g) Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.71±4.92	6.68±5.19	4.90±3.41	4.96±3.43	2.66±0.87	2.65±0.86				
2	6.73±4.94	6.70±5.33	4.88±0.00	4.88±0.00	2.63±0.00	2.62±0.85				
3	6.74±4.95	6.71±4.92	4.87±3.08	4.88±3.56	2.56±0.77	2.54±0.75				
4	6.75±4.96	6.74±4.86	4.87±3.79	4.89±3.10	2.46±0.67	2.49±1.00				
5	6.79±5.00	6.76±4.97	4.93±3.61	4.91±3.12	2.43±1.11	2.33±1.01				
6	6.82±5.33	6.78±0.00	4.94±3.15	4.91±3.12	2.35±0.86	2.29±0.80				
7	6.85±5.06	6.81±5.02	4.95±3.16	4.91±3.12	2.25±0.76	2.25±0.47				
8	6.85±5.06	6.79±5.01	4.91±3.42	4.90±3.11	2.18±0.86	2.21±0.72				
9	6.83±5.34	6.76±4.97	4.89±3.40	4.87±3.08	2.07±0.88	2.15±0.83				

Mean ± SD of replicates per treatment

Appendix 4: Effect of Gamma Irradiation on the Fungal Load (Log_{10} CFU/g) Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.58±3.79	5.56±3.77	3.44±1.65	3.39±1.90	2.05±0.56	2.02±0.83				
2	5.60±3.81	5.56±3.77	3.42±1.63	3.33±1.54	1.95±0.46	1.95±0.00				
3	5.61±3.82	5.57±3.78	3.46±1.67	3.35±1.86	1.88±0.10	1.82±0.50				
4	5.64±3.85	5.60±3.81	3.51±1.72	3.42±2.23	1.75±0.04	1.37±0.11				
5	5.67±3.88	5.64±3.85	3.55±2.06	3.47±1.98	1.31±0.18	1.09±0.7				
6	5.69±3.90	5.67±3.88	3.59±1.80	3.55±1.76	1.02±0.17	1.04±0.00				
7	5.72±4.40	5.69±3.90	3.62±2.30	3.60±2.28	0.79±0.69	0.81±0.28				
8	5.69±4.20	5.67±3.88	3.64±2.15	3.64±1.85	0.74±0.57	0.79±0.53				
9	5.69±4.18	5.66±3.87	3.62±1.83	3.63±1.84	0.71±0.78	0.72±0.76				

Mean ± SD of replicates per treatment

Appendix 5: Effect of Gamma Irradiation on the Viable Bacterial Count (Log_{10} CFU/g) Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	7.27±5.78	7.26±6.38	5.84±4.96	5.73±4.75	3.54±2.67	3.54±2.70	1.81±0.32	1.40±0.00	0.16±0.85	
2	7.35±6.47	7.37±6.18	5.80±4.31	5.68±4.89	3.63±2.31	3.46±2.49	1.34±0.46	1.18±0.47		
3	7.41±5.92	7.43±6.64	5.79±4.00	5.64±4.78	3.52±2.51	3.34±2.49	0.88±0.11	0.80±0.52		
4	7.48±5.69	7.49±6.85	5.73±4.78	5.61±4.29	3.53±2.52	3.39±2.30	0.10±0.00			
5	7.49±6.00	7.54±6.66	5.74±4.95	5.63±4.44	3.49±2.64	3.34±2.39				
6	7.51±6.63	7.59±6.58	5.79±4.30	5.66±4.34	3.45±2.66	3.30±2.81				
7	7.64±6.85	7.67±6.35	5.80±4.49	5.65±4.18	3.37±2.38	3.27±2.78				
8	7.63±6.84	7.62±6.61	5.80±4.71	5.64±4.69	3.37±2.19	3.26±2.38				
9	7.60±6.89	7.58±6.79	5.74±4.99	5.60±4.59	3.34±2.39	3.23±2.14				

Mean ± SD of replicates per treatment

Appendix 6: Effect of Gamma Irradiation on the Viable Bacterial Count (Log_{10} CFU/g) Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.72±3.53	5.69±3.37	3.48±1.69	3.47±2.15	2.94±1.47	2.93±1.74	1.87±0.38	1.88±0.79		
2	4.76±3.27	5.73±3.54	3.46±2.14	3.47±1.68	2.92±1.13	2.91±1.42	1.64±0.15	1.63±0.44		
3	4.78±3.29	5.31±4.12	3.53±2.34	3.49±1.70	2.89±1.57	2.90±1.58	1.47±0.15	1.39±0.60		
4	4.80±3.31	5.33±4.12	3.55±2.23	3.53±2.21	2.88±1.93	2.87±1.08	1.26±0.17	1.30±0.28		
5	4.85±3.06	5.44±3.95	3.59±2.10	3.59±2.10	2.84±1.96	2.83±1.50	1.14±0.30	1.02±0.17		
6	4.89±3.57	5.41±4.77	3.63±2.31	3.63±1.84	2.80±1.48	2.78±1.46	0.98±0.03	0.95±0.16		
7	4.93±3.61	5.40±4.08	3.60±1.81	3.60±2.11	2.75±1.26	2.74±1.25	0.79±0.30	0.76±0.33		
8	4.93±3.13	5.33±4.38	3.57±2.08	3.55±2.06	2.71±0.92	2.71±1.22	0.62±0.70	0.57±0.92		
9	4.89±3.40	5.31±3.52	3.54±2.05	3.52±0.00	2.68±1.36	2.68±0.89	0.36±0.83	0.29±0.80		

Mean ± SD of replicates per treatment

1 Appendix 7: Effect of Gamma Irradiation on the Viable Bacterial Count (Log_{10} CFU/g) Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.69±3.90	5.67±4.49	3.56±2.72	3.44±2.60	2.97±1.65	2.44±1.35	1.81±0.06	1.78±0.16		
2	5.72±3.93	5.69±4.20	3.61±2.65	3.43±2.42	2.95±1.76	2.43±1.42	1.75±0.01	1.55±0.23		
3	5.73±4.24	5.71±4.39	3.51±2.56	3.45±1.93	2.94±1.62	2.39±1.51	1.62±0.67	1.43±0.36		
4	5.76±4.27	5.73±4.54	3.50±2.49	3.44±1.95	2.92±1.60	2.31±1.34	1.36±0.48	1.36±0.04		
5	5.78±4.46	5.73±4.94	3.54±2.46	3.47±1.98	2.89±1.40	2.26±1.38	1.19±0.30	1.15±0.14		
6	5.79±4.30	5.73±4.94	3.58±2.26	3.54±2.05	2.86±1.07	2.15±1.40	0.99±0.50	0.99±0.65		
7	5.81±4.62	5.69±4.50	3.61±2.52	3.53±2.21	2.82±1.50	2.03±1.24	0.73±0.36	0.70±0.79		
8	5.80±4.61	5.67±4.35	3.56±2.07	3.50±2.01	2.79±1.47	1.99±0.67	0.50±0.82	0.45±1.04		
9	5.78±4.46	5.63±4.31	3.54±2.05	3.45±1.96	2.75±1.43	1.91±0.72				

Mean ± SD of replicates per treatment

Appendix 8: Effect of Gamma Irradiation on the Viable Bacterial Count (Log_{10} CFU/g) Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.54±3.75	5.53±4.04	3.62±2.13	3.39±2.07	2.94±1.15	2.90±1.11	1.29±0.20	1.22±0.57		
2	5.56±4.07	5.56±3.77	3.60±1.81	3.39±1.90	2.91±1.42	2.90±1.11	1.11±0.21	1.02±0.30		
3	5.60±0.00	5.58±3.79	3.60±1.81	3.42±2.10	2.87±1.08	2.84±1.35	0.95±0.00	0.87±0.45		
4	5.62±3.83	5.60±0.00	3.61±1.82	3.47±2.15	2.82±1.03	2.51±1.42	0.87±0.22	0.79±0.70		
5	5.64±3.85	5.62±3.83	3.63±0.00	3.54±2.44	2.53±1.52	2.47±1.15	0.80±0.52	0.69±0.80		
6	5.67±3.88	5.66±3.87	3.66±1.87	3.61±1.82	2.43±1.42	2.38±1.19	0.64±0.85	0.58±0.61		
7	5.69±3.90	5.67±4.35	3.69±2.20	3.63±2.31	2.27±0.91	2.21±1.02	0.57±0.75	0.49±0.00		
8	5.66±4.17	5.62±4.43	3.65±1.86	3.62±1.83	2.19±0.70	2.13±1.12	0.37±0.95	0.32±0.87		
9	5.62±3.83	5.56±4.07	3.62±1.83	3.56±2.24	2.13±0.64	2.05±1.04	0.21±1.58	0.19±0.90		

Mean ± SD of replicates per treatment

1 Appendix 9: Effect of Gamma Irradiation on the Total Spore Forming Bacteria(Log_{10} CFU/g) Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.66±3.87	5.64±4.15	4.64±3.15	4.62±3.30	3.58±1.79	3.30±0.00	1.79±0.30	1.33±0.23		
2	5.69±4.20	5.69±4.20	4.61±2.82	4.59±2.80	3.52±2.20	3.30±0.00	1.29±0.20	1.15±0.36		
3	5.77±4.58	5.74±4.42	4.60±0.00	4.57±3.26	3.46±1.67	3.32±1.83	0.94±0.56	0.86±0.33		
4	5.79±4.30	5.79±3.40	4.57±3.08	4.56±3.47	3.44±1.95	3.35±1.86	0.36±0.64	0.31±1.18		
5	5.83±4.51	5.81±0.00	4.61±3.12	4.61±3.12	3.42±2.10	3.26±1.00	0.21±0.06	0.02±1.46		
6	5.85±4.53	5.83±4.04	4.64±2.85	4.65±3.16	3.37±1.88	3.24±1.45				
7	5.84±4.75	5.86±4.07	4.67±3.18	4.71±2.92	3.35±1.47	3.21±1.0				
8	5.82±4.63	5.83±4.07	4.65±2.86	4.67±3.18	3.32±1.83	3.20±1.4				
9	5.80±0.00	5.80±4.31	4.63±3.13	4.62±3.30	3.30±1.51	3.17±1.85				

Mean ± SD of replicates per treatment

Appendix 10: Effect of Gamma Irradiation on the Viable Bacterial Count (Log_{10} CFU/g) Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	3.82±2.03	3.80±0.00	2.69±0.90	2.58±1.70	2.49±0.00	2.46±0.97	1.24±0.36	1.28±0.80		
2	3.84±0.00	3.81±2.02	2.67±1.35	2.59±1.50	2.48±0.75	2.45±0.96	1.12±0.07	1.21±0.12		
3	3.87±2.08	3.82±2.03	2.63±1.31	2.59±1.01	2.46±1.27	2.32±1.13	0.98±0.81	1.15±0.85		
4	3.89±2.40	3.86±2.37	2.63±0.00	2.60±0.81	2.39±0.90	2.25±0.93	0.82±0.50	0.81±0.98		
5	3.91±2.42	3.88±2.56	2.65±1.33	2.62±0.00	2.32±1.00	2.14±0.65	0.68±0.52	0.61±0.48		
6	3.94±2.62	3.88±0.00	2.68±0.89	2.65±0.86	2.21±0.72	2.11±0.32	0.33±0.46	0.29±0.59		
7	3.97±2.78	3.90±2.11	2.71±0.00	2.66±1.00	2.23±1.13	2.06±0.74				
8	3.98±2.66	3.89±2.10	2.69±0.90	2.67±0.00	2.22±0.00	2.00±0.00				
9	3.94±2.43	3.86±2.37	2.64±1.32	2.65±0.86	2.19±0.70	2.16±0.67				

Mean ± SD of replicates per treatment

Appendix 11: Effect of Gamma Irradiation on the Spore Forming Bacteria (Log_{10} CFU/g) Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.39±2.90	4.39±2.60	3.31±1.52	3.28±2.19	2.89±1.10	2.88±1.09	1.88±0.79	1.89±0.10		
2	4.40±3.08	4.41±2.92	3.28±1.49	3.29±1.50	2.88±1.56	2.87±1.38	1.61±0.29	1.64±0.76		
3	4.42±2.63	4.43±3.11	3.31±1.82	3.32±2.01	2.84±1.35	2.83±1.51	1.49±0.17	1.43±0.42		
4	4.46±2.97	4.47±3.28	3.34±1.85	3.36±1.57	2.86±1.07	2.77±0.98	1.18±0.85	1.15±0.14		
5	4.52±3.20	5.29±3.80	3.43±2.24	3.34±1.55	2.83±0.00	2.77±1.45	1.00±0.21	1.05±0.25		
6	4.58±2.79	5.32±0.00	3.49±1.70	3.38±0.00	2.75±1.43	2.71±0.00	0.94±0.06	0.95±0.84		
7	4.61±3.12	5.34±0.00	3.51±2.10	3.41±1.62	2.74±1.25	2.69±1.20	0.73±0.55	0.70±0.51		
8	4.60±2.81	5.34±3.55	3.47±1.98	3.37±2.05	2.71±1.22	2.66±1.17	0.56±0.47	0.47±0.46		
9	4.57±2.78	5.29±3.80	3.46±1.97	3.32±2.00	2.68±0.89	2.62±1.30	0.35±0.34	0.33±0.13		

Mean ± SD of replicates per treatment

Appendix 12: Effect of Gamma Irradiation on the Spore Forming Bacteria (Log_{10} CFU/g) Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.33±4.25	5.31±3.82	3.57±2.25	3.29±1.50	2.91±1.42	2.84±1.35	1.27±0.22	1.21±0.28		
2	5.42±3.93	5.35±3.86	3.57±1.78	3.27±0.00	2.88±1.62	2.85±1.36	1.12±0.11	0.99±0.50		
3	5.46±3.67	5.41±3.92	3.58±0.00	3.29±1.50	2.82±1.33	2.81±1.32	0.91±0.12	0.85±0.00		
4	5.48±0.00	5.45±3.66	3.60±1.81	3.35±2.03	2.75±1.26	2.32±1.13	0.84±0.33	0.81±0.33		
5	5.54±4.05	5.48±3.99	3.61±0.00	3.42±2.10	2.25±1.46	2.25±0.76	0.80±1.52	0.76±0.52		
6	5.58±3.79	5.53±3.74	3.64±1.85	3.52±2.03	2.10±0.91	2.19±0.70	0.75±0.03	0.67±0.65		
7	5.61±3.82	5.55±4.05	3.66±2.17	3.57±2.38	1.98±0.66	2.06±1.18	0.69±0.80	0.57±0.44		
8	5.63±0.00	5.55±3.76	3.62±1.83	3.55±2.23	1.96±0.64	2.01±0.22	0.42±1.07	0.39±1.10		
9	5.62±3.83	5.52±3.73	3.57±0.00	3.52±2.20	1.93±0.61	1.93±0.40	0.25±1.07	0.19±1.30		

Mean ± SD of replicates per treatment

Appendix 13: Effect of Gamma Irradiation on the Oleoresin content (g/100g) of Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	25.47±0.67	25.98±0.02	26.93±0.06	26.97±0.01	31.46±0.03	31.60±0.01	30.52±0.01	30.66± 0.00	29.69±0.04	29.87±0.02
2	25.94±0.06	25.92±0.05	26.91±0.01	26.98±0.01	31.44±0.01	31.60±0.01	30.50±0.01	30.62± 0.03	29.63±0.02	29.83±0.02
3	25.85±0.07	25.90±0.00	26.89±0.02	26.96±0.01	31.40±0.03	31.59±0.04	30.45±0.04	30.59± 0.01	29.60±0.01	29.77±0.08
4	25.88±0.01	25.87±0.03	26.88±0.00	26.96±0.01	31.35±0.03	31.58±0.00	30.42±0.03	30.54± 0.01	29.58±0.03	29.70±0.01
5	25.88±0.02	25.86±0.01	26.87±0.03	26.94±0.01	31.34±0.02	31.52±0.05	30.39±0.01	30.50± 0.03	29.55±0.00	29.68±0.00
6	25.86±0.06	25.84±0.02	26.83±0.05	26.91±0.01	31.30±0.01	31.46±0.04	30.35±0.05	30.45± 0.01	29.52±0.00	29.63±0.06
7	25.85±0.01	25.83±0.05	26.81±0.04	26.89±0.02	31.29±0.04	31.41±0.00	30.28±0.00	30.39± 0.01	29.48±0.03	29.57±0.02
8	25.85±0.01	25.84±0.01	26.79±0.01	26.83±0.03	31.24±0.05	31.39±0.01	30.27±0.06	30.36± 0.06	29.47±0.01	29.54±0.01
9	25.83±0.01	25.83±0.01	26.74±0.03	26.81±0.01	31.22±0.03	31.36±0.01	30.25±0.00	30.34± 0.00	29.42±0.04	29.57±0.01

Mean ± SD of replicates per treatment

Appendix 14: Effect of Gamma Irradiation on the Oleoresin Content (g/100g) of Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.59±0.09	5.61±0.02	5.57±0.08	5.56±0.03	5.55±0.01	5.56±0.06	5.58±0.13	5.61±0.02	5.54±0.05	5.55±0.15
2	5.63±0.03	5.60±0.01	5.54±0.06	5.55±0.07	5.56±0.05	5.55±0.03	5.56±0.05	5.56±0.07	5.54±0.11	5.56±0.05
3	5.63±0.07	5.60±0.01	5.58±0.16	5.57±0.02	5.58±0.15	5.58±0.17	5.57±0.10	5.58±0.01	5.56±0.03	5.55±0.06
4	5.65±0.05	5.62±0.25	5.58±0.13	5.57±0.31	5.59±0.06	5.58±0.08	5.59±0.09	5.60±0.01	5.61±0.01	5.55±0.07
5	5.63±0.05	5.64±0.13	5.69±0.14	5.58±0.16	5.60±0.13	5.61±0.16	5.60±0.06	5.59±0.01	5.60±0.07	5.60±0.05
6	5.61±0.01	5.63±0.01	5.62±0.04	5.61±0.04	5.60±0.00	5.62±0.02	5.62±0.00	5.59±0.01	5.60±0.03	5.60±0.03
7	5.61±0.03	5.63±0.02	5.59±0.01	5.60±0.01	5.61±0.01	5.61±0.01	5.59±0.01	5.60±0.01	5.60±0.02	5.61±0.03
8	5.60±0.01	5.61±0.04	5.60±0.00	5.59±0.01	5.60±0.02	5.61±0.01	5.60±0.01	5.61±0.01	5.61±0.05	5.61±0.02
9	5.62±0.01	5.60±0.01	5.60±0.01	5.60±0.01	5.61±0.01	5.62±0.01	5.60±0.02	5.63±0.01	5.60±0.01	5.61±0.01

Mean ± SD of replicates per treatment

Appendix 15: Effect of Gamma Irradiation on the Oleoresin Content (g/100g) of Ginger

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	12.71±0.03	12.59±0.05	12.55±0.05	12.58±0.03	12.42±0.08	12.13±0.18	12.05±0.06	11.71±0.21	11.77±0.08	11.34±0.36
2	12.68±0.03	12.59±0.01	12.54±0.01	12.51±0.10	12.38±0.08	11.90±0.10	12.67±0.15	11.65±0.25	11.46±0.12	10.94±0.31
3	12.67±0.02	12.60±0.21	12.58±0.14	12.59±0.14	12.51±0.04	12.05±0.08	12.40±0.05	12.01±0.04	11.93±0.06	11.68±0.24
4	12.67±0.18	12.61±0.08	12.58±0.01	12.59±0.06	12.58±0.02	12.41±0.09	12.35±0.15	12.30±0.01	12.33±0.03	12.21±0.06
5	12.67±0.07	12.59±0.14	12.62±0.09	12.59±0.02	12.62±0.02	12.54±0.06	12.43±0.11	12.36±0.06	12.43±0.09	12.36±0.01
6	12.67±0.02	12.61±0.01	12.64±0.01	12.60±0.00	12.63±0.01	12.54±0.01	12.54±0.01	12.42±0.01	12.50±0.01	12.42±0.01
7	12.66±0.00	12.59±0.01	12.65±0.01	12.59±0.01	12.62±0.02	12.56±0.01	12.57±0.02	12.45±0.01	12.55±0.01	12.44±0.01
8	12.68±0.01	12.60±0.02	12.66±0.00	12.58±0.00	12.64±0.00	12.56±0.00	12.61±0.00	12.49±0.00	12.50±0.00	12.47±0.00
9	12.67±0.02	12.57±0.00	12.67±0.01	12.58±0.01	12.65±0.00	12.55±0.00	12.60±0.01	12.53±0.00	12.63±0.00	12.51±0.00

Mean ± SD of replicates per treatment

Appendix 16: Effect of Gamma Irradiation on the Oleoresin Content (g/100g) of Ashanti Pepper

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	12.83±0.02	12.81±0.02	12.75±0.04	12.35±0.01	12.25±0.10	12.25±0.10	11.93±0.04	11.88±0.05	11.69±0.10	11.62±0.09
2	12.81±0.03	12.78±0.02	12.67±0.06	12.29±0.02	12.14±0.06	12.14±0.06	11.87±0.08	11.85±0.04	11.61±0.08	11.43±0.08
3	12.82±0.41	12.81±0.01	12.73±0.33	12.36±0.21	12.21±0.13	12.21±0.13	12.19±0.14	12.19±0.05	12.01±0.05	11.95±0.08
4	12.83±0.05	12.79±0.30	12.76±0.38	12.40±0.06	12.29±0.13	12.29±0.13	12.30±0.06	12.36±0.08	12.30±0.21	12.26±0.06
5	12.83±0.10	12.80±0.16	12.77±0.33	12.45±0.13	12.38±0.03	12.38±0.03	12.41±0.27	12.38±0.11	12.35±0.19	12.29±0.13
6	12.83±0.01	12.81±0.01	12.79±0.01	12.51±0.02	12.40±0.00	12.40±0.00	12.44±0.01	12.41±0.01	12.39±0.01	12.34±0.01
7	12.83±0.00	12.82±0.04	12.81±0.01	12.55±0.00	12.44±0.01	12.44±0.01	12.44±0.01	12.45±0.00	12.46±0.01	12.41±0.01
8	12.84±0.01	12.81±0.01	12.83±0.01	12.65±0.01	12.51±0.01	12.51±0.01	12.53±0.01	12.50±0.01	12.50±0.00	12.45±0.00
9	12.83±0.01	12.81±0.00	12.82±0.00	12.72±0.00	12.56±0.01	12.56±0.01	12.60±0.02	12.55±0.00	12.55±0.01	12.50±0.00

Mean ± SD of replicates per treatment

Appendix 17: Effect of Gamma Irradiation on the Active Ingredents of Casicum: Capsicum Content (mg/100g).

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	63.80±0.40	63.74±0.35	63.72±0.25	63.70±0.15	63.73±0.07	63.73±0.01	63.73±0.04	63.73±0.01	63.75±0.06	63.75±0.01
2	63.59±0.49	63.73±0.39	63.74±0.02	63.75±0.07	63.76±0.06	63.73±0.04	63.74±0.07	63.73±0.04	63.72±0.01	63.75±0.08
3	63.77±0.81	63.70±0.25	63.76±0.34	63.69±0.27	63.73±0.03	63.74±0.08	63.72±0.03	63.75±0.07	63.73±0.03	63.73±0.01
4	63.72±0.11	63.73±0.13	63.78±0.16	63.69±0.26	63.73±0.00	63.73±0.07	63.69±0.27	63.71±0.31	63.71±0.25	63.71±0.02
5	63.78±0.42	63.71±0.39	63.67±0.25	63.77±0.05	63.73±0.27	63.70±0.08	63.74±0.02	63.73±0.01	63.72±0.03	63.69±0.22
6	63.97±0.08	63.75±0.09	63.69±0.01	63.70±0.12	63.71±0.05	63.70±0.03	63.70±0.01	63.70±0.01	63.70±0.01	63.71±0.04
7	63.90±0.03	63.69±0.01	63.68±0.00	63.71±0.02	63.68±0.06	63.69±0.00	63.70±0.01	63.70±0.01	63.72±0.00	63.71±0.05
8	63.81±0.10	63.72±0.02	63.69±0.01	63.70±0.03	63.70±0.03	63.71±0.00	63.69±0.01	63.70±0.02	63.71±0.04	63.69±0.01
9	63.80±0.14	63.70±0.01	63.66±0.08	63.72±0.01	63.70±0.01	63.71±0.04	63.68±0.01	63.70±0.01	63.69±0.00	63.69±0.00

Mean ± SD of replicates per treatment

Appendix 18: Effect of Gamma Irradiation on the Linalool Content (mg/100g) of Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	38.76±0.35	38.72±0.08	38.79±0.01	38.96±0.10	39.02±0.02	39.19±0.01	39.21±0.01	39.33±0.02	39.40±0.06	39.49±0.01
2	38.76±0.19	38.75±0.01	38.78±0.00	38.88±0.00	39.02±0.09	39.23±0.01	39.25±0.01	39.35±0.02	39.40±0.03	39.56±0.03
3	38.76±0.00	38.76±0.00	38.80±0.05	38.90±0.05	39.04±0.02	39.16±0.25	39.28±0.00	39.38±0.00	39.45±0.01	39.63±0.01
4	38.81±0.24	38.73±0.10	38.82±0.08	38.93±0.02	39.03±0.05	39.25±0.05	39.34±0.03	39.43±0.01	39.49±0.00	39.72±0.01
5	38.81±0.27	38.76±0.05	38.80±0.01	39.02±0.14	39.03±0.10	39.33±0.03	39.38±0.02	39.51±0.02	39.54±0.03	39.79±0.01
6	38.84±0.34	38.75±0.05	38.80±0.00	38.93±0.03	38.94±0.04	39.33±0.07	39.42±0.03	39.58±0.03	39.60±0.01	39.87±0.02
7	38.78±0.15	38.81±0.27	38.81±0.04	38.94±0.06	39.08±0.03	39.38±0.02	39.44±0.03	39.67±0.01	39.69±0.01	39.95±0.05
8	38.82±0.06	38.82±0.31	38.91±0.18	38.02±0.17	38.98±0.00	39.24±0.35	39.45±0.00	39.74±0.03	39.79±0.01	40.08±0.00
9	38.88±0.14	38.80±0.06	38.82±0.01	38.99±0.01	39.11±0.01	39.44±0.07	39.50±0.00	39.80±0.00	39.89±0.01	40.14±0.02

Mean ± SD of replicates per treatment

Appendix 19: Effect of Gamma Irradiation on the Active Ingredient of Ginger: Gingerol ((mg/100g).

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	87.73±1.30	88.29±1.17	86.15±0.25	86.12±0.24	85.11±0.48	85.15±0.19	84.22±0.33	82.85±0.25	83.66±0.36	82.79±0.13
2	88.09±0.46	88.30±0.71	86.13±0.68	86.00±0.21	85.09±0.11	85.07±0.82	84.24±0.24	82.50±0.25	83.17±0.29	82.69±0.71
3	88.09±0.29	88.13±0.71	86.13±0.52	86.00±0.28	85.09±1.30	85.20±1.60	84.23±0.54	82.49±0.05	83.16±0.68	82.68±1.59
4	88.09±0.05	88.30±1.66	86.13±0.24	86.01±0.06	85.07±1.12	85.14±1.61	84.23±1.77	82.49±0.33	83.16±0.92	82.68±0.83
5	88.06±0.33	88.31±0.50	86.14±0.56	86.03±0.31	85.10±0.78	85.12±1.03	84.21±0.96	81.50±0.24	83.24±0.12	82.71±0.95
6	88.00±0.14	87.90±0.14	85.42±0.62	85.89±0.07	85.15±0.64	85.33±0.95	84.30±0.42	81.18±0.99	82.58±0.14	82.10±0.14
7	87.84±0.13	88.03±0.81	85.81±0.26	85.24±0.28	84.89±0.13	84.34±0.52	83.99±0.16	80.81±0.30	81.99±0.00	82.01±0.01
8	87.97±0.12	87.79±0.13	85.38±0.55	85.68±0.46	85.00±0.07	85.14±0.37	84.23±0.32	81.00±0.00	81.23±0.04	81.48±0.00
9	87.40±0.14	87.88±0.33	85.47±0.08	85.78±0.18	85.00±0.00	85.23±0.32	84.02±0.11	80.89±0.13	80.99±0.01	81.08±0.14

Mean ± SD of replicates per treatment

Appendix 20: Effect of Gamma Irradiation on the Oleoresin Content (g/100g) of Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	45.50±0.25	45.50±0.25	44.50±0.55	45.00±0.25	40.50±0.25	38.50±0.50	39.50±0.50	37.50±0.50	37.50±0.15	36.50±0.35
2	46.00±0.10	45.00±0.10	43.50±0.20	44.00±0.50	41.50±0.50	38.00±0.20	36.50±0.35	35.50±0.35	36.00±0.20	35.50±0.50
3	46.25±0.13	45.80±0.85	44.00±0.00	43.99±0.11	41.75±0.11	39.14±0.37	36.47±0.83	35.84±0.53	35.98±0.18	35.93±0.11
4	46.15±0.49	45.65±0.49	43.95±0.35	44.14±0.74	41.48±0.74	39.20±0.19	36.47±0.70	36.06±0.04	36.01±0.37	36.03±0.18
5	46.10±0.28	45.65±0.11	43.92±0.04	44.24±0.29	41.59±0.29	39.02±0.14	36.49±0.58	35.65±0.28	36.12±0.06	36.04±0.08
6	46.01±0.01	46.00±0.00	44.07±0.04	44.13±0.32	42.23±0.32	40.96±0.03	39.37±1.18	37.76±0.21	36.90±0.17	36.88±0.17
7	46.00±0.02	45.98±0.01	44.19±0.01	44.23±0.35	43.28±0.35	41.61±0.11	41.00±0.00	40.07±0.12	36.19±0.13	39.43±0.63
8	45.97±0.01	46.00±0.00	43.35±0.01	44.28±0.01	43.99±0.01	42.87±0.25	42.19±0.05	41.60±0.07	40.93±0.06	40.61±0.04
9	46.00±0.06	45.99±0.04	44.34±0.05	44.51±0.08	44.09±0.08	44.33±0.18	43.11±0.06	42.80±0.12	41.74±0.06	41.55±0.13

Mean ± SD of replicates per treatment

Appendix 21: Effect of Gamma Irradiation on the Essential Oil Content (%v/w): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	2.40±0.02	2.39±0.01	2.39±0.01	2.23±0.11	2.32±0.05	2.14±0.08	2.23±0.03	1.96±0.23	2.18±0.01	1.89±0.04
2	2.38±0.04	2.28±0.04	2.36±0.01	2.07±0.03	2.31±0.04	2.05±0.06	2.19±0.02	1.88±0.19	2.03±0.10	1.87±0.11
3	2.37±0.04	2.26±0.01	2.35±0.07	2.04±0.06	2.27±0.01	2.03±0.04	2.17±0.13	1.70±0.29	2.02±0.05	1.87±0.10
4	2.36±0.04	2.27±0.13	2.34±0.01	1.99±0.06	2.27±0.04	1.99±0.04	2.17±0.01	1.79±0.13	2.01±0.01	1.74±0.07
5	2.35±0.07	2.26±0.00	2.30±0.01	1.99± .04	2.28±0.04	1.96±0.04	2.14±0.06	1.52±0.16	2.00±0.04	1.88±0.10
6	2.37±0.02	2.25±0.01	2.29±0.01	2.04± .06	2.29±0.04	2.02±0.03	2.17±0.09	1.75±0.08	2.09±0.13	1.93±0.07
7	2.36±0.04	2.25±0.00	2.32±0.06	2.07± .07	2.31±0.04	2.04±0.03	2.22±0.08	1.89±0.13	2.13±0.10	1.93±0.37
8	2.34±0.06	2.16±0.03	2.31±0.01	2.10± .08	2.32±0.02	2.08±0.03	2.27±0.04	2.07±0.05	2.18±0.11	2.02±0.03
9	2.34±0.05	2.16±0.06	2.34±0.00	2.14± .01	2.34±0.04	2.11±0.01	2.33±0.01	2.12±0.01	2.30±0.01	2.12±0.10

Mean ± SD of replicates per treatment

Appendix 22: Effect of Gamma Irradiation on the Volatile Oil Content (%v/w) of Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	9.53±0.01	9.11±0.01	9.53±0.01	8.94±0.01	9.29±0.01	8.82±0.03	9.11±0.01	8.76±0.05	8.87±0.01	8.36±0.05
2	9.49±0.01	8.03±0.03	9.66±0.03	7.91±0.03	9.25±0.01	7.60±0.02	9.02±0.03	7.51±0.18	8.85±0.01	6.99±0.01
3	9.45±0.65	8.01±0.34	9.44±0.56	7.90±0.31	9.20±0.39	7.32±0.18	9.00±0.10	6.98±0.20	8.84±0.13	6.97±0.02
4	9.46±0.19	8.02±0.43	9.43±0.31	7.90±0.06	9.22±0.53	7.26±0.19	8.99±0.22	7.00±0.12	8.84±0.25	6.97±0.43
5	9.46±0.08	8.00±0.25	9.43±0.15	7.88±0.09	9.21±0.24	7.00±0.53	9.00±0.11	6.99±0.01	8.83±0.26	6.95±0.25
6	9.43±0.01	8.04±0.22	9.42±0.12	7.93±0.19	9.25±0.10	7.05±0.06	9.12±0.17	7.07±0.06	8.96±0.23	7.04±0.08
7	9.43±0.01	7.93±0.10	9.40±0.00	7.93±0.13	9.25±0.01	7.66±0.06	9.24±0.17	7.19±0.01	9.09±0.13	7.09±0.13
8	9.42±0.01	7.89±0.13	9.41±0.07	7.91±0.21	9.36±0.08	7.76±0.06	9.26±0.16	7.24±0.05	9.25±0.07	7.21±0.08
9	9.42±0.01	7.78±0.05	9.42±0.06	7.75±0.07	9.41±0.11	7.88±0.03	9.36±0.01	6.33±0.03	9.34±0.03	7.34±0.07

Mean ± SD of replicates per treatment

Appendix 23: Effect of Gamma Irradiation on the Total Carbohydrate Content (g/100g) Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	22.89±0.04	22.89±0.01	22.84±0.06	22.88±0.02	22.87±0.03	22.87±0.03	22.87±0.01	22.87±0.01	22.84±0.01	22.86±0.01
2	22.86±0.01	22.87±0.01	22.88±0.01	22.88±0.01	22.87±0.03	22.87±0.01	22.88±0.01	22.88±0.00	22.88±0.01	22.88±0.00
3	22.85±0.02	22.86±0.00	22.88±0.01	22.90±0.02	22.87±0.01	22.88±0.02	22.86±0.00	22.87±0.01	22.87±0.01	22.87±0.01
4	22.86±0.01	22.88±0.01	22.87±0.02	22.86±0.01	22.89±0.01	22.87±0.01	22.86±0.01	22.87±0.01	22.87±0.01	22.87±0.01
5	22.87±0.01	22.86±0.01	22.86±0.03	22.87±0.01	22.88±0.01	22.88±0.01	22.88±0.01	22.88±0.01	22.88±0.01	22.88±0.01
6	22.86±0.01	22.86±0.01	22.85±0.01	22.87±0.01	22.88±0.01	22.85±0.00	22.88±0.02	22.85±0.00	22.87±0.00	22.87±0.01
7	22.86±0.01	22.86±0.01	22.86±0.01	22.88±0.00	22.86±0.00	22.87±0.01	22.86±0.01	22.87±0.01	22.88±0.00	22.88±0.01
8	22.86±0.02	22.87±0.01	22.86±0.00	22.87±0.01	22.86±0.00	22.88±0.00	22.86±0.00	22.88±0.00	22.86±0.00	22.86±0.01
9	22.86±0.00	22.86±0.00	22.87±0.02	22.88±0.01	22.86±0.01	22.87±0.00	22.87±0.02	22.87±0.00	22.86±0.01	22.86±0.05

Mean ± SD of replicates per treatment

Appendix 24: Effect of Gamma Irradiation on the Available Carbohydrate Content (g/100g) Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	9.44±0.01	9.44±0.01	9.44±0.00	9.44±0.00	9.44±0.00	9.43±0.00	9.44±0.00	9.44±0.00	9.44±0.00	9.44±0.00
2	9.44±0.00	9.42±0.00	9.43±0.01	9.44±0.00	9.44±0.00	9.43±0.00	9.43±0.00	9.44±0.00	9.42±0.00	9.43±0.01
3	9.43±0.01	9.44±0.00	9.45±0.01	9.44±0.00	9.43±0.01	9.43±0.01	9.44±0.01	9.44±0.01	9.44±0.01	9.44±0.00
4	9.44±0.01	9.44±0.02	9.43±0.01	9.43±0.01	9.43±0.01	9.44±0.00	9.42±0.00	9.44±0.00	9.42±0.00	9.42±0.00
5	9.43±0.01	9.43±0.01	9.43±0.01	9.42±0.00	9.43±0.01	9.44±0.00	9.43±0.01	9.43±0.02	9.44±0.01	9.44±0.01
6	9.42±0.02	9.42±0.02	9.43±0.01	9.43±0.00	9.43±0.02	9.43±0.01	9.43±0.00	9.43±0.00	9.44±0.01	9.43±0.01
7	9.42±0.01	9.43±0.02	9.41±0.00	9.42±0.00	9.43±0.01	9.44±0.00	9.42±0.00	9.43±0.01	9.42±0.00	9.42±0.00
8	9.42±0.00	9.41±0.00	9.42±0.00	9.42±0.01	9.41±0.00	9.42±0.01	9.43±0.03	9.41±0.00	9.43±0.00	9.43±0.00
9	9.42±0.02	9.40±0.00	9.42±0.01	9.42±0.00	9.43±0.01	9.43±0.01	9.42±0.01	9.42±0.02	9.43±0.02	9.44±0.00

Mean ± SD of replicates per treatment

Appendix 25: Effect of Gamma Irradiation on the Total Available Carbohydrate (g/100g):Ginger

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	44.15±0.27	44.25±0.00	44.17±0.03	44.20±0.14	44.16±0.00	44.22±0.03	44.15±0.00	44.16±0.01	44.21±0.01	44.19±0.01
2	44.24±0.28	44.41±0.01	44.28±0.14	44.30±0.30	44.19±0.01	44.28±0.15	44.29±0.13	44.29±0.11	44.21±0.00	44.31±0.16
3	44.39±0.21	44.30±0.14	44.37±0.02	44.37±0.01	44.35±0.00	44.37±0.01	44.35±0.07	44.36±0.03	44.34±0.03	44.33±0.04
4	44.34±0.00	44.36±0.03	44.37±0.02	44.39±0.01	44.35±0.00	44.37±0.02	44.32±0.16	44.43±0.00	44.40±0.00	44.38±0.04
5	44.36±0.03	44.38±0.00	44.35±0.00	44.35±0.00	44.38±0.00	44.34±0.00	44.42±0.01	44.42±0.01	44.41±0.01	44.41±0.01
6	44.34±0.03	44.36±0.01	44.34±0.02	44.33±0.04	44.34±0.00	44.34±0.02	44.36±0.03	44.40±0.01	44.39±0.01	44.37±0.03
7	44.34±0.01	44.35±0.01	44.33±0.01	44.35±0.00	44.37±0.01	44.34±0.00	44.39±0.01	44.36±0.03	44.38±0.00	44.36±0.00
8	44.35±0.00	44.36±0.00	44.34±0.01	44.35±0.02	44.36±0.01	44.36±0.00	44.37±0.01	44.36±0.01	44.37±0.01	44.37±0.22
9	44.34±0.00	44.33±0.01	44.34±0.03	44.35±0.01	44.34±0.00	44.34±0.01	44.33±0.01	44.38±0.03	44.36±0.00	44.36±0.00

Mean ± SD of replicates per treatment

Appendix 26: Effect of Gamma Irradiation on the Total Available Carbohydrate(g/100g): Ashanti Pepper

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	49.00±0.13	48.97±0.01	49.22±0.83	48.94±0.06	48.97±0.01	48.94±0.05	48.93±0.0	48.93±0.00	48.94±0.01	49.00±0.14
2	48.80±0.28	49.04±0.20	48.93±0.04	49.05±0.19	48.94±0.01	48.94±0.04	48.93±0.0	48.92±0.02	49.10±0.15	48.94±0.02
3	48.93±0.04	48.93±0.04	49.06±0.21	48.97±0.01	49.03±0.07	48.94±0.04	48.95±0.0	48.94±0.05	48.96±0.03	48.91±0.01
4	48.94±0.03	48.93±0.04	48.94±0.01	48.93±0.00	48.94±0.01	48.94±0.01	48.94±0.0	48.94±0.01	48.94±0.00	48.94±0.01
5	48.92±0.00	48.92±0.00	48.91±0.01	48.92±0.01	49.03±0.18	49.02±0.18	49.03±0.0	48.93±0.00	48.92±0.01	48.93±0.01
6	48.94±0.05	48.92±0.02	48.92±0.01	48.93±0.00	48.96±0.03	48.96±0.03	48.98±0.0	48.94±0.04	48.93±0.03	48.92±0.00
7	48.97±0.05	48.93±0.02	48.91±0.00	48.93±0.01	48.92±0.00	48.91±0.01	48.99±0.0	48.94±0.05	48.94±0.01	48.94±0.01
8	48.93±0.07	48.94±0.20	48.91±0.01	48.94±0.06	48.92±0.01	49.02±0.02	48.90±0.0	48.90±0.03	48.91±0.00	48.92±0.00
9	48.91±0.01	48.90±0.00	49.00±0.00	48.87±0.01	48.91±0.01	48.91±0.03	48.97±0.0	48.91±0.04	48.88±0.01	48.90±0.00

Mean ± SD of replicates per treatment

Appendix 27: Effect of Gamma Irradiation on the Sucrose Content (g/100g) of Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.42±0.02	4.41±0.06	4.42±0.01	4.42±0.01	4.45±0.07	4.41±0.04	4.35±0.07	4.35±0.07	4.31±0.04	4.32±0.02
2	4.41±0.00	4.42±0.01	4.41±0.01	4.41±0.01	4.40±0.00	4.40±0.00	4.35±0.04	4.35±0.04	4.30±0.05	4.30±0.03
3	4.41±0.01	4.41±0.07	4.40±0.01	4.41±0.01	4.41±0.01	4.41±0.01	4.35±0.02	4.35±0.02	4.35±0.07	4.29±0.00
4	4.41±0.03	4.41±0.06	4.41±0.04	4.41±0.05	4.40±0.00	4.41±0.01	4.35±0.06	4.35±0.06	4.30±0.04	4.31±0.10
5	4.41±0.01	4.41±0.02	4.41±0.01	4.41±0.01	4.41±0.01	4.41±0.02	4.35±0.01	4.40±0.01	4.31±0.00	4.31±0.01
6	4.41±0.01	4.41±0.01	4.41±0.01	4.41±0.01	4.41±0.01	4.41±0.00	4.35±0.04	4.36±0.04	4.31±0.02	4.30±0.01
7	4.41±0.05	4.41±0.01	4.41±0.01	4.41±0.01	4.40±0.02	4.41±0.01	4.35±0.07	4.35±0.07	4.29±0.01	4.30±0.01
8	4.41±0.02	4.41±0.01	4.41±0.00	4.41±0.01	4.40±0.02	4.40±0.01	4.35±0.04	4.36±0.04	4.30±0.11	4.30±0.11
9	4.41±0.00	4.41±0.00	4.41±0.01	4.41±0.01	4.40±0.00	4.41±0.00	4.35±0.04	4.36±0.04	4.31±0.11	4.30±0.08

Mean ± SD of replicates per treatment

Appendix 28: Effect of Gamma Irradiation on the Sucrose Content (g/100g) of Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.34±0.06	1.35±0.01	1.34±0.01	1.34±0.01	1.34±0.03	1.36±0.04	1.34±0.07	1.35±0.02	1.33±0.01	1.32±0.02
2	1.34±0.03	1.34±0.01	1.34±0.01	1.34±0.01	1.34±0.02	1.34±0.00	1.34±0.03	1.35±0.04	1.32±0.00	1.31±0.00
3	1.34±0.03	1.32±0.02	1.34±0.02	1.33±0.02	1.33±0.04	1.33±0.04	1.34±0.01	1.34±0.01	1.30±0.03	1.29±0.01
4	1.34±0.01	1.30±0.01	1.33±0.02	1.33±0.02	1.33±0.02	1.32±0.03	1.33±0.01	1.34±0.01	1.29±0.01	1.28±0.00
5	1.33±0.05	1.26±0.03	1.33±0.01	1.33±0.01	1.33±0.00	1.32±0.00	1.32±0.01	1.32±0.01	1.28±0.03	1.27±0.03
6	1.32±0.02	1.22±0.01	1.32±0.00	1.32±0.00	1.32±0.02	1.31±0.03	1.31±0.01	1.31±0.01	1.28±0.01	1.27±0.01
7	1.30±0.00	1.19±0.01	1.32±0.01	1.31±0.01	1.31±0.01	1.31±0.00	1.30±0.00	1.30±0.00	1.27±0.05	1.26±0.04
8	1.28±0.06	1.18±0.03	1.31±0.02	1.30±0.02	1.30±0.01	1.31±0.01	1.29±0.04	1.29±0.04	1.27±0.02	1.26±0.01
9	1.25±0.07	1.18±0.03	1.31±0.01	1.29±0.01	1.30±0.02	1.30±0.00	1.28±0.03	1.28±0.03	1.26±0.02	1.25±0.04

Mean ± SD of replicates per treatment

Appendix 29: Effect of Gamma Irradiation on the Sucrose Content (g/100g) of Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	0.42±0.02	0.42±0.04	0.43±0.01	0.43±0.02	0.42±0.02	0.42±0.02	0.43±0.04	0.42±0.06	0.42±0.06	0.44±0.03
2	0.42±0.02	0.42±0.02	0.42±0.01	0.42±0.02	0.41±0.00	0.41±0.00	0.42±0.01	0.42±0.05	0.42±0.05	0.44±0.01
3	0.42±0.00	0.42±0.01	0.42±0.00	0.42±0.00	0.42±0.00	0.42±0.00	0.42±0.03	0.42±0.05	0.42±0.05	0.42±0.05
4	0.42±0.03	0.42±0.05	0.42±0.01	0.42±0.02	0.42±0.02	0.42±0.03	0.42±0.01	0.42±0.01	0.41±0.01	0.41±0.01
5	0.42±0.01	0.42±0.00	0.41±0.01	0.41±0.02	0.41±0.02	0.41±0.02	0.41±0.01	0.42±0.00	0.40±0.00	0.40±0.00
6	0.42±0.02	0.42±0.03	0.42±0.02	0.42±0.01	0.41±0.01	0.41±0.01	0.41±0.00	0.42±0.01	0.39±0.01	0.40±0.03
7	0.42±0.02	0.42±0.02	0.42±0.01	0.42±0.01	0.41±0.04	0.41±0.02	0.41±0.02	0.42±0.04	0.39±0.04	0.39±0.00
8	0.42±0.00	0.42±0.00	0.42±0.01	0.42±0.01	0.41±0.01	0.41±0.01	0.40±0.02	0.42±0.03	0.38±0.03	0.37±0.03
9	0.42±0.04	0.42±0.04	0.41±0.01	0.41±0.01	0.40±0.03	0.40±0.03	0.40±0.01	0.42±0.04	0.38±0.04	0.38±0.00

Mean ± SD of replicates per treatment

Appendix 30: Effect of Gamma Irradiation on the Sucrose Content (g/100g) Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.37±0.02	4.37±0.02	4.37±0.01	4.37±0.04	4.38±0.05	4.34±0.08	4.32±0.05	4.31±0.12	4.25±0.04	4.25±0.07
2	4.37±0.01	4.37±0.02	4.37±0.04	4.37±0.00	4.38±0.06	4.35±0.08	4.32±0.03	4.30±0.01	4.25±0.05	4.25±0.07
3	4.37±0.00	4.37±0.01	4.37±0.01	4.37±0.01	4.36±0.03	4.37±0.15	4.30±0.11	4.30±0.00	4.25±0.01	4.25±0.02
4	4.37±0.04	4.37±0.00	4.37±0.00	4.37±0.04	4.37±0.03	4.37±0.04	4.31±0.08	4.29±0.00	4.24±0.01	4.24±0.03
5	4.37±0.05	4.37±0.03	4.37±0.05	4.37±0.07	4.36±0.03	4.36±0.07	4.30±0.03	4.30±0.03	4.25±0.06	4.25±0.07
6	4.37±0.02	4.37±0.00	4.37±0.00	4.37±0.01	4.36±0.03	4.36±0.04	4.31±0.00	4.29±0.01	4.24±0.00	4.24±0.01
7	4.37±0.03	4.37±0.05	4.37±0.05	4.37±0.00	4.37±0.00	4.37±0.03	4.31±0.01	4.29±0.00	4.25±0.05	4.25±0.04
8	4.37±0.02	4.37±0.06	4.37±0.07	4.37±0.05	4.37±0.05	4.36±0.03	4.31±0.03	4.29±0.08	4.25±0.08	4.24±0.10
9	4.37±0.00	4.37±0.04	4.36±0.03	4.36±0.03	4.37±0.03	4.37±0.03	4.30±0.11	4.29±0.01	4.25±0.03	4.25±0.10

Mean ± SD of replicates per treatment

Appendix 31: Effect of Gamma Irradiation on the Total Reducing Sugar Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	9.40±0.05	9.43±0.04	9.46±0.03	9.52±0.01	9.55±0.01	9.58±0.04	9.63±0.03	9.67±0.01	9.70±0.01	9.72±0.03
2	9.40±0.01	9.41±0.01	9.47±0.03	9.52±0.03	9.55±0.00	9.57±0.03	9.64±0.07	9.69±0.02	9.69±0.01	9.72±0.04
3	9.41±0.04	9.42±0.02	9.47±0.01	9.53±0.01	9.56±0.01	9.57±0.01	9.65±0.01	9.67±0.01	9.71±0.01	9.73±0.02
4	9.40±0.03	9.39±0.01	9.48±0.01	9.52±0.01	9.56±0.01	9.58±0.01	9.65±0.03	9.68±0.01	9.70±0.01	9.73±0.01
5	9.40±0.00	9.38±0.00	9.48±0.03	9.52±0.00	9.55±0.05	9.59±0.01	9.65±0.00	9.70±0.01	9.71±0.03	9.74±0.01
6	9.40±0.03	9.39±0.00	9.47±0.00	9.51±0.03	9.55±0.03	9.61±0.01	9.65±0.01	9.70±0.01	9.71±0.01	9.74±0.02
7	9.38±0.02	9.39±0.01	9.48±0.03	9.51±0.03	9.56±0.01	9.60±0.01	9.68±0.01	9.70±0.01	9.71±0.01	9.73±0.00
8	9.40±0.02	9.41±0.01	9.49±0.02	9.52±0.01	9.54±0.07	9.61±0.01	9.69±0.01	9.71±0.01	9.71±0.01	9.73±0.01
9	9.39±0.00	9.39±0.01	9.49±0.01	9.51±0.01	9.55±0.03	9.62±0.03	9.69±0.01	9.71±0.01	9.72±0.02	9.74±0.01

Mean ± SD of replicates per treatment

Appendix 32: Effect of Gamma Irradiation on the Total Reducing Sugar Content (g/100g): Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	3.24±0.03	3.24±0.00	3.23±0.04	3.23±0.01	3.27±0.01	3.33±0.01	3.37±0.02	3.38±0.03	3.46±0.01	3.48±0.00
2	3.25±0.01	3.25±0.01	3.25±0.01	3.26±0.00	3.28±0.02	3.30±0.00	3.37±0.01	3.41±0.02	3.48±0.01	3.51±0.01
3	3.25±0.02	3.22±0.00	3.26±0.03	3.29±0.01	3.30±0.02	3.33±0.01	3.39±0.01	3.42±0.03	3.48±0.03	3.52±0.00
4	3.24±0.00	3.25±0.01	3.24±0.03	3.26±0.03	3.30±0.00	3.32±0.03	3.40±0.00	3.44±0.00	3.48±0.01	3.52±0.02
5	3.23±0.01	3.24±0.01	3.25±0.01	3.26±0.01	3.27±0.01	3.32±0.00	3.37±0.01	3.38±0.03	3.48±0.06	3.54±0.00
6	3.21±0.01	3.24±0.01	3.25±0.01	3.26±0.01	3.28±0.02	3.34±0.01	3.39±0.01	3.38±0.01	3.49±0.01	3.55±0.01
7	3.23±0.00	3.22±0.01	3.26±0.00	3.25±0.00	3.29±0.01	3.34±0.01	3.37±0.01	3.38±0.01	3.49±0.01	3.56±0.01
8	3.23±0.01	3.22±0.00	3.26±0.01	3.25±0.01	3.29±0.01	3.34±0.01	3.38±0.00	3.39±0.01	3.50±0.01	3.55±0.01
9	3.22±0.01	3.23±0.01	3.25±0.00	3.27±0.01	3.29±0.00	3.35±0.00	3.38±0.01	3.39±0.01	3.50±0.01	3.57±0.01

Mean ± SD of replicates per treatment

Appendix 33: Effect of Gamma Irradiation on the Total Reducing Sugar Content (g/100g): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	13.61±0.03	13.62±0.02	13.66±0.02	13.67±0.03	13.69±0.01	13.77±0.02	13.78±0.03	13.95±0.01	14.03±0.07	14.21±0.01
2	13.58±0.02	13.58±0.05	13.67±0.01	13.68±0.01	13.69±0.01	13.76±0.00	13.79±0.01	13.97±0.02	14.06±0.00	14.24±0.01
3	13.57±0.01	13.56±0.00	13.67±0.03	13.66±0.00	13.71±0.02	13.78±0.00	13.79±0.00	13.96±0.02	14.07±0.04	14.25±0.01
4	13.61±0.01	13.60±0.03	13.65±0.02	13.65±0.03	13.71±0.01	13.79±0.01	13.81±0.01	13.97±0.02	14.09±0.01	14.27±0.02
5	13.62±0.01	13.61±0.01	13.66±0.01	13.67±0.01	13.72±0.01	13.78±0.00	13.82±0.02	13.98±0.02	14.11±0.01	14.28±0.01
6	13.62±0.03	13.62±0.04	13.66±0.03	13.67±0.01	13.71±0.00	12.80±0.01	13.82±0.01	13.98±0.02	14.09±0.04	14.30±0.01
7	13.63±0.01	13.62±0.02	13.65±0.01	13.66±0.03	13.73±0.01	13.81±0.01	13.82±0.01	13.98±0.02	14.11±0.01	14.30±0.05
8	13.62±0.02	13.61±0.00	13.65±0.00	13.67±0.01	13.73±0.00	13.80±0.03	13.85±0.05	13.96±0.02	14.12±0.03	14.31±0.01
9	13.62±0.03	13.61±0.04	13.66±0.01	13.67±0.02	13.74±0.00	13.82±0.01	13.86±0.03	13.98±0.01	14.14±0.01	14.33±0.02

Mean ± SD of replicates per treatment

Appendix 34: Effect of Gamma Irradiation on the Total Reducing Sugar Content (g/100g): Piper guineense.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	9.13±0.01	9.14±0.01	9.20±0.01	9.19±0.00	9.25±0.01	9.27±0.01	9.37±0.01	9.43±0.01	9.50±0.01	9.6±0.01
2	9.14±0.00	9.15±0.01	9.20±0.02	9.21±0.01	9.27±0.01	9.30±0.01	9.38±0.01	9.44±0.00	9.52±0.01	9.6±0.00
3	9.14±0.03	9.16±0.01	9.19±0.01	9.21±0.02	9.28±0.01	9.31±0.01	9.38±0.02	9.46±0.01	9.52±0.02	9.6±0.01
4	9.15±0.01	9.16±0.01	9.20±0.00	9.20±0.01	9.28±0.02	9.32±0.01	9.38±0.01	9.46±0.00	9.53±0.01	9.6±0.01
5	9.15±0.01	9.17±0.01	9.20±0.01	9.20±0.00	9.29±0.01	9.32±0.01	9.38±0.01	9.47±0.01	9.54±0.01	9.6±0.00
6	9.16±0.01	9.17±0.01	9.21±0.02	9.23±0.01	9.30±0.00	9.32±0.00	9.39±0.01	9.48±0.01	9.54±0.01	9.6±0.01
7	9.16±0.00	9.17±0.01	9.20±0.01	9.23±0.02	9.30±0.01	9.33±0.01	9.38±0.02	9.48±0.03	9.55±0.02	9.6±0.02
8	9.17±0.01	9.17±0.01	9.21±0.01	9.23±0.01	9.31±0.01	9.35±0.01	9.38±0.01	9.48±0.01	9.57±0.01	9.6±0.01
9	9.17±0.02	9.16±0.03	9.22±0.01	9.24±0.01	9.31±0.01	9.35±0.00	9.38±0.00	9.46±0.02	9.58±0.01	9.6±0.01

Mean ± SD of replicates per treatment

Appendix 35: Effect of Gamma Irradiation on the Hexose Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.40±0.01	4.40±0.03	4.51±0.01	4.58±0.02	4.80±0.00	4.81±0.03	4.98±0.03	4.99±0.01	5.04±0.05	5.12±0.01
2	4.41±0.04	4.41±0.00	4.59±0.09	4.63±0.04	4.87±0.01	4.86±0.02	5.01±0.01	5.05±0.01	5.05±0.02	5.15±0.03
3	4.41±0.00	4.40±0.05	4.63±0.00	4.66±0.00	4.90±0.00	4.92±0.01	5.05±0.02	5.08±0.03	5.08±0.02	5.16±0.01
4	4.41±0.03	4.40±0.01	4.68±0.02	4.70±0.02	4.94±0.05	4.93±0.02	5.05±0.01	5.09±0.05	5.12±0.00	5.19±0.01
5	4.40±0.01	4.40±0.00	4.68±0.00	4.72±0.02	4.91±0.03	4.95±0.02	5.08±0.00	5.09±0.01	5.14±0.03	5.22±0.01
6	4.41±0.05	4.40±0.03	4.70±0.01	4.74±0.05	4.90±0.05	4.94±0.00	5.07±0.04	5.10±0.00	5.15±0.01	5.22±0.02
7	4.40±0.01	4.41±0.00	4.71±0.01	4.73±0.02	4.82±0.05	4.94±0.01	5.09±0.03	5.10±0.01	5.18±0.01	5.23±0.00
8	4.40±0.00	4.40±0.00	4.76±0.01	4.72±0.02	4.92±0.00	4.93±0.03	5.08±0.01	5.12±0.01	5.18±0.03	5.23±0.01
9	4.40±0.03	4.40±0.02	4.70±0.00	4.73±0.01	4.92±0.02	4.93±0.00	5.08±0.00	5.12±0.02	5.18±0.00	5.24±0.01

Mean ± SD of replicates per treatment

Appendix 36: Effect of Gamma Irradiation on the Hexose Content(g/100g): Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	3.23±0.00	3.24±0.01	3.23±0.04	3.25±0.06	3.27±0.01	3.32±0.01	3.34±0.01	3.38±0.01	3.40±0.00	3.47±0.01
2	3.23±0.01	3.23±0.01	3.25±0.02	3.25±0.05	3.29±0.01	3.33±0.01	3.36±0.01	3.40±0.01	3.41±0.01	3.51±0.01
3	3.23±0.02	3.23±0.00	3.25±0.06	3.24±0.01	3.29±0.00	3.34±0.00	3.38±0.01	3.41±0.01	3.43±0.01	3.52±0.00
4	3.21±0.04	3.23±0.01	3.24±0.01	3.25±0.01	3.30±0.01	3.33±0.01	3.39±0.01	3.41±0.01	3.44±0.02	3.53±0.03
5	3.23±0.01	3.23±0.01	3.24±0.05	3.24±0.01	3.30±0.00	3.34±0.01	3.41±0.01	3.41±0.01	3.43±0.01	3.54±0.00
6	3.22±0.03	3.23±0.02	3.25±0.06	3.24±0.00	3.31±0.02	3.34±0.01	3.40±0.01	3.41±0.01	3.45±0.01	3.54±0.03
7	3.23±0.02	3.23±0.01	3.24±0.03	3.24±0.01	3.29±0.01	3.34±0.00	3.41±0.01	3.41±0.02	3.47±0.01	3.54±0.01
8	3.22±0.05	3.24±0.01	3.24±0.00	3.24±0.02	3.30±0.01	3.34±0.01	3.40±0.03	3.40±0.00	3.47±0.00	3.55±0.01
9	3.22±0.02	3.23±0.01	3.24±0.03	3.24±0.01	3.29±0.01	3.35±0.01	3.40±0.01	3.40±0.01	3.49±0.01	3.55±0.01

Mean ± SD of replicates per treatment

Appendix 37: Effect of Gamma Irradiation on the Hexose Content (g/100g): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	13.58±0.11	13.57±0.07	13.65±0.05	13.67±0.01	13.68±0.01	13.72±0.03	13.76±0.03	13.88±0.02	14.02±0.01	14.20±0.01
2	13.54±0.10	13.54±0.10	13.66±0.01	13.68±0.01	13.69±0.03	13.72±0.01	13.77±0.02	13.88±0.03	14.03±0.03	14.23±0.04
3	13.55±0.05	13.55±0.07	13.66±0.03	13.68±0.02	13.69±0.04	13.73±0.05	13.79±0.04	13.91±0.01	14.07±0.02	14.24±0.03
4	13.59±0.07	13.56±0.05	13.66±0.02	13.68±0.03	13.70±0.05	13.74±0.05	13.79±0.03	13.92±0.01	14.08±0.03	14.26±0.01
5	13.56±0.03	13.55±0.01	13.67±0.02	13.68±0.05	13.71±0.01	13.74±0.01	13.79±0.01	13.91±0.04	14.10±0.01	14.27±0.05
6	13.55±0.01	13.55±0.03	13.66±0.04	13.69±0.02	13.70±0.02	13.75±0.01	13.80±0.05	13.90±0.05	14.11±0.05	14.29±0.03
7	13.55±0.03	13.56±0.10	13.66±0.02	13.69±0.03	13.72±0.07	13.75±0.01	13.81±0.03	13.90±0.05	14.11±0.03	14.30±0.04
8	13.55±0.01	13.55±0.04	13.65±0.01	13.68±0.04	13.72±0.04	13.74±0.05	13.84±0.03	13.94±0.01	14.11±0.03	14.31±0.01
9	13.55±0.07	13.55±0.02	13.65±0.02	13.69±0.02	13.72±0.03	13.77±0.03	13.85±0.01	13.96±0.03	14.12±0.01	14.33±0.02

Mean ± SD of replicates per treatment

Appendix 38: Effect of Gamma Irradiation on the Hexose Content(g/100g): Ashanti Pepper

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	9.11±0.03	9.11±0.03	9.17±0.01	9.18±0.0	9.23±0.04	9.25±0.03	9.35±0.01	9.40±0.01	9.47±0.01	9.59±0.01
2	9.12±0.02	9.12±0.04	9.18±0.02	9.19±0.0	9.24±0.03	9.28±0.04	9.36±0.03	9.40±0.03	9.47±0.04	9.59±0.02
3	9.11±0.01	9.12±0.02	9.19±0.03	9.20±0.0	9.26±0.05	9.29±0.03	9.37±0.01	9.41±0.03	9.48±0.02	9.61±0.03
4	9.11±0.02	9.12±0.03	9.18±0.05	9.20±0.0	9.26±0.02	9.31±0.02	9.36±0.02	9.41±0.03	9.51±0.03	9.62±0.04
5	9.12±0.03	9.12±0.03	9.18±0.02	9.22±0.0	9.27±0.04	9.30±0.05	9.36±0.03	9.42±0.02	9.53±0.04	9.64±0.01
6	9.13±0.04	9.12±0.04	9.19±0.07	9.22±0.0	9.28±0.05	9.32±0.04	9.36±0.02	9.43±0.01	9.52±0.05	9.64±0.04
7	9.11±0.01	9.12±0.02	9.19±0.06	9.22±0.0	9.29±0.02	9.34±0.03	9.36±0.03	9.43±0.02	9.54±0.02	9.64±0.03
8	9.12±0.03	9.12±0.05	9.20±0.05	9.23±0.0	9.30±0.03	9.34±0.04	9.36±0.02	9.45±0.01	9.55±0.01	9.66±0.02
9	9.12±0.01	9.13±0.03	9.21±0.04	9.22±0.0	9.31±0.02	9.34±0.01	9.37±0.01	9.45±0.03	9.56±0.01	9.66±0.01

Mean ± SD of replicates per treatment

Appendix 39: Effect of Gamma Irradiation on the Glucose Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	2.95±0.03	2.96±0.03	3.06±0.01	3.12±0.00	3.35±0.03	3.35±0.03	3.48±0.02	3.48±0.01	3.52 ±0.9	3.61±0.01
2	2.96±0.04	2.97±0.01	3.13±0.03	3.18±0.03	3.31±0.01	3.40±0.01	3.49±0.01	3.53±0.01	3.51 ±0.1	3.61±0.01
3	2.96±0.03	2.95±0.06	3.20±0.03	3.20±0.00	3.33±0.04	3.43±0.01	3.52±0.02	3.55±0.03	3.53 ±0.2	3.60±0.00
4	2.97±0.03	2.95±0.00	3.24±0.01	3.23±0.01	3.38±0.04	3.42±0.01	3.51±0.02	3.56±0.01	3.56 ±0.0	3.62±0.00
5	2.96±0.02	2.95±0.01	3.22±2.00	3.25±0.02	3.39±0.01	3.43±0.02	3.53±0.03	3.53±0.01	3.57 ±0.2	3.63±0.00
6	2.96±0.04	2.95±0.06	3.28±0.03	3.27±0.02	3.36±0.01	3.43±0.03	3.52±0.02	3.54±0.00	3.57 ±0.0	3.63±0.02
7	2.95±0.01	2.97±0.01	3.24±0.02	3.26±0.01	3.37±0.01	3.41±0.03	3.53±0.04	3.53±0.00	3.59 ±0.0	3.63±0.01
8	2.95±0.03	2.95±0.02	3.23±0.01	3.23±0.02	3.42±0.01	3.40±0.03	3.52±0.04	3.54±0.01	3.59 ±0.3	3.62±0.00
9	2.95±0.06	2.95±0.07	3.20±0.00	3.23±0.00	3.40±0.03	3.41±0.02	3.52±0.03	3.53±0.04	3.60 ±0.1	3.63±0.00

Mean ± SD of replicates per treatment

Appendix 40: Effect of Gamma Irradiation on the Glucose Content (g/100g): Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	2.19±0.01	2.18±0.01	2.17±0.05	2.17±0.06	2.18±0.01	2.11±0.01	2.20±0.00	2.23±0.00	2.22±0.01	2.26±0.01
2	2.19±0.01	2.18±0.01	2.17±0.01	2.15±0.07	2.18±0.03	2.10±0.00	2.21±0.00	2.25±0.01	2.21±0.02	2.30±0.03
3	2.19±0.01	2.18±0.01	2.20±0.01	2.13±0.01	2.18±0.01	2.10±0.02	2.23±0.01	2.25±0.03	2.21±0.00	2.29±0.01
4	2.17±0.03	2.18±0.01	2.12±0.02	2.11±0.01	2.18±0.01	2.19±0.01	2.23±0.01	2.24±0.02	2.21±0.03	2.29±0.07
5	2.20±0.02	2.19±0.01	2.10±0.06	2.09±0.01	2.18±0.01	2.19±0.01	2.24±0.01	2.22±0.01	2.20±0.01	2.30±0.01
6	2.17±0.05	2.18±0.01	2.11±0.02	2.13±0.03	2.16±0.01	2.18±0.00	2.24±0.01	2.21±0.04	2.24±0.01	2.30±0.00
7	2.18±0.02	2.17±0.03	2.10±0.03	2.09±0.02	2.17±0.02	2.19±0.01	2.21±0.00	2.20±0.02	2.24±0.02	2.29±0.00
8	2.17±0.03	2.16±0.02	2.11±0.02	2.08±0.02	2.17±0.04	2.18±0.03	2.20±0.03	2.19±0.02	2.24±0.01	2.30±0.01
9	2.16±0.04	2.16±0.03	2.10±0.04	2.08±0.01	2.16±0.02	2.21±0.00	2.24±0.01	2.20±0.03	2.14±0.01	2.31±0.01

Mean ± SD of replicates per treatment

Appendix 41: Effect of Gamma Irradiation on the Glucose Content (g/100g): Ginger

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	7.79±0.01	7.78±0.01	7.75±0.01	7.76±0.01	7.82±0.01	7.85±0.03	7.85±0.05	7.93±0.01	8.03±0.00	8.19±0.02
2	7.74±0.05	7.74±0.02	7.75±0.02	7.77±0.01	7.79±0.01	7.83±0.03	7.84±0.01	7.93±0.01	8.02±0.05	8.20±0.04
3	7.76±0.01	7.76±0.01	7.74±0.02	7.75±0.03	7.78±0.01	7.80±0.06	7.86±0.01	7.94±0.02	8.04±0.01	8.19±0.02
4	7.78±0.04	7.72±0.00	7.73±0.04	7.75±0.03	7.77±0.00	7.80±0.07	7.84±0.06	7.98±0.01	8.04±0.04	8.19±0.00
5	7.76±0.02	7.74±0.02	7.74±0.05	7.75±0.01	7.78±0.01	7.78±0.00	7.81±0.02	7.90±0.07	8.05±0.01	8.19±0.01
6	7.75±0.03	7.73±0.03	7.73±0.03	7.75±0.01	7.77±0.02	7.78±0.02	7.81±0.05	7.88±0.03	8.05±0.02	8.20±0.01
7	7.73±0.03	7.74±0.02	7.71±0.00	7.74±0.04	7.77±0.01	7.78±0.02	7.78±0.03	7.84±0.03	8.04±0.05	8.20±0.04
8	7.77±0.01	7.72±0.02	7.71±0.01	7.73±0.00	7.77±0.01	7.79±0.01	7.78±0.03	7.83±0.00	8.05±0.04	8.19±0.02
9	7.77±0.00	7.72±0.02	7.75±0.05	7.75±0.02	7.76±0.03	7.77±0.02	7.78±0.05	7.85±0.02	8.03±0.01	8.19±0.03

Mean ± SD of replicates per treatment

Appendix 42: Effect of Gamma Irradiation on the Glucose Content (g/100g): Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	7.02±0.01	7.02±0.01	7.03±0.03	7.02±0.06	7.03±0.04	7.01±0.03	7.10±0.01	7.14±0.00	7.21±0.02	7.28±0.01
2	7.01±0.01	7.01±0.01	7.03±0.01	6.97±0.01	7.01±0.00	7.04±0.01	7.10±0.01	7.10±0.03	7.20±0.03	7.26±0.01
3	7.02±0.01	7.01±0.03	7.03±0.01	6.99±0.01	7.02±0.02	7.04±0.03	7.10±0.01	7.10±0.02	7.20±0.03	7.26±0.04
4	6.99±0.02	7.01±0.05	7.02±0.01	7.00±0.03	7.00±0.02	7.05±0.01	7.09±0.02	7.08±0.00	7.20±0.02	7.26±0.05
5	6.99±0.00	7.01±0.02	7.01±0.03	6.98±0.03	7.00±0.01	7.03±0.05	7.07±0.01	7.09±0.05	7.21±0.01	7.28±0.04
6	7.00±0.05	7.01±0.06	6.99±0.03	6.98±0.00	7.01±0.00	7.04±0.01	7.06±0.03	7.08±0.01	7.19±0.02	7.21±0.03
7	6.98±0.03	6.99±0.02	6.98±0.01	6.96±0.03	7.02±0.01	7.02±0.01	7.05±0.03	7.09±0.03	7.20±0.02	7.26±0.01
8	6.99±0.02	6.98±0.00	6.98±0.01	6.95±0.01	7.02±0.01	7.04±0.01	7.04±0.04	7.12±0.01	7.21±0.01	7.28±0.02
9	6.99±0.00	7.00±0.01	6.99±0.00	6.94±0.01	6.99±0.01	7.04±0.01	7.04±0.00	7.10±0.01	7.22±0.00	7.29±0.02

Mean ± SD of replicates per treatment

Appendix 43: Effect of Gamma Irradiation on the Fructose Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.45±0.02	1.44±0.00	1.46±0.01	1.46±0.02	1.46±0.03	1.46±0.00	1.50±0.00	1.52±0.03	1.52±0.01	1.4 ±0.0
2	1.45±0.00	1.45±0.01	1.46±0.02	1.46±0.01	1.46±0.03	1.46±0.01	1.52±0.01	1.54±0.01	1.54±0.01	1.4 ±0.0
3	1.45±0.01	1.45±0.01	1.46±0.01	1.46±0.00	1.47±0.03	1.49±0.01	1.53±0.00	1.55±0.00	1.56±0.01	1.4 ±0.0
4	1.45±0.05	1.45±0.01	1.45±0.00	1.47±0.01	1.47±0.01	1.51±0.01	1.55±0.01	1.56±0.00	1.57±0.01	1.4 ±0.0
5	1.45±0.01	1.46±0.01	1.46±0.00	1.47±0.01	1.47±0.03	1.52±0.00	1.55±0.03	1.58±0.01	1.59±0.01	1.4 ±0.0
6	1.45±0.01	1.45±0.02	1.47±0.03	1.48±0.01	1.49±0.00	1.52±0.03	1.56±0.02	1.58±0.01	1.60±0.00	1.4 ±0.0
7	1.45±0.01	1.46±0.01	1.48±0.03	1.47±0.01	1.50±0.01	1.53±0.02	1.56±0.01	1.59±0.01	1.61±0.01	1.4 ±0.0
8	1.45±0.03	1.46±0.02	1.48±0.03	1.49±0.00	1.51±0.01	1.53±0.00	1.56±0.03	1.59±0.00	1.61±0.01	1.4 ±0.0
9	1.46±0.04	1.45±0.04	1.50±0.00	1.50±0.01	1.52±0.01	1.53±0.02	1.56±0.03	1.59±0.01	1.61±0.01	1.4 ±0.0

Mean ± SD of replicates per treatment

Appendix 44: Effect of Gamma Irradiation on the Fructose Content (g/100g): Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.06±0.01	1.06±0.00	1.07±0.05	1.08±0.01	1.10±0.01	1.11±0.01	1.14±0.01	1.15±0.00	1.19±0.01	1.21±0.02
2	1.06±0.00	1.06±0.01	1.08±0.01	1.10±0.01	1.11±0.01	1.13±0.01	1.15±0.01	1.16±0.01	1.21±0.01	1.22±0.02
3	1.06±0.01	1.06±0.03	1.10±0.01	1.12±0.01	1.12±0.01	1.14±0.01	1.15±0.00	1.16±0.05	1.22±0.01	1.23±0.01
4	1.06±0.01	1.06±0.01	1.13±0.01	1.14±0.01	1.12±0.00	1.14±0.00	1.16±0.00	1.18±0.03	1.23±0.01	1.24±0.03
5	1.06±0.01	1.06±0.01	1.14±0.00	1.16±0.02	1.13±0.01	1.15±0.01	1.17±0.02	1.19±0.01	1.24±0.01	1.24±0.01
6	1.07±0.02	1.07±0.01	1.14±0.01	1.16±0.03	1.13±0.00	1.16±0.00	1.17±0.01	1.20±0.01	1.24±0.02	1.24±0.01
7	1.07±0.00	1.07±0.00	1.14±0.00	1.16±0.01	1.13±0.01	1.16±0.01	1.10±0.01	1.21±0.00	1.24±0.01	1.25±0.01
8	1.07±0.01	1.08±0.01	1.14±0.02	1.16±0.00	1.13±0.03	1.16±0.01	1.10±0.00	1.22±0.02	1.24±0.01	1.25±0.00
9	1.08±0.02	1.08±0.01	1.14±0.01	1.16±0.02	1.14±0.01	1.17±0.02	1.11±0.02	1.22±0.01	1.24±0.00	1.25±0.02

Mean ± SD of replicates per treatment.

Appendix 45: Effect of Gamma Irradiation on the Fructose Content (g/100g): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.79±0.01	5.79±0.02	5.81±0.01	5.81±0.00	5.87±0.01	5.88±0.01	5.92±0.02	5.95±0.01	5.99±0.01	6.01±0.01
2	5.80±0.05	5.81±0.02	5.81±0.01	5.81±0.02	5.90±0.01	5.90±0.02	5.93±0.01	5.95±0.00	6.01±0.01	6.03±0.00
3	5.79±0.00	5.81±0.01	5.83±0.01	5.83±0.01	5.92±0.02	5.92±0.00	5.94±0.02	5.98±0.01	6.03±0.02	6.06±0.02
4	5.80±0.04	5.81±0.00	5.83±0.02	5.83±0.04	5.93±0.01	5.95±0.01	5.95±0.02	6.00±0.03	6.04±0.01	6.07±0.01
5	5.81±0.01	5.81±0.00	5.83±0.03	5.84±0.01	5.94±0.01	5.96±0.00	5.98±0.01	6.02±0.02	6.05±0.00	6.08±0.00
6	5.81±0.02	5.82±0.02	5.84±0.01	5.84±0.00	5.94±0.00	5.97±0.01	5.99±0.04	6.05±0.01	6.06±0.01	6.09±0.01
7	5.82±0.00	5.83±0.01	5.85±0.02	5.85±0.03	5.95±0.01	5.98±0.00	6.06±0.03	6.09±0.02	6.07±0.03	6.10±0.00
8	5.83±0.01	5.83±0.01	5.85±0.01	5.85±0.00	5.95±0.00	5.98±0.03	6.06±0.00	6.11±0.01	6.07±0.00	6.13±0.01
9	5.83±0.00	5.83±0.00	5.85±0.00	5.85±0.00	5.96±0.00	6.01±0.01	6.07±0.04	6.12±0.01	6.09±0.01	6.14±0.01

Mean ± SD of replicates per treatment

Appendix 46: Effect of Gamma Irradiation on the Fructose Content (g/100g): Piper Guineense.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	2.09±0.01	2.10±0.01	2.14±0.01	2.17±0.03	2.23±0.01	2.24±0.04	2.25±0.02	2.26±0.01	2.27±0.01	2.32±0.02
2	2.12±0.00	2.11±0.01	2.15±0.01	2.20±0.00	2.23±0.00	2.24±0.00	2.27±0.02	2.30±0.00	2.27±0.01	2.33±0.01
3	2.12±0.01	2.11±0.01	2.16±0.01	2.22±0.01	2.24±0.00	2.26±0.01	2.27±0.01	2.32±0.00	2.29±0.02	2.35±0.01
4	2.13±0.01	2.11±0.04	2.17±0.01	2.22±0.04	2.25±0.01	2.26±0.01	2.28±0.01	2.33±0.00	2.31±0.01	2.36±0.01
5	2.13±0.00	2.12±0.02	2.17±0.03	2.24±0.01	2.26±0.01	2.28±0.02	2.29±0.01	2.34±0.03	2.33±0.01	2.37±0.01
6	2.13±0.01	2.12±0.01	2.10±0.02	2.25±0.02	2.27±0.01	2.28±0.00	2.30±0.01	2.35±0.01	2.34±0.01	2.38±0.03
7	2.14±0.02	2.13±0.00	2.12±0.02	2.26±0.00	2.27±0.00	2.29±0.01	2.31±0.01	2.35±0.01	2.34±0.00	2.38±2.00
8	2.14±0.01	2.14±0.00	2.12±0.00	2.27±0.01	2.28±0.02	2.30±0.00	2.32±0.00	2.35±0.01	2.34±0.00	2.38±0.03
9	2.13±0.01	2.13±0.04	2.12±0.01	2.28±0.00	2.29±0.01	2.30±0.01	2.33±0.01	2.35±0.01	2.34±0.01	2.38±0.01

Mean ± SD of replicates per treatment

(7

Appendix 47: Effect of Gamma Irradiation on the Protein Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	15.64±0.08	15.65±0.01	15.69±0.06	15.66±0.03	15.69±0.06	15.68±0.00	15.68±0.00	15.68±0.01	15.66±0.03	15.65±0.01
2	15.67±0.09	15.66±0.03	15.64±0.06	15.65±0.01	15.69±0.06	15.66±0.04	15.67±0.01	15.63±0.01	15.64±0.06	15.69±0.06
3	15.64±0.00	15.69±0.06	15.69±0.06	15.66±0.03	15.66±0.03	15.64±0.01	15.66±0.04	15.67±0.09	15.68±0.06	15.60±0.00
4	15.65±0.02	15.66±0.03	15.65±0.01	15.62±0.02	15.67±0.02	15.68±0.00	15.68±0.07	15.64±0.06	15.64±0.06	15.67±0.09
5	15.65±0.03	15.66±0.06	15.67±0.04	15.67±0.09	15.66±0.03	15.65±0.03	15.66±0.03	15.68±0.00	15.63±0.01	15.68±0.07
6	15.61±0.04	15.64±0.00	15.64±0.01	15.63±0.01	15.66±0.03	15.64±0.00	15.63±0.02	15.66±0.02	15.61±0.01	15.64±0.01
7	15.64±0.03	15.64±0.00	15.62±0.00	15.63±0.01	15.63±0.01	15.62±0.02	15.63±0.01	15.63±0.01	15.63±0.01	15.64±0.01
8	15.62±0.03	15.64±0.01	15.65±0.01	15.62±0.01	15.63±0.01	15.63±0.01	15.64±0.01	15.66±0.02	15.62±0.02	15.62±0.01
9	15.63±0.01	15.63±0.01	15.63±0.01	15.63±0.01	15.63±0.01	15.63±0.00	15.62±0.02	15.64±0.01	15.65±0.01	15.63±0.01

Mean ± SD of replicates per treatment

Appendix 48: Effect of Gamma Irradiation on the Protein Content (g/100g): Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	25.18±0.03	25.18±0.02	25.16±0.06	25.14±0.04	25.14±0.03	25.16±0.05	25.15±0.01	25.16±0.03	25.15±0.04	25.15±0.04
2	25.16±0.06	25.16±0.06	25.14±0.09	25.17±0.04	25.17±0.01	25.16±0.00	25.15±0.01	25.15±0.05	25.16±0.03	25.15±0.01
3	25.14±0.03	25.14±0.03	25.16±0.06	25.14±0.09	25.16±0.00	25.17±0.00	25.16±0.06	25.17±0.01	25.16±0.03	25.16±0.04
4	25.13±0.08	25.11±0.00	25.14±0.03	25.16±0.06	25.16±0.00	25.16±0.03	25.17±0.01	25.14±0.03	25.16±0.06	25.16±0.00
5	25.12±0.07	25.18±0.02	25.16±0.06	25.16±0.00	25.18±0.03	25.18±0.09	25.14±0.03	25.15±0.01	25.16±0.03	25.18±0.03
6	25.17±0.01	25.17±0.01	25.14±0.00	25.17±0.01	25.16±0.00	25.16±0.03	25.17±0.01	25.18±0.00	25.15±0.01	25.18±0.02
7	25.16±0.02	25.16±0.00	25.16±0.00	25.16±0.03	25.17±0.01	25.16±0.02	25.17±0.01	25.15±0.01	25.14±0.00	25.15±0.01
8	25.18±0.02	25.19±0.01	25.17±0.01	25.16±0.00	25.17±0.01	25.17±0.05	25.18±0.03	25.16±0.03	25.18±0.03	25.16±0.03
9	25.17±0.05	25.15±0.01	25.16±0.00	25.17±0.01	25.17±0.04	25.17±0.01	25.16±0.03	25.15±0.05	25.20±0.01	25.18±0.03

Mean ± SD of replicates per treatment

Appendix 49: Effect of Gamma Irradiation on the Protein Content (g/100g): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	11.98±0.03	12.05±0.06	12.00±0.07	12.03±0.04	12.00±0.06	12.00±0.01	12.02±0.03	11.98±0.02	11.99±0.05	11.99±0.01
2	12.03±0.04	12.03±0.07	12.00±0.04	12.02±0.01	12.02±0.02	12.01±0.04	12.02±0.04	12.01±0.01	12.00±0.01	12.01±0.02
3	12.00±0.01	12.01±0.01	12.00±0.00	12.00±0.01	12.02±0.02	12.00±0.03	12.01±0.00	12.01±0.01	12.01±0.02	12.01±0.01
4	11.99±0.01	12.01±0.01	12.01±0.01	12.01±0.03	11.99±0.01	12.00±0.01	11.99±0.01	11.99±0.01	12.00±0.01	12.01±0.05
5	12.01±0.01	12.00±0.01	12.02±0.03	11.97±0.10	12.02±0.01	12.01±0.01	12.01±0.03	12.00±0.02	12.01±0.04	11.99±0.01
6	11.99±0.01	12.01±0.00	11.99±0.01	11.99±0.06	12.00±0.04	12.00±0.02	12.00±0.02	11.97±0.01	11.99±0.01	11.99±0.03
7	11.99±0.05	11.98±0.00	11.98±0.00	12.00±0.00	12.00±0.00	11.99±0.03	11.98±0.01	11.99±0.01	12.00±0.08	12.00±0.02
8	11.98±0.00	11.98±0.02	11.96±0.00	11.97±0.01	12.02±0.01	12.00±0.03	11.98±0.03	11.99±0.04	11.99±0.01	12.01±0.01
9	11.97±0.08	11.99±0.03	11.97±0.01	11.97±0.00	12.01±0.01	12.00±0.02	11.98±0.01	11.98±0.00	12.02±0.02	12.01±0.01

Mean ± SD of replicates per treatment

Appendix 50: Effect of Gamma Irradiation on the Protein Content (g/100g): Ashanti Pepper

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	13.33±0.04	13.39±0.06	13.38±0.03	13.39±0.01	13.40±0.01	13.38±0.03	13.39±0.01	13.41±0.03	13.39±0.01	13.40±0.04
2	13.34±0.06	13.43±0.18	13.38±0.07	13.41±0.01	13.40±0.06	13.41±0.04	13.39±0.03	13.40±0.03	13.39±0.01	13.39±0.00
3	13.36±0.04	13.39±0.01	13.40±0.06	13.40±0.14	13.41±0.06	13.39±0.01	13.39±0.03	13.40±0.02	13.32±0.02	13.39±0.01
4	13.39±0.04	13.41±0.16	13.39±0.06	13.39±0.03	13.41±0.01	13.39±0.03	13.38±0.02	13.41±0.01	13.40±0.04	13.42±0.04
5	13.40±0.06	13.36±0.04	13.40±0.13	13.39±0.01	13.41±0.01	13.44±0.08	13.41±0.01	13.38±0.01	13.39±0.03	13.39±0.01
6	13.40±0.02	13.37±0.04	13.40±0.04	13.40±0.00	13.37±0.01	13.42±0.01	13.39±0.03	13.38±0.01	13.38±0.02	13.38±0.01
7	13.35±0.03	13.42±0.01	13.38±0.01	13.40±0.03	13.40±0.02	13.38±0.01	13.39±0.00	13.39±0.01	13.38±0.01	13.39±0.01
8	13.39±0.01	13.39±0.00	13.39±0.02	13.39±0.03	13.40±0.00	13.39±0.01	13.38±0.00	13.39±0.01	13.40±0.00	13.38±0.03
9	13.41±0.01	13.38±0.03	13.38±0.01	13.39±0.00	13.41±0.01	13.41±0.01	13.40±0.00	13.40±0.00	13.38±0.02	13.38±0.01

Mean ± SD of replicates per treatment

Appendix 51: Effect of Gamma Irradiation on the Lipid Content (g/100g): Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	18.81±0.28	18.80±0.06	18.88±0.11	18.91±0.03	18.93±0.04	19.02±0.02	19.05±0.03	19.17±0.09	19.21±0.08	19.31±0.18
2	18.79±0.24	18.80±0.07	18.90±0.16	18.92±0.04	18.92±0.01	19.01±0.07	19.03±0.03	19.17±0.03	19.21±0.04	19.28±0.10
3	18.77±0.11	18.78±0.14	18.86±0.21	18.92±0.04	18.92±0.06	19.01±0.04	19.03±0.24	19.20±0.02	19.25±0.08	19.31±0.08
4	18.78±0.10	18.77±0.10	18.86±0.18	18.92±0.06	18.92±0.03	19.00±0.01	19.04±0.08	19.20±0.03	19.26±0.03	19.30±0.03
5	18.79±0.01	18.76±0.17	18.86±0.14	18.91±0.07	18.93±0.01	19.02±0.06	19.02±0.05	19.19±0.06	19.24±0.04	19.29±0.07
6	18.75±0.03	18.78±0.16	18.86±0.08	18.91±0.04	18.92±0.03	19.03±0.01	19.02±0.11	19.20±0.01	19.25±0.10	19.29±0.08
7	18.79±0.13	18.78±0.01	18.86±0.04	18.92±0.07	18.93±0.01	19.04±0.06	19.02±0.08	19.19±0.01	19.26±0.04	19.29±0.12
8	18.78±0.14	18.79±0.01	18.86±0.18	18.91±0.07	18.92±0.04	19.03±0.01	19.05±0.07	19.22±0.04	19.24±0.06	19.31±0.02
9	18.80±0.06	18.80±0.04	18.86±0.04	18.92±0.01	18.92±0.04	19.05±0.02	19.03±0.06	19.21±0.02	19.22±0.05	19.30±0.03

Mean ± SD of replicates per treatment

Appendix 52: Effect of Gamma Irradiation on the Lipid Content (g/100g): Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	25.00±0.07	24.95±0.07	25.35±0.07	25.61±0.04	25.55±0.08	25.76±0.04	25.67±0.04	25.86±0.06	25.82±0.01	26.06±0.06
2	24.97±0.11	24.98±0.07	25.35±0.13	25.66±0.04	25.56±0.05	25.75±0.07	25.68±0.04	25.85±0.01	25.84±0.02	26.11±0.02
3	24.93±0.01	24.96±0.13	25.41±0.06	25.65±0.06	25.56±0.01	25.77±0.02	25.69±0.01	25.86±0.14	25.84±0.05	26.09±0.06
4	24.95±0.06	24.94±0.09	25.40±0.01	25.68±0.04	25.56±0.08	25.77±0.04	25.72±0.02	25.87±0.05	25.85±0.01	26.08±0.03
5	24.98±0.00	24.91±0.21	25.44±0.22	25.63±0.01	25.56±0.04	25.78±0.02	25.71±0.02	25.88±0.24	25.85±0.01	26.09±0.01
6	25.00±0.01	24.91±0.07	25.44±0.01	25.67±0.08	25.56±0.01	25.77±0.04	25.71±0.01	25.87±0.03	25.83±0.06	26.10±0.04
7	25.01±0.04	24.90±0.10	25.44±0.18	25.67±0.02	25.56±0.06	25.77±0.03	25.70±0.02	25.86±0.14	25.83±0.08	26.10±0.08
8	24.97±0.01	24.92±0.03	25.42±0.04	25.76±0.02	25.56±0.01	25.77±0.01	25.72±0.04	25.87±0.03	25.86±0.04	26.09±0.00
9	24.97±0.10	24.96±0.00	25.43±0.02	25.66±0.01	25.56±0.01	25.77±0.04	25.72±0.03	25.88±0.03	25.86±0.01	26.11±0.05

Mean ± SD of replicates per treatment

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Appendix 53: Effect of Gamma Irradiation on the Lipid Content (g/100g): Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	8.02±0.10	7.97±0.04	8.23±0.11	8.29±0.01	8.28±0.04	8.39±0.04	8.37±0.02	8.56±0.06	8.47±0.01	8.66±0.06
2	7.99±0.01	7.98±0.08	8.22±0.11	8.33±0.03	8.25±0.06	8.40±0.03	8.36±0.06	8.55±0.05	8.47±0.05	8.68±0.14
3	8.04±0.08	7.96±0.06	8.20±0.01	8.35±0.06	8.28±0.05	8.40±0.01	8.36±0.06	8.54±0.08	8.47±0.06	8.65±0.08
4	7.99±0.12	7.96±0.04	8.22±0.04	8.33±0.03	8.27±0.01	8.42±0.02	8.37±0.01	8.55±0.07	8.46±0.06	8.66±0.07
5	8.05±0.15	7.99±0.04	8.23±0.01	8.35±0.08	8.28±0.03	8.41±0.03	8.36±0.05	8.55±0.08	8.48±0.01	8.66±0.01
6	8.06±0.00	8.02±0.02	8.23±0.03	8.35±0.01	8.27±0.03	8.41±0.01	8.36±0.03	8.55±0.07	8.48±0.03	8.67±0.02
7	8.05±0.07	7.98±0.14	8.23±0.06	8.37±0.04	8.27±0.01	8.42±0.02	8.36±0.03	8.55±0.05	8.48±0.06	8.66±0.01
8	8.04±0.02	8.00±0.03	8.24±0.01	8.37±0.10	8.28±0.04	8.42±0.08	8.36±0.05	8.55±0.03	8.47±0.06	8.65±0.07
9	8.04±0.01	8.03±0.04	8.24±0.06	8.36±0.10	8.27±0.01	8.43±0.04	8.37±0.01	8.57±0.01	8.49±0.02	8.67±0.05

Mean ± SD of replicates per treatment

Appendix 54: Effect of Gamma Irradiation on the Lipid Content (g/100g): Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	16.46±0.06	16.45±0.06	16.53±0.13	16.67±0.06	16.60±0.08	16.74±0.06	16.70±0.14	16.83±0.04	16.78±0.03	17.02±0.08
2	16.47±0.09	16.53±0.18	16.53±0.11	16.62±0.08	16.69±0.01	16.76±0.04	16.69±0.06	16.84±0.06	16.78±0.02	17.03±0.04
3	16.45±0.14	16.52±0.06	16.52±0.06	16.63±0.07	16.60±0.01	16.77±0.04	16.60±0.06	16.85±0.07	16.77±0.04	17.02±0.02
4	16.46±0.16	16.53±0.11	16.52±0.08	16.65±0.21	16.58±0.06	16.76±0.06	16.68±0.03	16.84±0.08	16.77±0.10	17.03±0.02
5	16.45±0.07	16.52±0.06	16.52±0.16	16.63±0.04	16.58±0.01	16.76±0.06	16.68±0.04	16.84±0.01	16.77±0.09	17.02±0.11
6	16.47±0.01	16.51±0.04	16.52±0.04	16.63±0.03	16.58±0.01	16.74±0.04	16.69±0.02	16.84±0.09	16.77±0.06	17.01±0.04
7	16.45±0.07	16.52±0.01	16.51±0.04	16.63±0.11	16.59±0.01	16.75±0.07	16.69±0.10	16.85±0.06	16.76±0.07	17.02±0.02
8	16.46±0.01	16.50±0.01	16.52±0.02	16.65±0.08	16.59±0.06	16.74±0.01	16.69±0.01	16.84±0.06	16.77±0.01	17.01±0.03
9	16.46±0.07	16.53±0.04	16.51±0.15	16.62±0.03	16.59±0.08	16.74±0.06	16.68±0.02	16.85±0.07	16.78±0.03	17.02±0.02

Mean ± SD of replicates per treatment

Appendix 55: Effect of Gamma Irradiation on the Free Fatty Acid Content (g/100g) of Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	3.62±0.03	3.64±0.04	3.60±0.02	3.62±0.03	3.66±0.04	3.67±0.03	3.53±0.13	3.74±0.14	3.56±0.01	3.79±0.10
2	3.59±0.09	3.66±0.06	3.62±0.03	3.63±0.08	3.51±0.10	3.71±0.11	3.53±0.02	3.75±0.05	3.58±0.04	3.78±0.01
3	3.60±0.07	3.66±0.07	3.61±0.11	3.65±0.11	3.51±0.11	3.72±0.15	3.54±0.20	3.73±0.11	3.58±0.25	3.76±0.24
4	3.60±0.17	3.60±0.05	3.62±0.13	3.63±0.07	3.52±0.20	3.72±0.18	3.53±0.01	3.74±0.01	3.56±0.16	3.77±0.04
5	3.61±0.03	3.65±0.03	3.62±0.12	3.66±0.06	3.52±0.13	3.71±0.06	3.52±0.08	3.75±0.14	3.57±0.11	3.78±0.04
6	3.61±0.03	3.63±0.02	3.59±0.07	3.64±0.02	3.55±0.06	3.75±0.07	3.53±0.04	3.75±0.05	3.58±0.02	3.76±0.00
7	3.62±0.00	3.60±0.02	3.62±0.02	3.65±0.01	3.53±0.00	3.74±0.01	3.51±0.00	3.78±0.04	3.56±0.02	3.76±0.04
8	3.58±0.01	3.60±0.01	3.61±0.03	3.64±0.01	3.54±0.08	3.77±0.00	3.52±0.04	3.77±0.01	3.56±0.00	3.78±0.01
9	3.59±0.02	3.60±0.00	3.62±0.04	3.64±0.06	3.51±0.05	3.75±0.05	3.54±0.01	3.78±0.00	3.55±0.03	3.78±0.03

Mean ± SD of replicates per treatmen

Appendix 56: Effect of Gamma Irradiation on the Free Fatty Acid Content (g/100g) of Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.95±0.06	1.96±0.01	1.95±0.04	2.57±0.08	2.03±0.03	2.72±0.03	2.04±0.07	2.77±0.06	2.06±0.06	2.89±0.04
2	1.96±0.13	1.97±0.04	1.97±0.16	2.54±0.16	2.01±0.06	2.71±0.04	2.04±0.05	2.77±0.09	2.07±0.09	2.90±0.11
3	1.95±0.04	1.95±0.08	1.96±0.06	2.56±0.08	2.02±0.00	2.71±0.18	2.01±0.04	2.75±0.05	2.05±0.05	2.87±0.11
4	1.96±0.12	1.96±0.16	1.97±0.20	2.57±0.03	2.02±0.04	2.71±0.01	2.06±0.20	2.77±0.09	2.07±0.09	2.88±0.04
5	1.95±0.08	1.98±0.01	1.99±0.04	2.59±0.14	2.03±0.01	2.70±0.14	2.05±0.07	2.75±0.07	2.05±0.07	2.89±0.06
6	1.98±0.03	1.98±0.01	1.97±0.01	2.62±0.02	2.01±0.09	2.73±0.01	2.08±0.01	2.77±0.00	2.07±0.00	2.91±0.01
7	1.97±0.01	1.97±0.02	1.98±0.00	2.60±0.14	2.99±0.07	2.73±0.11	2.05±0.07	2.76±0.09	2.06±0.09	2.92±0.13
8	1.97±0.06	1.97±0.00	1.97±0.01	2.60±0.15	2.99±0.08	2.72±0.00	2.10±0.01	2.75±0.01	2.09±0.01	2.95±0.07
9	1.96±0.00	1.98±0.06	1.98±0.02	2.61±0.00	2.00±0.01	2.68±0.04	2.08±0.17	2.76±0.02	2.12±0.02	2.92±0.00

Mean ± SD of replicates per treatment

Appendix 57: Effect of Gamma Irradiation on the Free Fatty Acid Content (g/100g) of Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.53±0.04	1.53±0.02	1.64±0.05	1.65±0.04	1.65±0.03	1.74±0.06	1.69±0.08	1.75±0.04	1.68±0.03	1.81±0.02
2	1.53±0.03	1.54±0.06	1.63±0.05	1.63±0.05	1.67±0.02	1.71±0.05	1.69±0.06	1.74±0.01	1.67±0.01	1.76±0.05
3	1.52±0.13	1.54±0.07	1.64±0.07	1.64±0.07	1.65±0.01	1.69±0.23	1.68±0.14	1.76±0.10	1.69±0.01	1.81±0.01
4	1.54±0.06	1.55±0.14	1.63±0.01	1.63±0.03	1.66±0.00	1.70±0.18	1.70±0.10	1.74±0.06	1.68±0.04	1.81±0.02
5	1.53±0.13	1.53±0.16	1.65±0.09	1.60±0.14	1.67±0.03	1.71±0.04	1.67±0.17	1.75±0.01	1.66±0.04	1.76±0.18
6	1.55±0.10	1.55±0.04	1.66±0.00	1.63±0.11	1.72±0.02	1.73±0.00	1.67±0.05	1.78±0.01	1.66±0.01	1.78±0.04
7	1.57±0.04	1.55±0.00	1.72±0.05	1.62±0.07	1.70±0.01	1.74±0.06	1.70±0.15	1.76±0.01	1.68±0.00	1.77±0.06
8	1.56±0.00	1.59±0.08	1.69±0.04	1.62±0.04	1.70±0.00	1.70±0.07	1.70±0.12	1.77±0.01	1.70±0.13	1.78±0.04
9	1.56±0.00	1.55±0.01	1.67±0.02	1.63±0.00	1.71±0.04	1.75±0.01	1.70±0.00	1.78±0.01	1.71±0.17	1.78±0.02

Mean ± SD of replicates per treatment

Appendix 58: Effect of Gamma Irradiation on the Free Fatty Acid Content (g/100g) of Ashanti Pepper

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	1.70±0.11	1.72±0.07	1.86±0.11	2.25±0.14	1.83±0.09	2.43±0.06	1.86±0.11	3.03±0.10	1.93±0.15	3.33±0.08
2	1.73±0.13	1.76±0.06	1.95±0.06	2.22±0.19	1.86±0.09	2.44±0.06	1.87±0.09	3.05±0.31	1.95±0.16	3.40±0.00
3	1.74±0.03	1.75±0.08	1.94±0.08	2.20±0.06	1.84±0.03	2.42±0.13	1.87±0.13	3.04±0.06	1.99±0.11	3.39±0.07
4	1.72±0.16	1.75±0.08	1.96±0.08	2.18±0.27	1.85±0.03	2.43±0.20	1.88±0.01	3.03±0.08	1.94±0.18	3.37±0.00
5	1.71±0.11	1.74±0.01	1.96±0.01	2.21±0.08	1.86±0.03	2.45±0.14	1.86±0.24	3.04±0.03	1.96±0.16	3.35±0.08
6	1.72±0.02	1.73±0.00	1.90±0.00	2.23±0.02	1.86±0.03	2.50±0.01	1.85±0.12	3.06±0.00	1.99±0.08	3.38±0.08
7	1.71±0.10	1.73±0.03	1.97±0.03	2.22±0.00	1.85±0.06	2.52±0.02	1.88±0.00	3.04±0.08	1.96±0.00	3.42±0.05
8	1.72±0.08	1.74±0.01	1.98±0.08	2.25±0.03	1.87±0.09	2.52±0.00	1.90±0.01	3.05±0.07	1.97±0.02	3.38±0.01
9	1.69±0.00	1.72±0.03	1.98±0.00	2.24±0.00	1.91±0.00	2.52±0.04	1.88±0.01	3.08±0.04	1.98±0.02	3.39±0.00

Appendix 59: Effect of Gamma Irradiation on the Moisture Content (g/100g) of Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G		G	W	G	W	G	W	G
Time (Months)										
1	4.75±0.08	4.75±0.06	4.75±0.06	4.74±0.12	4.80±0.01	4.75±0.06	4.69±0.09	4.72±0.04	4.72±0.05	4.73±0.05
2	4.70±0.02	4.72±0.02	4.70±0.13	4.68±0.01	4.74±0.06	4.74±0.06	4.73±0.04	4.73±0.04	4.74±0.04	4.71±0.03
3	4.69±0.11	4.72±0.00	4.66±0.03	4.68±0.11	4.74±0.13	4.74±0.08	4.72±0.05	4.71±0.03	4.73±0.18	4.74±0.09
4	4.69±0.06	4.71±0.05	4.70±0.16	4.67±0.01	4.74±0.06	4.73±0.14	4.73±0.14	4.72±0.07	4.73±0.04	4.76±0.16
5	4.70±0.01	4.71±0.01	4.73±0.08	4.68±0.03	4.77±0.16	4.73±0.04	4.73±0.10	4.72±0.07	4.72±0.05	4.75±0.08
6	4.68±0.03	4.69±0.01	4.69±0.02	4.66±0.04	4.76±0.17	4.75±0.01	4.74±0.06	4.74±0.01	4.73±0.12	4.76±0.08
7	4.69±0.04	4.69±0.01	4.67±0.02	4.67±0.02	4.73±0.04	4.73±0.04	4.73±0.03	4.73±0.04	4.75±0.08	4.78±0.06
8	4.66±0.04	4.68±0.04	4.68±0.03	4.66±0.00	4.72±0.04	4.72±0.09	4.70±0.01	4.73±0.02	4.73±0.01	4.72±0.04
9	4.67±0.03	4.67±0.05	4.67±0.04	4.67±0.02	4.73±0.01	4.72±0.08	4.69±0.01	4.72±0.05	4.74±0.05	4.73±0.00

Mean ± SD of replicates per treatment

Appendix 60: Effect of Gamma Irradiation on the Moisture Content (g/100g) of Coriander

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.41±0.15	6.37±0.06	6.39±0.14	6.36±0.23	6.40±0.09	6.38±0.17	6.40±0.13	6.33±0.11	6.40±0.07	6.38±0.03
2	6.37±0.08	6.34±0.11	6.35±0.03	6.35±0.19	6.35±0.07	6.34±0.06	6.41±0.15	6.28±0.10	6.39±0.07	6.33±0.04
3	6.36±0.18	6.33±0.09	6.38±0.11	6.34±0.11	6.34±0.03	6.34±0.13	6.39±0.13	6.27±0.08	6.38±0.08	6.33±0.01
4	6.36±0.16	6.32±0.07	6.31±0.13	6.34±0.04	6.36±0.09	6.33±0.10	6.38±0.04	6.29±0.19	6.37±0.07	6.32±0.07
5	6.37±0.01	6.31±0.13	6.36±0.11	6.33±0.07	6.34±0.10	6.33±0.04	6.39±0.12	6.28±0.13	6.36±0.08	6.32±0.09
6	6.35±0.13	6.32±0.02	6.34±0.06	6.33±0.04	6.34±0.04	6.34±0.04	6.38±0.01	6.25±0.08	6.37±0.07	6.22±0.01
7	6.36±0.08	6.33±0.04	6.36±0.04	6.32±0.03	6.33±0.04	6.33±0.07	6.37±0.03	6.25±0.01	6.34±0.01	6.26±0.00
8	6.36±0.02	6.30±0.04	6.35±0.07	6.33±0.01	6.34±0.04	6.34±0.06	6.35±0.12	6.26±0.06	6.32±0.06	6.26±0.02
9	6.34±0.06	6.29±0.01	6.35±0.07	6.33±0.04	6.34±0.14	6.33±0.01	6.37±0.00	6.24±0.01	6.33±0.02	6.27±0.01

Mean ± SD of replicates per treatment

Appendix 61: Effect of Gamma Irradiation on the Moisture Content (g/100g) of Ginger.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.07±0.05	6.08±0.18	6.10±0.14	5.94±0.20	5.91±0.06	6.03±0.03	5.95±0.11	5.94±0.04	5.95±0.08	5.95±0.04
2	5.95±0.00	5.90±0.01	5.98±0.04	5.91±0.15	5.85±0.08	5.89±0.01	5.91±0.08	5.82±0.10	5.94±0.06	5.89±0.14
3	5.95±0.28	5.90±0.14	5.97±0.06	5.85±0.07	5.83±0.11	5.88±0.12	5.90±0.14	5.81±0.25	5.92±0.04	5.87±0.04
4	5.97±0.11	5.85±0.20	5.97±0.01	5.89±0.16	5.84±0.10	5.88±0.04	5.90±0.10	5.80±0.14	5.95±0.16	5.88±0.10
5	5.96±0.03	5.90±0.14	5.97±0.12	5.89±0.16	5.85±0.11	5.89±0.13	5.91±0.02	5.81±0.11	5.93±0.02	5.89±0.09
6	5.94±0.06	5.89±0.01	5.95±0.01	5.79±0.02	5.82±0.02	5.84±0.08	5.89±0.02	5.80±0.01	5.90±0.03	5.89±0.12
7	5.96±0.01	5.88±0.01	5.95±0.00	5.74±0.01	5.84±0.01	5.88±0.09	5.89±0.04	5.75±0.07	5.91±0.00	5.86±0.14
8	5.96±0.04	5.86±0.00	5.96±0.01	5.77±0.02	5.84±0.00	5.86±0.07	5.88±0.00	5.77±0.00	5.90±0.01	5.86±0.10
9	5.95±0.01	5.87±0.01	5.94±0.00	5.64±0.02	5.73±0.01	5.87±0.02	5.90±0.01	5.77±0.02	5.89±0.13	5.89±0.13

Mean ± SD of replicates per treatment

Appendix 62: Effect of Gamma Irradiation on the Moisture Content (g/100g) of Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.66±0.06	6.68±0.18	6.63±0.18	6.62±0.05	6.67±0.05	6.60±0.14	6.64±0.07	6.66±0.06	6.67±0.07	6.66±0.03
2	6.57±0.08	6.54±0.06	6.65±0.05	6.52±0.04	6.64±0.01	6.57±0.08	6.61±0.13	6.62±0.05	6.64±0.08	6.58±0.04
3	6.56±0.06	6.51±0.08	6.64±0.14	6.52±0.15	6.62±0.02	6.55±0.17	6.60±0.01	6.60±0.14	6.63±0.11	6.56±0.14
4	6.57±0.05	6.51±0.15	6.63±0.02	6.51±0.08	6.63±0.02	6.57±0.13	6.60±0.14	6.60±0.03	6.63±0.14	6.57±0.04
5	6.57±0.17	6.50±0.06	6.64±0.14	6.52±0.08	6.64±0.08	6.57±0.10	6.61±0.02	6.64±0.09	6.63±0.04	6.58±0.14
6	6.55±0.00	6.50±0.07	6.64±0.06	6.49±0.04	6.60±0.03	6.50±0.02	6.60±0.04	6.57±0.09	6.60±0.01	6.54±0.06
7	6.54±0.06	6.48±0.04	6.63±0.03	6.48±0.02	6.59±0.01	6.46±0.10	6.55±0.06	6.56±0.02	6.69±0.01	6.54±0.04
8	6.55±0.03	6.46±0.00	6.59±0.05	6.44±0.01	6.53±0.01	6.45±0.02	6.56±0.00	6.53±0.01	6.67±0.01	6.53±0.04
9	6.55±0.00	6.45±0.03	6.56±0.04	6.41±0.01	6.56±0.11	6.44±0.05	6.55±0.02	6.51±0.00	6.66±0.01	6.52±0.02

Mean ± SD of replicates per treatment

Appendix 63: Effect of Gamma Irradiation on the Ash Content (g/100g) of Capsicum.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	4.47±0.06	4.50±0.07	4.53±0.02	4.52±0.11	4.55±0.06	4.56±0.04	4.57±0.05	4.51±0.04	4.57±0.03	4.59±0.01
2	4.50±0.71	4.50±0.22	4.55±0.01	4.56±0.06	4.50±0.07	4.53±0.25	4.53±0.08	4.55±0.64	4.58±0.20	4.54±0.05
3	4.53±0.11	4.53±0.12	4.56±0.06	4.55±0.05	4.53±0.04	4.58±0.03	4.54±0.07	4.57±0.26	4.53±0.32	4.50±0.08
4	4.52±0.08	4.50±0.06	4.53±0.03	4.51±0.08	4.55±0.22	4.53±0.04	4.51±0.01	4.52±0.02	4.53±0.11	4.55±0.07
5	4.50±0.07	4.53±0.01	4.54±0.13	4.52±0.04	4.54±0.08	4.56±0.17	4.50±0.04	4.52±0.03	4.52±0.02	4.50±0.71
6	4.52±0.02	4.55±0.07	4.52±0.02	4.52±0.06	4.54±0.07	4.52±0.03	4.53±0.05	4.52±0.01	4.54±0.08	4.51±0.01
7	4.51±0.01	4.53±0.05	4.50±0.01	4.57±0.03	4.51±0.01	4.50±0.00	4.54±0.00	4.52±0.01	4.53±0.02	4.52±0.00
8	4.55±0.01	4.52±0.06	4.53±0.03	4.53±0.00	4.53±0.01	4.52±0.03	4.55±0.01	4.55±0.01	4.53±0.05	4.50±0.00
9	4.52±0.02	4.54±0.00	4.53±0.02	4.52±0.02	4.54±0.01	4.52±0.00	4.52±0.03	4.55±0.03	4.51±0.00	4.52±0.02

Mean ± SD of replicates per treatment

Appendix 64: Effect of Gamma Irradiation on the Ash Content (g/100g) of Coriander.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	6.50±0.06	6.55±0.14	6.57±0.16	6.56±0.05	6.59±0.13	6.57±0.03	6.59±0.02	6.58±0.04	6.62±0.25	6.62±0.08
2	6.45±0.18	6.62±0.18	6.57±0.05	6.61±0.06	6.62±0.18	6.63±0.25	6.55±0.28	6.64±0.06	6.69±0.13	6.67±0.09
3	6.53±0.11	6.66±0.31	6.71±0.06	6.73±0.04	6.70±0.01	6.68±0.04	6.70±0.02	6.64±0.07	6.70±0.02	6.64±0.06
4	6.53±0.03	6.62±0.07	6.55±0.28	6.67±0.05	6.70±0.15	6.67±0.25	6.68±0.04	6.63±0.11	6.55±0.22	6.67±0.47
5	6.51±0.04	6.52±0.02	6.54±0.05	6.65±0.07	6.68±0.04	6.65±0.07	6.62±0.02	6.63±0.04	6.56±0.29	6.53±0.04
6	6.52±0.04	6.52±0.00	6.52±0.06	6.60±0.11	6.60±0.11	6.62±0.11	6.56±0.06	6.57±0.07	6.57±0.06	6.55±0.05
7	6.53±0.00	6.51±0.04	6.54±0.01	6.52±0.03	6.54±0.03	6.56±0.04	6.57±0.05	6.57±0.01	6.58±0.05	6.57±0.05
8	6.52±0.03	6.54±0.01	6.54±0.08	6.52±0.01	6.51±0.01	6.54±0.00	6.56±0.03	6.56±0.00	6.55±0.01	6.56±0.03
9	6.53±0.00	6.53±0.01	6.52±0.00	6.52±0.01	6.53±0.01	6.53±0.00	6.54±0.00	6.55±0.01	6.57±0.01	6.57±0.00

Mean ± SD of replicates per treatment

Appendix 65: Effect of Gamma Irradiation on the Ash Content (g/100g) of Ginger.

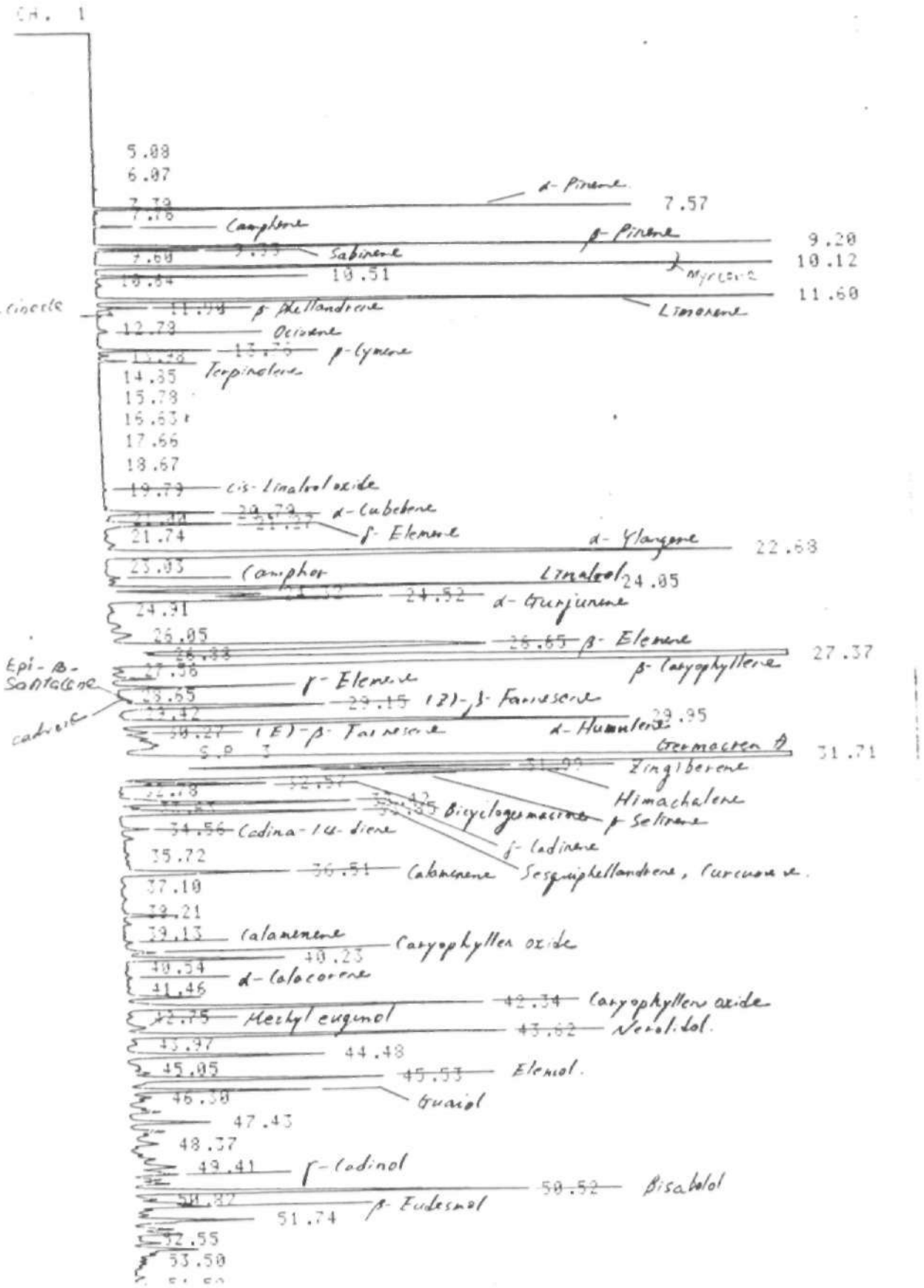
Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	5.99±0.01	6.00±0.04	6.01±0.01	6.00±0.05	6.00±0.01	6.01±0.01	5.99±0.01	5.99±0.02	5.99±0.02	6.01±0.01
2	5.97±0.02	6.01±0.01	6.01±0.01	6.01±0.01	5.99±0.01	6.01±0.01	5.99±0.00	5.99±0.01	6.01±0.01	6.00±0.01
3	6.00±0.03	6.02±0.01	6.00±0.01	6.00±0.01	6.00±0.01	6.01±0.01	6.00±0.00	6.00±0.01	5.99±0.01	6.02±0.03
4	5.97±0.01	6.00±0.02	6.00±0.01	5.99±0.01	6.00±0.01	6.00±0.00	6.00±0.00	6.00±0.00	6.01±0.01	6.00±0.02
5	5.99±0.02	6.00±0.00	5.99±0.01	6.01±0.01	6.00±0.00	5.99±0.00	6.01±0.01	6.00±0.01	6.00±0.04	6.00±0.00
6	5.99±0.01	5.97±0.11	5.97±0.01	6.01±0.01	5.96±0.10	6.02±0.02	6.03±0.01	5.98±0.00	5.97±0.01	5.98±0.03
7	5.93±0.06	5.98±0.00	6.00±0.00	5.99±0.04	5.97±0.01	6.01±0.00	6.00±0.04	5.98±0.03	5.99±0.04	5.97±0.01
8	6.00±0.00	5.98±0.03	5.97±0.01	5.98±0.00	6.00±0.00	5.97±0.01	6.03±0.02	5.98±0.00	5.97±0.01	5.94±0.08
9	5.98±0.01	5.98±0.00	5.99±0.01	6.00±0.00	5.97±0.01	5.96±0.00	5.97±0.01	6.00±0.03	5.96±0.00	6.03±0.01

Mean ± SD of replicates per treatment

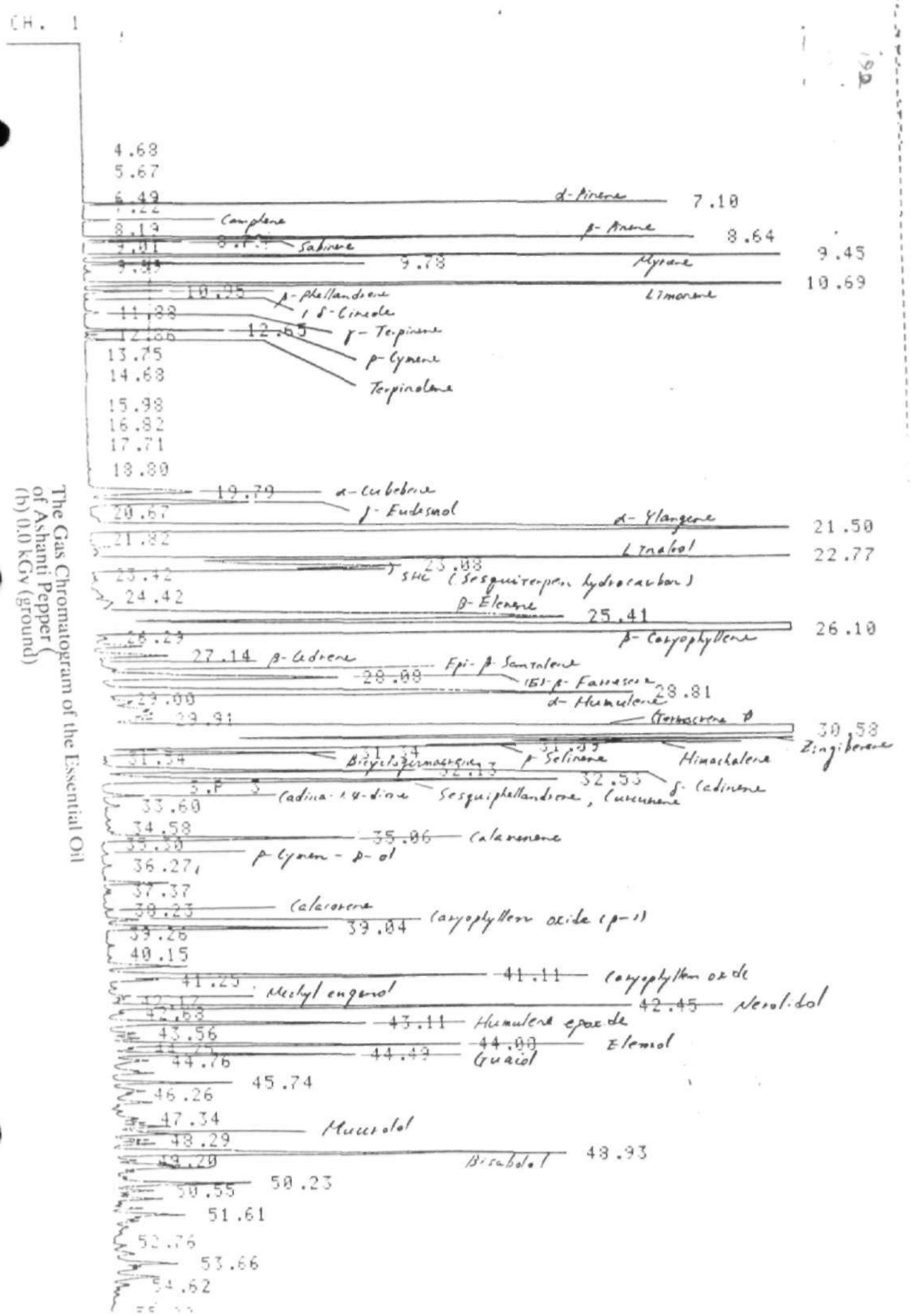
Appendix 66: Effect of Gamma Irradiation on the Ash Content (g/100g) of Ashanti Pepper.

Dose	0.0 kGy		2.5 kGy		5.0 kGy		7.5 kGy		10.0 kGy	
Treatment	W	G	W	G	W	G	W	G	W	G
Time (Months)										
1	7.53±0.04	7.55±0.01	7.59±0.01	7.56±0.04	7.56±0.03	7.58±0.02	7.57±0.05	7.56±0.03	7.57±0.02	7.57±0.04
2	7.55±0.14	7.57±0.04	7.57±0.03	7.58±0.03	7.63±0.25	7.58±0.03	7.58±0.02	7.60±0.05	7.59±0.01	7.59±0.08
3	7.61±0.23	7.59±0.01	7.57±0.03	7.57±0.05	7.56±0.05	7.56±0.06	7.59±0.05	7.56±0.07	7.58±0.03	7.60±0.01
4	7.58±0.14	7.63±0.01	7.58±0.06	7.55±0.07	7.51±0.08	7.57±0.05	7.54±0.06	7.60±0.01	7.52±0.04	7.55±0.07
5	7.69±0.12	7.60±0.02	7.59±0.03	7.52±0.01	7.59±0.41	7.59±0.01	7.51±0.03	7.52±0.02	7.59±0.06	7.55±0.08
6	7.57±0.05	7.60±0.10	7.56±0.03	7.53±0.00	7.52±0.04	7.51±0.01	7.52±0.01	7.54±0.01	7.56±0.03	7.54±0.00
7	7.59±0.11	7.59±0.06	7.56±0.00	7.55±0.05	7.54±0.00	7.56±0.03	7.54±0.00	7.53±0.00	7.57±0.01	7.58±0.00
8	7.60±0.16	7.60±0.02	7.58±0.00	7.62±0.01	7.55±0.02	7.54±0.00	7.56±0.04	7.55±0.01	7.55±0.01	7.56±0.00
9	7.66±0.04	7.62±0.01	7.61±0.00	7.58±0.08	7.58±0.00	7.55±0.07	7.54±0.01	7.56±0.03	7.58±0.00	7.54±0.00

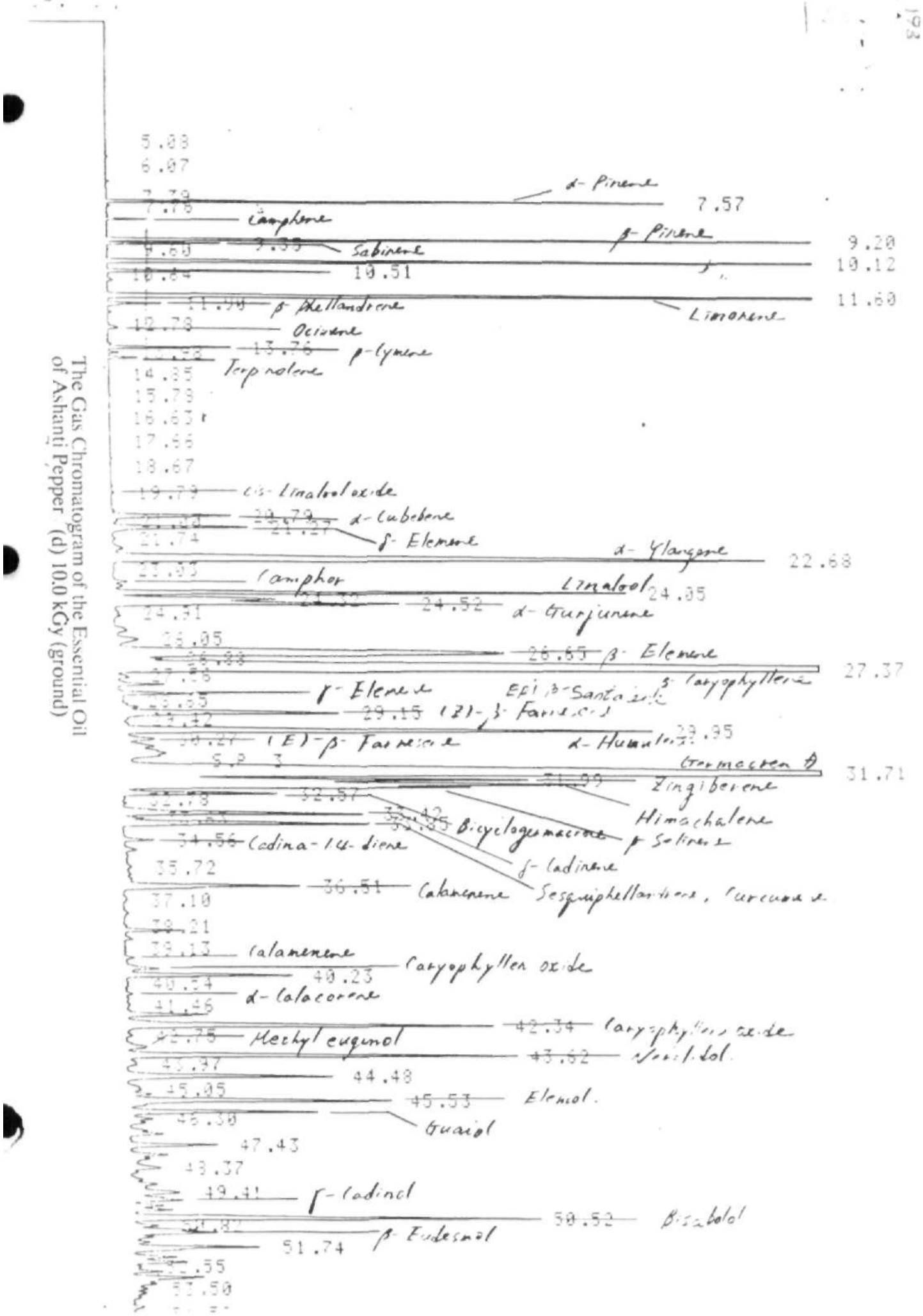
Mean ± SD of replicates per treatment



The Gas Chromatogram of the Essential Oil of Ashanti Pepper (a) 0.0 kGy (whole)

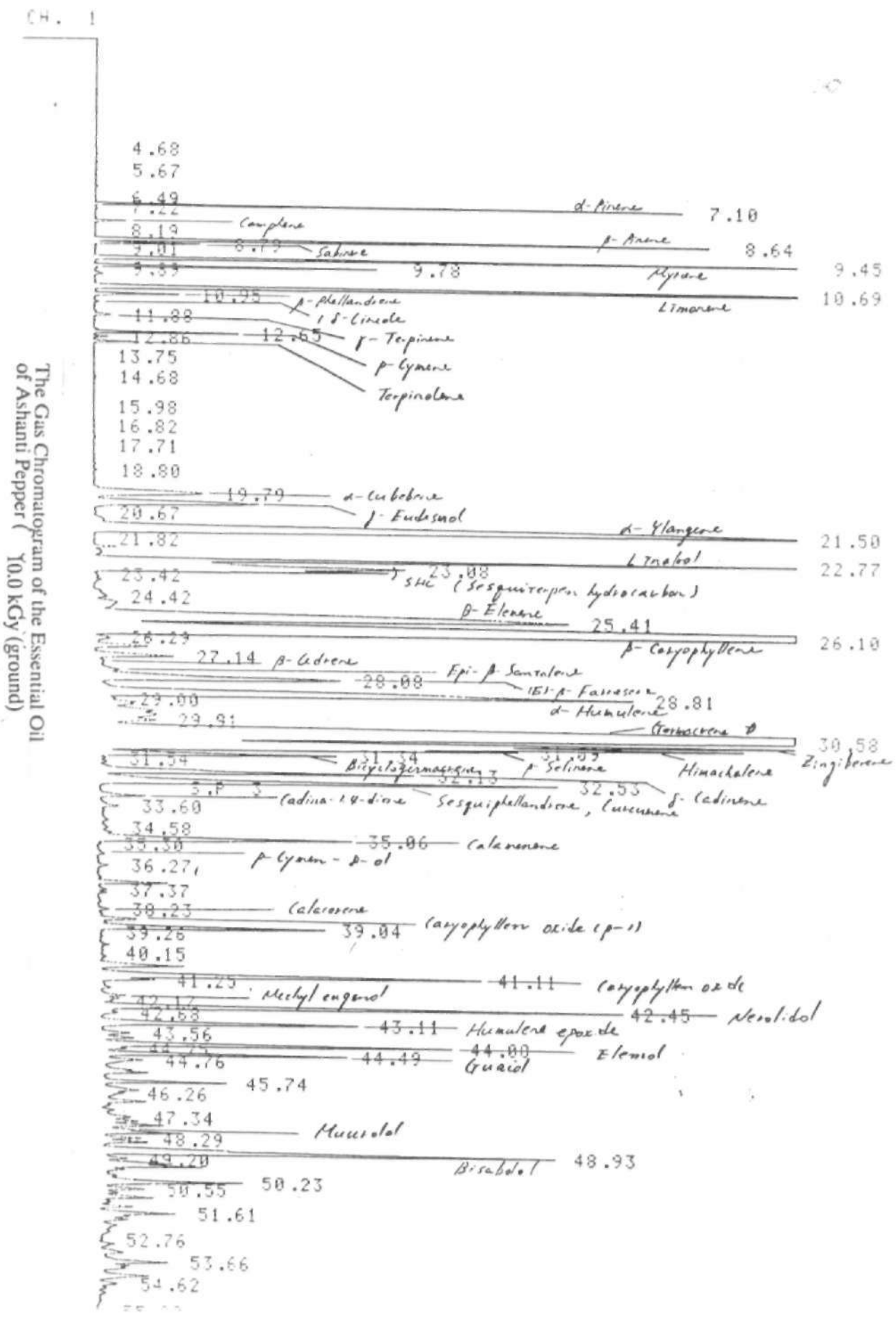


The Gas Chromatogram of the Essential Oil of Ashanti Pepper (b) 0.0 kGy (ground)

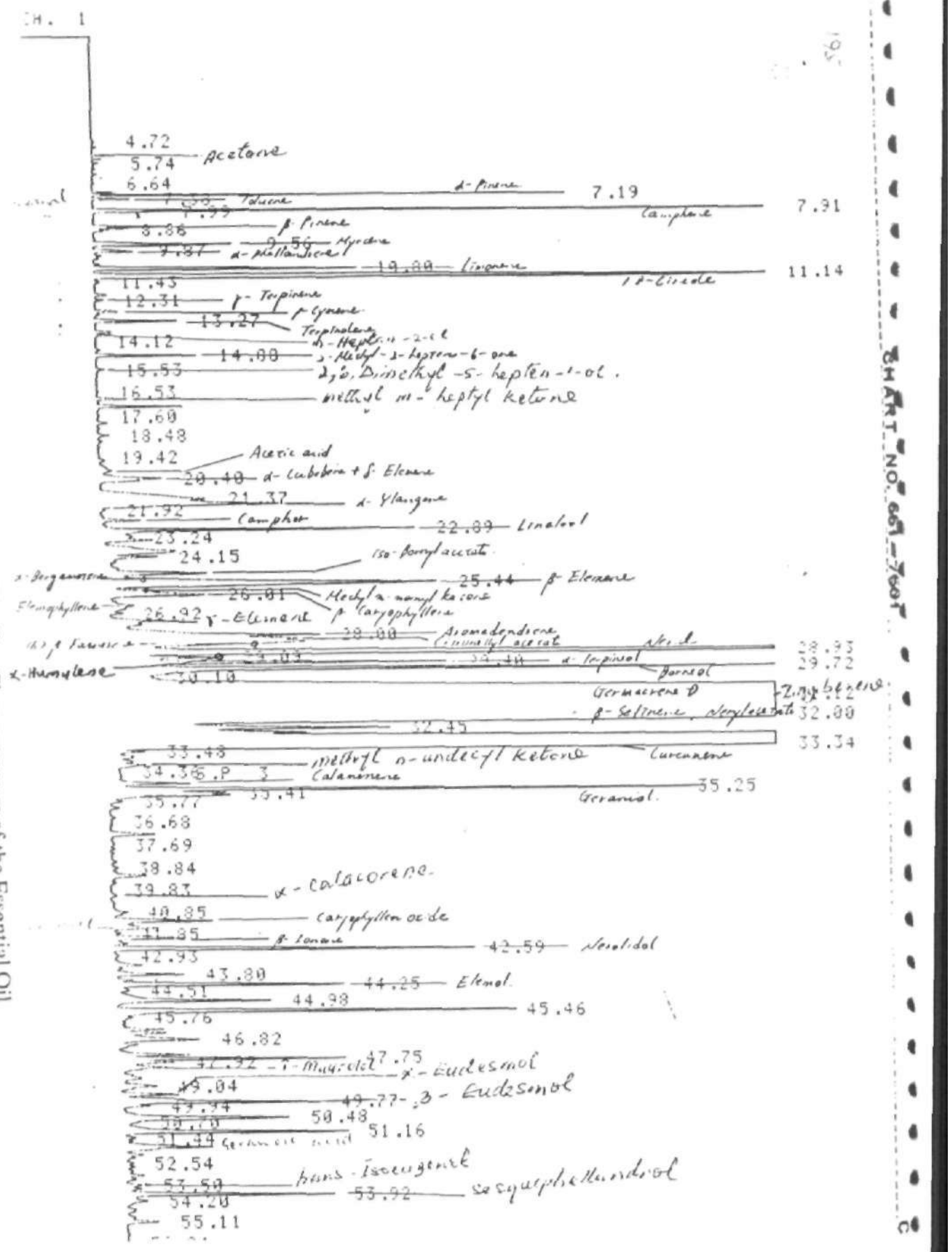


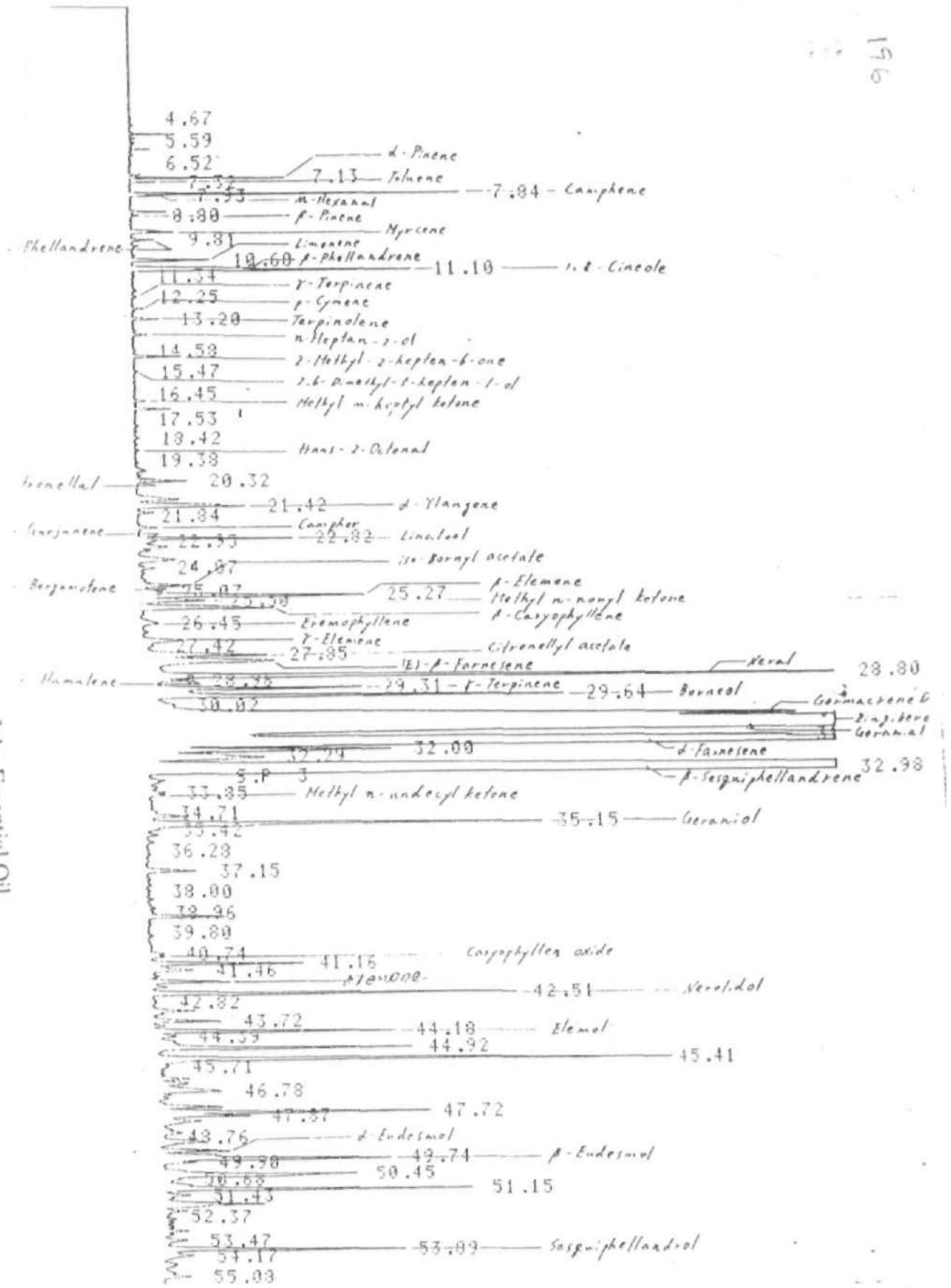
The Gas Chromatogram of the Essential Oil of Ashanti Pepper (d) 10.0 kGy (ground)

The Gas Chromatogram of the Essential Oil of Ashanti Pepper (Y0.0 kGy (ground)

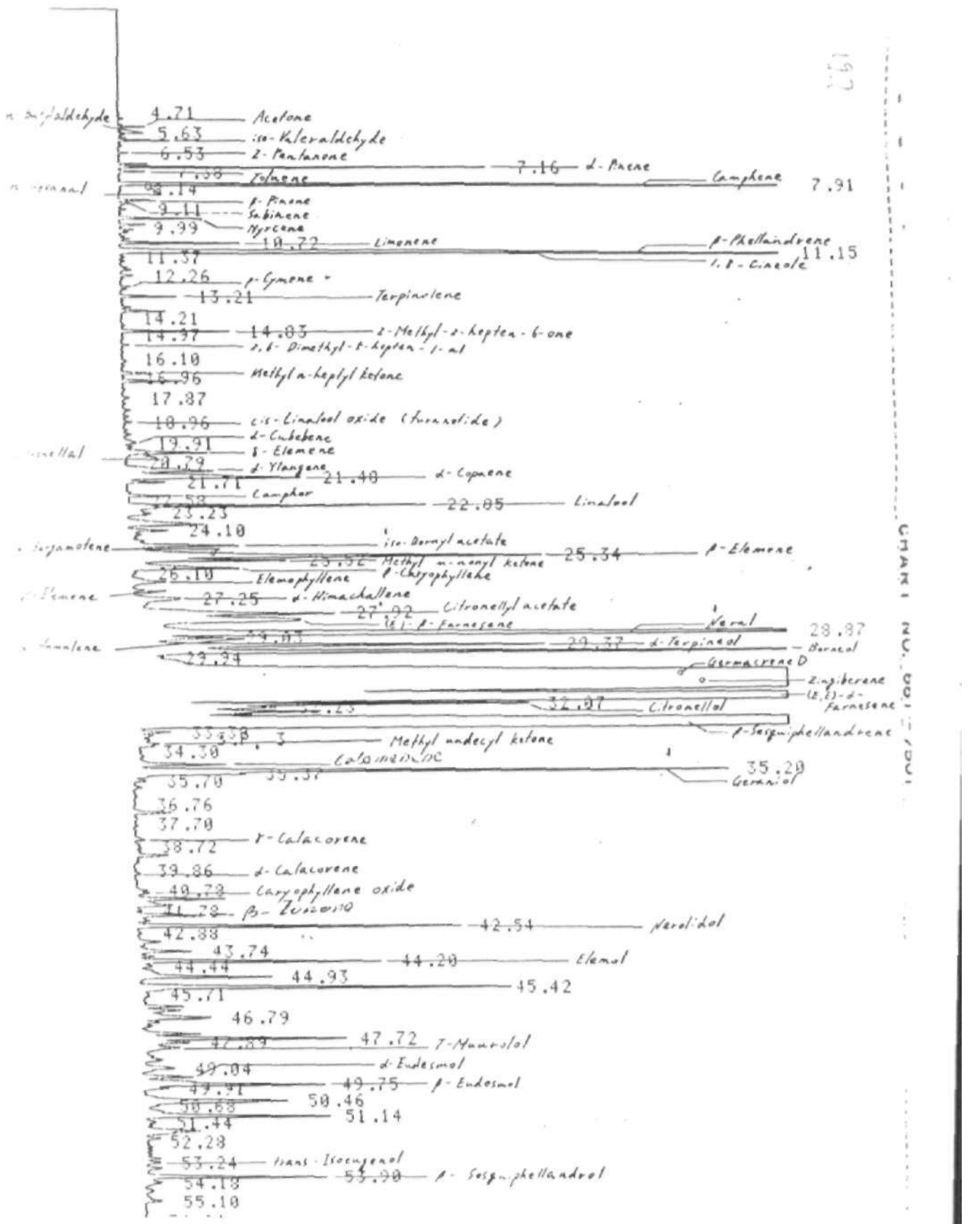


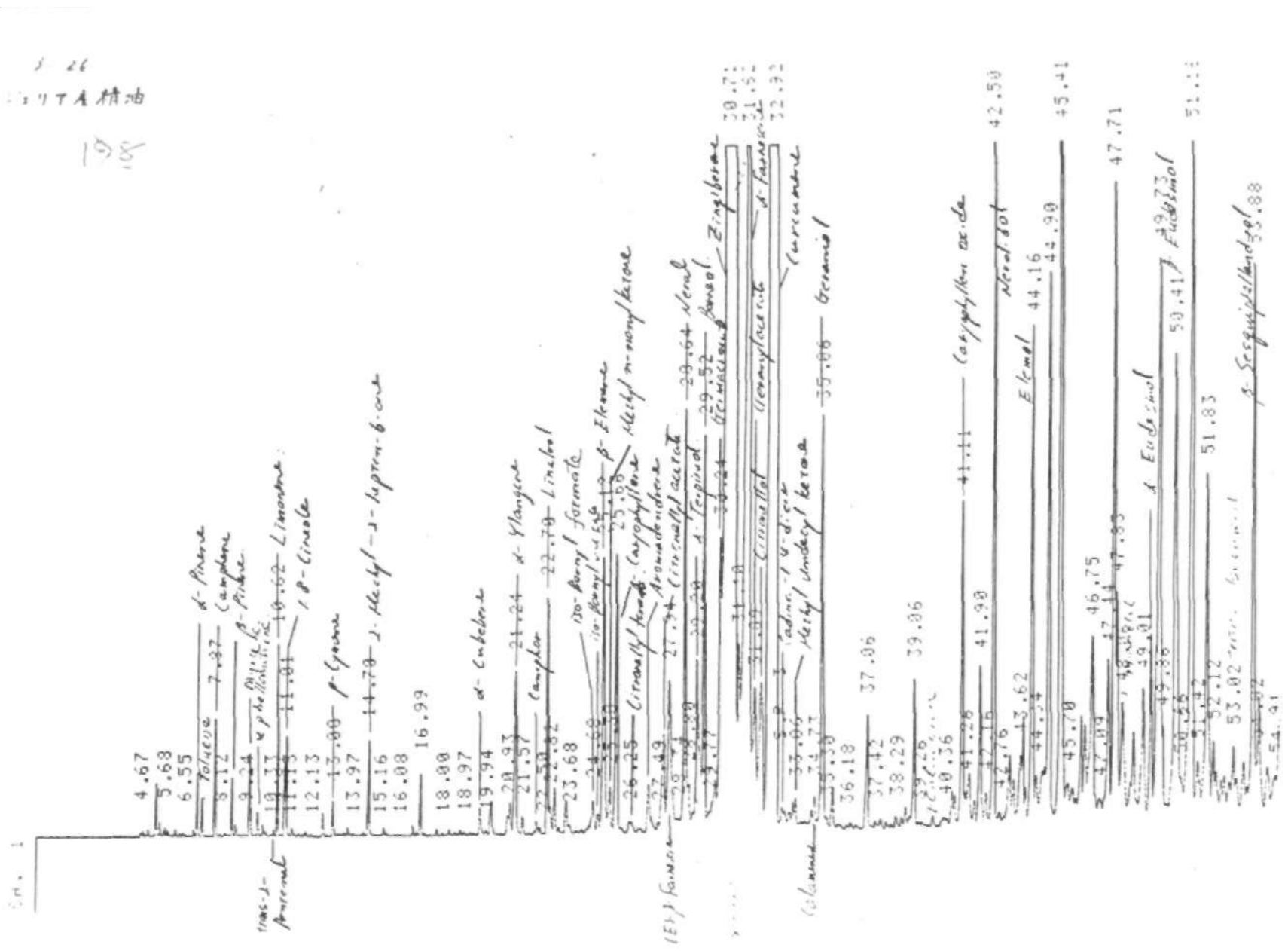
The Gas Chromatogram of the Essential Oil of Ginger (a) 0.0 kGv (whole)



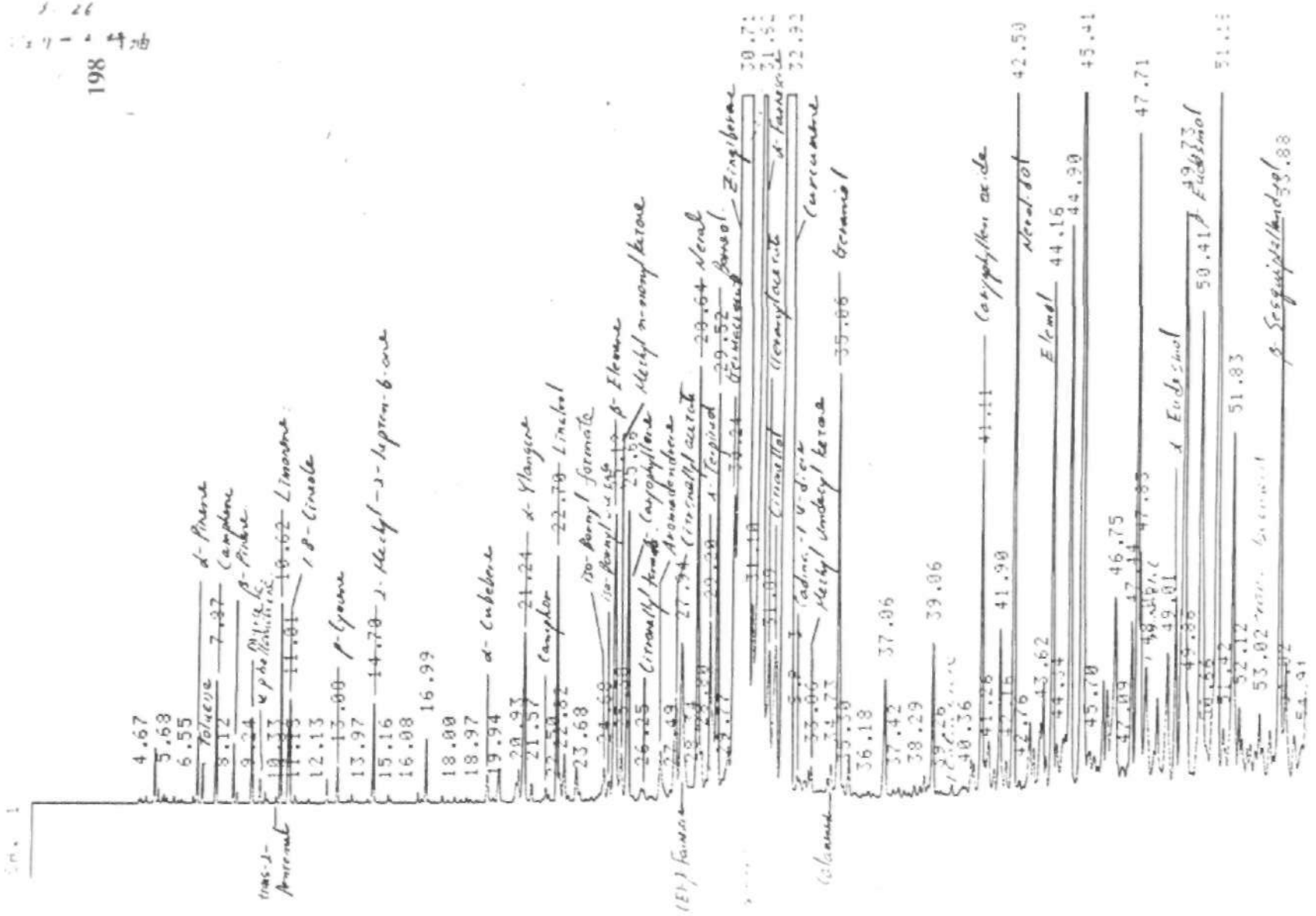


68 The Gas Chromatogram of the Essential Oil of Ginger (
(b) 0.0 kGy (ground)

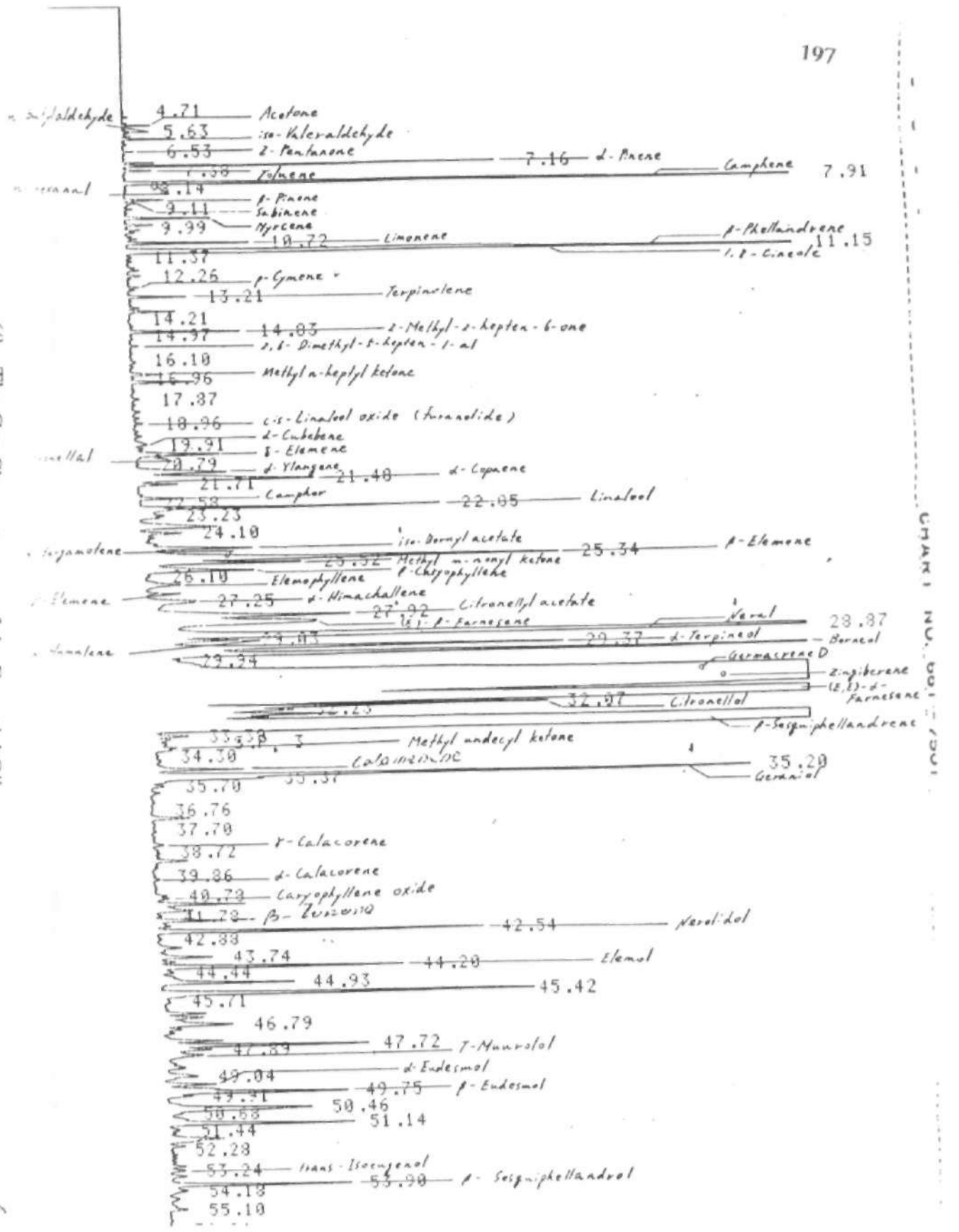

4.71 Acetone
5.63 iso-Valeraldehyde
6.53 2-Pentanone
7.16 d-Pinene
Camphene
7.91
9.14 β-Pinene
9.99 Myrcene
10.72 Limonene
β-Phellandrene
1,8-Cineole
11.15
11.57
12.26 p-Cymene
13.21 Terpinolene
14.21
14.37 14.83 2-Methyl-2-hepten-6-one
2,6-Dimethyl-2-hepten-1-al
16.10
16.96 Methyl n-heptyl ketone
17.87
18.96 cis-Linalool oxide (furanoid)
19.91 d-Cubebene
20.29 β-Elemene
21.40 d-Copaene
21.71 Camphor
22.85 Linalool
23.23
24.10 iso-Bornyl acetate
25.34 β-Elemene
Methyl n-nonyl ketone
β-Caryophyllene
25.10 Elemophyllene
27.25 d-Himachalene
27.92 Citronellyl acetate
(E)-β-Farnesene
Neral
28.87
29.37 d-Terpineol
Borneol
Germacrene D
Zingiberene
(E,E)-d-Farnesene
32.27 Citronellol
β-Sesquiphellandrene
33.38 Methyl undecyl ketone
34.30 Calamenene
35.20
Geraniol
35.70
36.76
37.70
38.72 γ-Calacorene
39.86 d-Calacorene
40.78 Caryophyllene oxide
41.78 β-Eudesmol
42.54 Nerolidol
42.88
43.74
44.20 Elemol
44.44
44.93
45.42
45.71
46.79
47.72 T-Muurolol
d-Eudesmol
49.04
49.75 β-Eudesmol
49.91
50.46
50.68
51.14
51.44
52.28
53.24 trans-Isoeugenol
53.90 β-Sesquiphellandrol
54.18
55.10



68 The Gas Chromatogram of the Essential Oil of Ginger ϒ0.0 kGy (ground)



68 The Gas Chromatogram of the Essential Oil of Ginger 10.0 kGy (ground)



68 The Gas Chromatogram of the Essential Oil of Ginger (c) 10.0 kGy (whole)

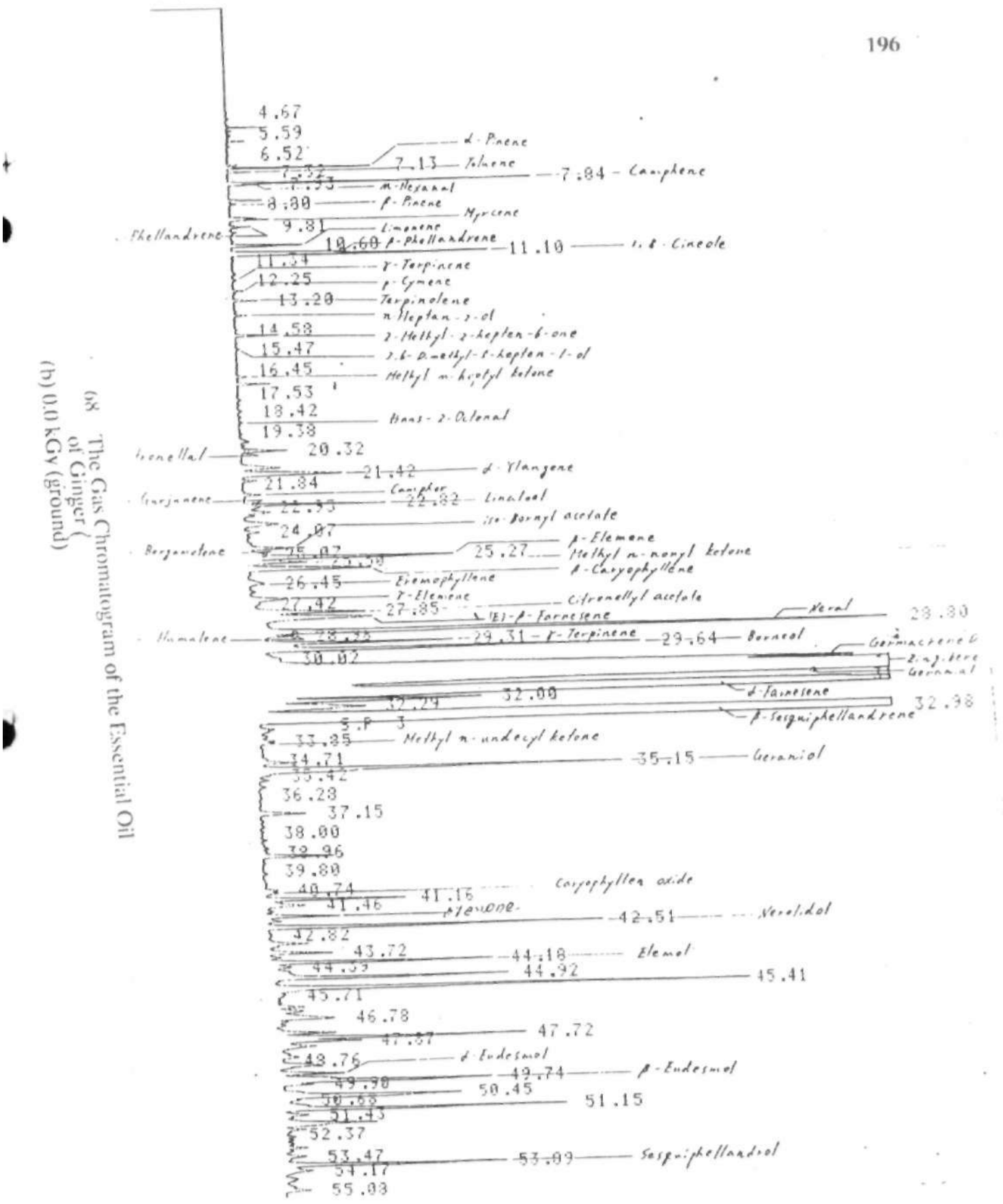
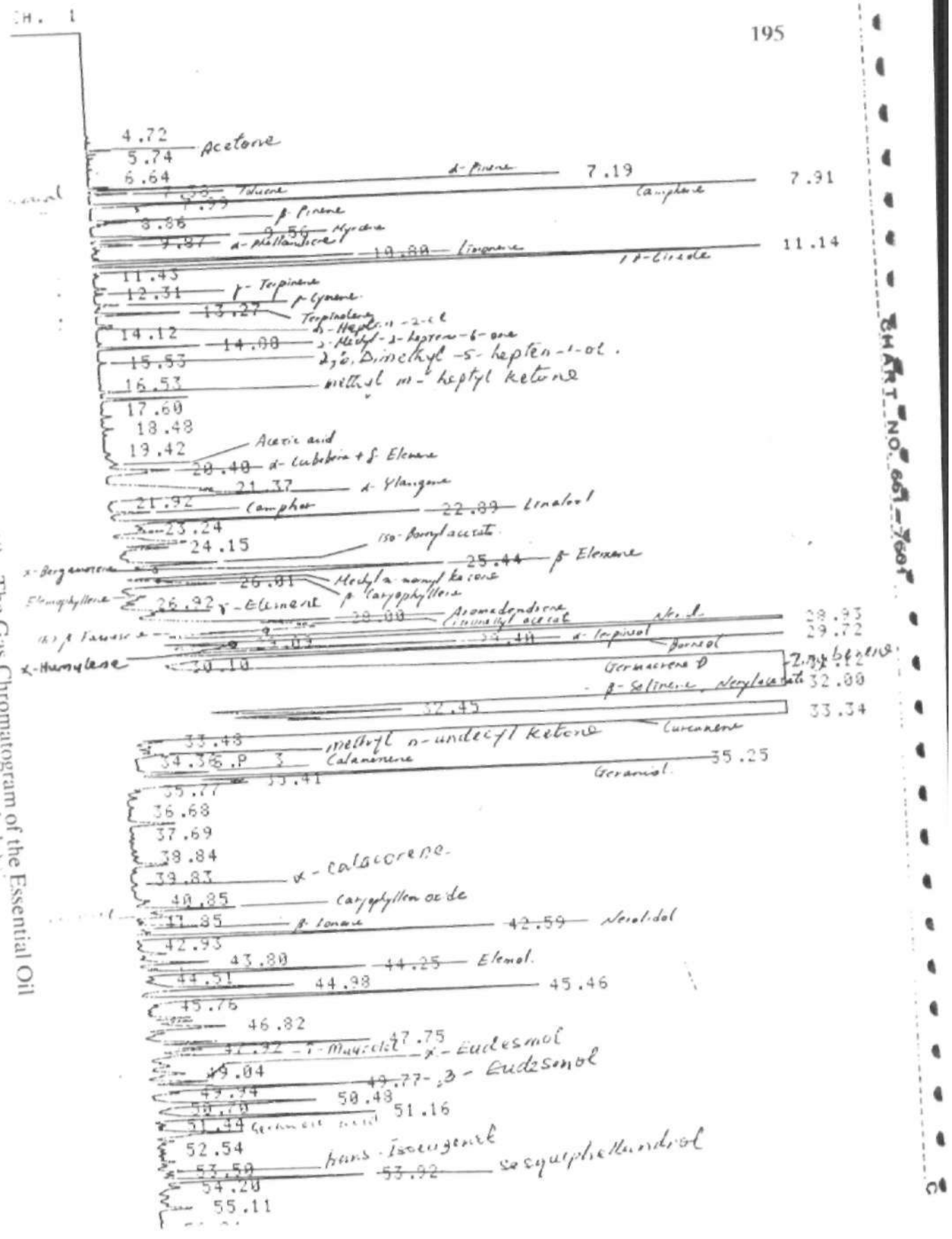
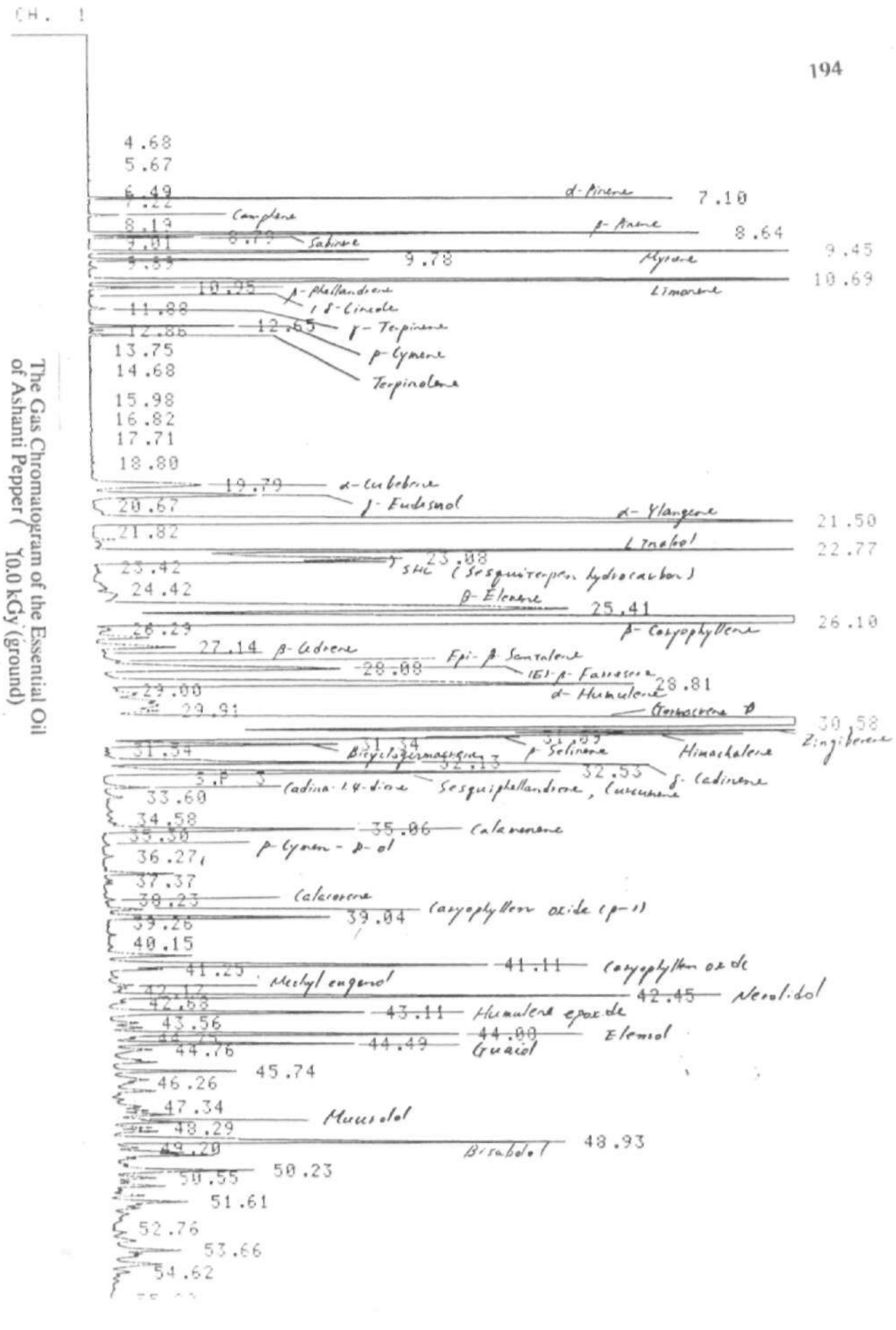


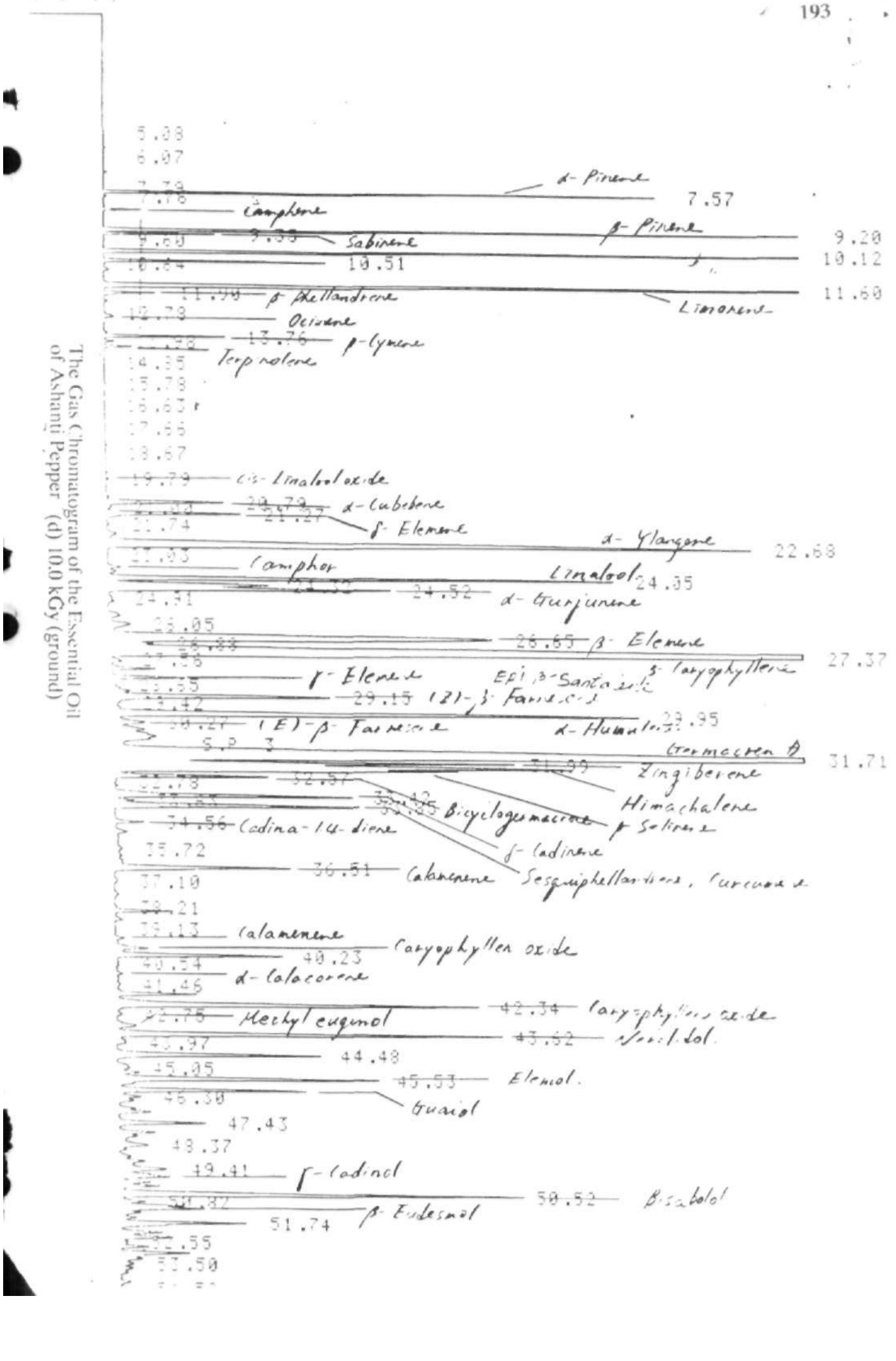
Fig. 68 The Gas Chromatogram of the Essential Oil of Ginger (b) 0.0 kGy (ground)



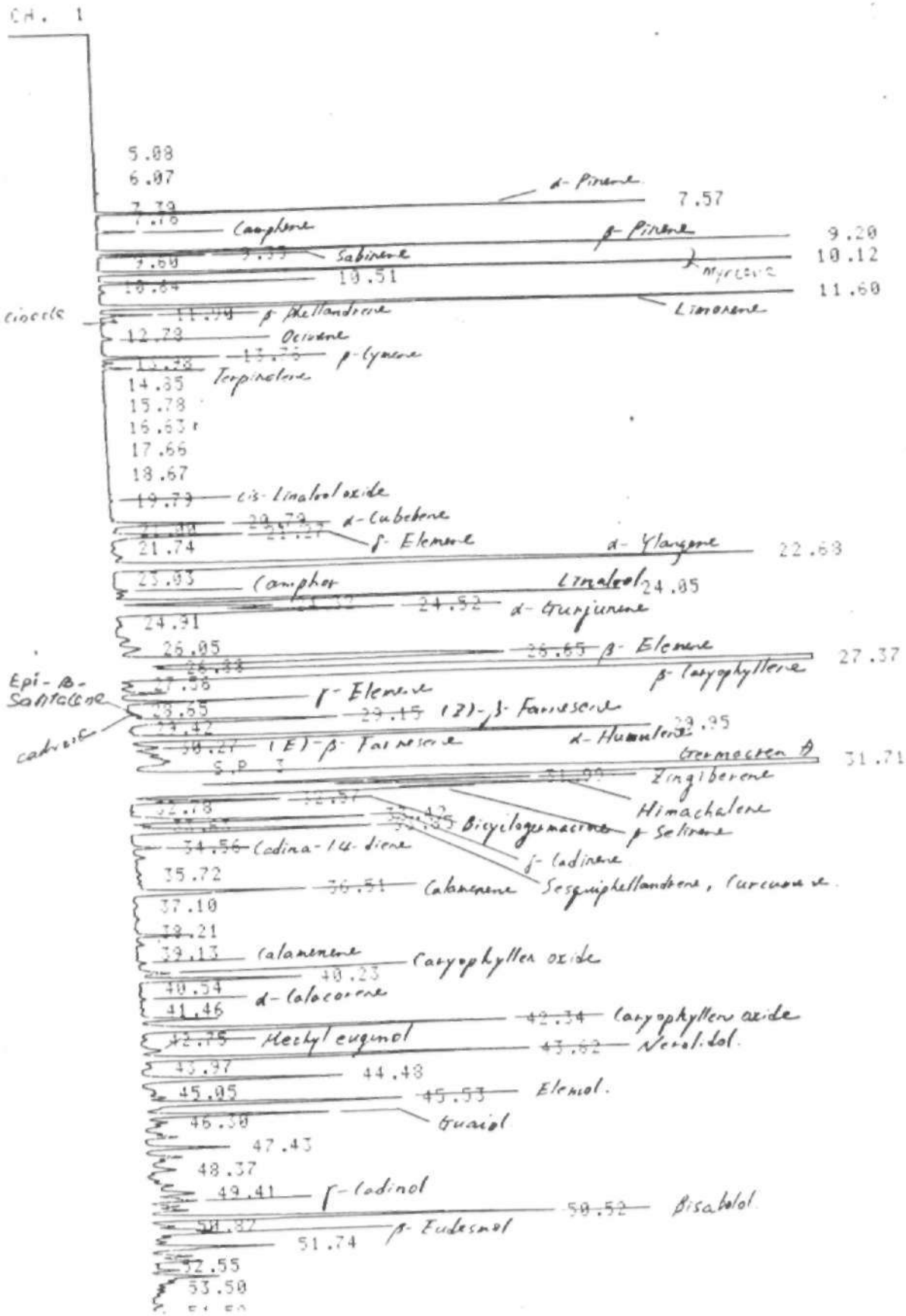
68 The Gas Chromatogram of the Essential Oil of Ginger (a) 0.0 kCv (whole)



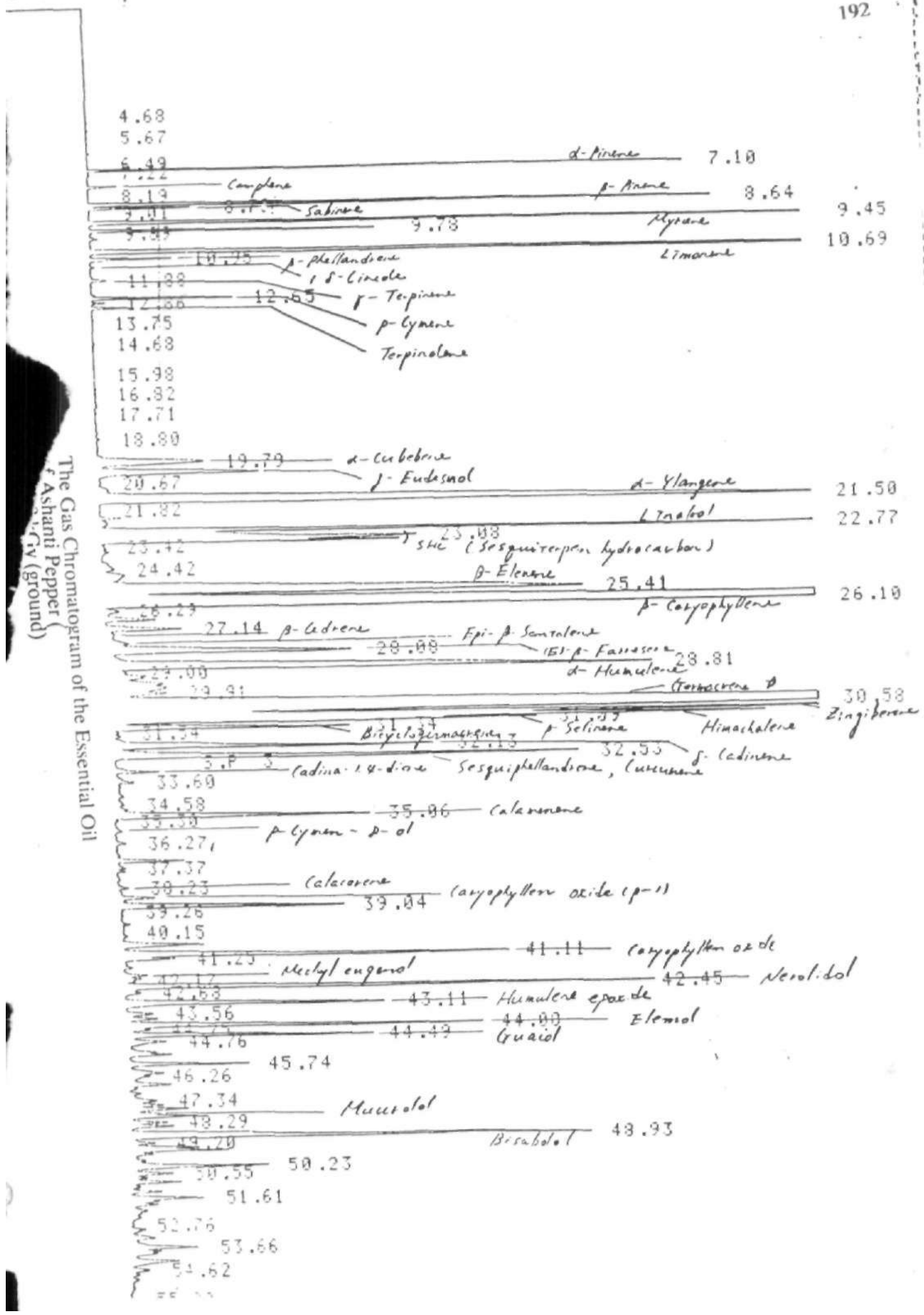
The Gas Chromatogram of the Essential Oil of Ashanti Pepper (Y0.0 kGy (ground)



The Gas Chromatogram of the Essential Oil of Ashanti Pepper (d) 10.0 kGy (ground)



The Gas Chromatogram of the Essential Oil of Ashanti Pepper (a) 0.0 kGy (whole)



The Gas Chromatogram of the Essential Oil of Ashanti Pepper (Piper Guineense Gv (ground)