Afdeling Voedselbestraling

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Verslag van deelname aan een Regional Workshop on Nuclear Techniques in Crop Production, te Piracicaba, Sao Paulo, Brazilië, gehouden van 18-23 november 1984.

Verzendlijst: direkteur, sektorhoofd, direktie VKA, direktie Algemene Zaken (2x), Langerak, DLO (2x), Oosterheert, afd. Microbiologie, IBVL, SI, Van Kooij (IAEA).

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Inleiding:

Op uitnodiging van de Interamerikaanse Commissie voor Nucleaire Energie (CIEN) en de Organisatie van Amerikaanse Staten (OAS) werd door ondergetekende een lezing gehouden op een Regional Workshop on Nuclear Techniques in Crop Production te Piracicaba, Brazilië.
De Workshop werd georganiseerd door het Centrum voor Nucleaire Energie in de Landbouw aan de Universiteit van Sao Paulo.
Het doel van de Workshop was een overzicht te geven van recente en lopende ontwikkelingen op het gebied van nucleaire-, radio-isotopen- en stabiele isotopen technieken ter verbetering van de oogstopbrengst.
Aan de Workshop namen ± 60 personen deel, voornamelijk afkomstig uit Midden- en Zuid-Amerika. Slechts enkele deelnemers (genodigden) waren afkomstig buiten dit gebied.

Programma van de Workshop

De Workshop was verdeeld in de volgende 5 hoofdsecties:

Sectie I en II - Plant Sciences; gebruik van nucleaire en gerelateerde technieken in:
Radiogenetics and Mutation Plant Breeding
Phytopathology
Entomology
Biochemistry
Plant Nutrition.

Sectie III en IV - Soil Sciences, isotoop en stralingsprocedures in:
Soil Fertility and Fertilizer use
Soil Physics
Soil Microbiology.

Sectie V - Disinfestation and Preservation of Foods, Feed and Food Products by radiation.

Elke sectie werd ingeleid door een "Keynote" (thema) spreker. Hiervoor was 1 uur + 10 minuten discussie beschikbaar. Alle andere deelnemers hielden een korte inleiding van 20 minuten. Vrijwel alle lezingen werden gepresenteerd in het Portugees of Spaans. Er vond geen vertaling plaats; dit was een grote handicap voor de alleen maar engels sprekende deelnemers, zoals ondergetekende. De lezingen van de "thema" sprekers werden uitsluitend in het Engels gehouden.
Aan het begin van de Workshop werd van alle lezingen een samenvatting in het Portugees of Spaans en Engels uitgereikt. De volledige tekst zal gepubliceerd worden in een Proceeding van de Workshop.

Openingsceremonie

Op de opening van de Workshop werd het woord gevoerd door:
- De Rector-Magnificus van de Universiteit van Sao Paulo.
- De direkteur van de Nationale Commissie voor Nucleaire Energie (CNEN).
- De direkteur van het Centrum voor Nucleaire Energie in de Landbouw (CENA).
- Vertegenwoordiger van de deelnemers.

Door de verschillende sprekers werd het doel van de Workshop nogmaals belicht: namelijk overdracht van kennis met betrekking tot het vreedzame gebruik van kernenergie ten behoeve van de landbouw.

Kort overzicht van de Workshop

Daar alle lezingen volledig gepubliceerd worden zullen alleen maar enkele aspecten van de Workshop belicht worden.
Ondergetekende was voorzitter en "Keynote" spreker van Sectie V - Disinfestation and Preservation of Foods, Feed and Food Products by Irradiation. Zijn lezing was getiteld: Irradiation of Foodstuffs; Possibilities and Application in Agriculture (zie bijlage).
Uit de discussie bleek, dat er veel belangstelling was voor deze toepassing met betrekking tot houdbaarheidsverlenging, reductie van verliezen en mogelijkheden van export naar Noord-Amerika en Europa.
Verder werden er in deze Sectie de volgende lezingen gegeven:

- F.M. Wiendl (Brazilië) Possibility of using Gamma irradiation in the preservation of "Mangara" Xanthosoma mafafa (Schott).
  Mangara is een knolprodukt, dat in de Braziliaanse keuken gebruikt wordt sinds de koloniale tijd. Een probleem van dit produkt is, de korte bewaarduur, spruitvorming en rotaantasting. Een stralingsdosis van > 75 Gy voorkwamm spruitvorming en rotaantasting, waardoor een bewaring van 8 maanden mogelijk was.
- E.W. Bleinroth (Brazilië) Preservation of potatoes by ^{60}Co gamma radiation.
  Bij 5°, 14° en 25°C werd de spruitvorming met een stralingsdosis van 150 Gy volledig tegengehouden. Het percentage rot nam echter bij 14° en 25°C door een stralingsbehandeling toe.
- F.M. Wiendl. Preservation of onions using ^{60}Co gamma radiation.
  Bij uien was reeds een dosis van 70 Gy voldoende om spruitvorming bij 0°, 10° en 25°C te voorkomen. Tussen bestraalde en onbestraalde uien werd geen chemisch verschil gevonden.
- F.W. Bleinroth. Preservation of Mangos cultivar "Haden" using ^{60}Co radiation.
  Een stralingsdosis van 350 Gy vertraagde de rijping en verlaagde het percentage rot. De reductie van rot werd vergroot door een combinatie van straling en bewaring in de Co_2 atmosfeer.
- M.L.A. Baracat (Brazilië) Utilization of gamma radiation to preserve hydrated fresh macaroni.
  Verse macaroni in plaats van gedroogde is zeer populair in Brazilië. Het hoge vochtgehalte in dit produkt veroorzaakt echter snel schimmelbederf. Het gebruik van natriumsorbaat vertraagt schimmelgroei, maar geeft smaakafwijkingen.
  Toepassing van een stralingsbehandeling met 10 kGy bleek een goed alternatief, zonder dat er een verandering van organoleptische eigenschappen optrad.
- S.H. Nemoto (Brazilië) Increase in "Champignon", Agaricus sp. shelf-life using gamma radiation.
  Een bestralingsbehandeling met 1,75 en 3,5 kGy gaf bij champignons een langere bewaarduur en een duidelijke kwaliteitsverbetering. Een lichte verkleuring van de lamellen na het koken, kon door toevoeging van citroenzuur of vitamine C voorkomen worden.

In Midden- en Zuid-Amerika treedt er naast bederf door micro-organismen ook veel schade op door insektenvraat. In Mexico bedraagt b.v. de schade door de Midfly 2,6 miljard dollar per jaar.
In de Workshop werd dan ook ruimschoots aandacht besteed aan de "sterile insect techniques" door middel van straling.
Een goed overzicht hoe men deze techniek in de praktijk moet aanpakken werd gegeven door dr S. Enkerlin uit Mexico.
Naast Mexico is ook in Brazilië (Wiendl) veel onderzoek op dit gebied gedaan, voornamelijk met betrekking tot optimale dosis voor steriliteit en mortaliteit.
Ook uit de lezingen van andere Secties, zoals Plant- en Soil Sciences, bleek het gebruik van radio-isotopen of straling veel toepassingsmogelijkheden te bieden onder andere met betrekking tot mutaties, N_2-fixatie, fysische bepalingen ten aanzien van de bodemstructuur, waterhuishouding, bemesting, biochemische processen etc.

Bezoeken:

Tijdens de Workshop werden enkele bezoeken gebracht aan Laboratoria, Instituten en Proefstations.

- Entomologisch en technologisch Laboratorium (CENA) USP te Paracicaba
  Sinds jaren worden op dit lab door dr Wiendl met behulp van straling desinfestatieproeven uitgevoerd met verschillende insekten en produkten. Er was dan ook veel kennis aanwezig. Uit zijn onderzoek bleek onder andere, dat de desinfestatiedosis verlaagd kon worden door een stralingsbehandeling in een verrijkte O_2 atmosfeer. De laatste jaren werden in dit lab ook technologische proeven uitgevoerd. Een beperking was het gebrek aan bewaarfaciliteiten. Een andere moeilijkheid was de lab resultaten te introduceren in de praktijk.
- Proefstation voor citrusfruit te Cordeiropolis
  Op dit proefstation werd onderzoek gedaan om met behulp van mutaties, citrusrassen te kweken, die resistent waren tegen fytopathologische organismen en virussen.

- Proefstation voor suikerrietcultures Vinhaca
  De suikerrietcultuur bloeit de laatste jaren weer sterk op in Brazilië, omdat men uit suikerriet alkohol maakt bestemd als brandstof voor auto's. In dit station werd voornamelijk onderzoek gedaan om met behulp van cultuurmaatregelen de produktie van suikerriet te verhogen.
- Instituut voor Levensmiddelen technologie (ITAL) Campinas
  In dit Instituut werden verwerkings- en bewaarproeven uitgevoerd met land- en tuinbouwprodukten en met melk-, zuivel- en vleesprodukten. Daarnaast werden er ook nog analyses uitgevoerd voor de kwaliteitscontrole van levensmiddelen. Het Instiuut was modern en zeer goed geoutilleerd, alleen was er een gebrek aan deskundigen waardoor vele laboratoria onderbezet waren. In het laboratorium van Dr Bleinroth werden bestralingsproeven uitgevoerd met aardappelen, uien, mangoes etc. onder verschillende bewaarcondities. Daar dit Instituut betere contacten met de industrie heeft dan het lab van dr Wiendl werd geadviseerd de bestralingsproeven zoveel mogelijk te combineren en ook "feasibilities" studies op te zetten voor de praktijk.

Algemeen

De Workshop was uitstekend georganiseerd en de meeste lezingen stonden op hoog wetenschappelijk peil. Uit deze Workshop bleek, dat er in Latijns Amerika erg veel potentieel aanwezig is met betrekking tot onderzoek met nucleaire technieken ten behoeve van de Landbouw. Voor een betere coördinatie en uitwisseling van gegevens zou het echter zinvol zijn als ook in Latijns-Amerika, analoog aan de ESNA, een Society voor Nuclear Techniques in Agriculture opgericht werd.
Verder zou het voor het voedselbestralingsprogramma in Brazilië wenselijk zijn als er een Pilot Plant voor Voedselbestraling opgericht werd b.v. bij het ITAL voor de uitvoering van praktijkproeven en het doen van feasibilities studies.

1985-01-30

IRRADIATION OF FOODSTUFFS - POSSIBILITIES AND APPLICATIONS IN AGRICULTURE

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1. INTRODUCTION

It is a well-known fact that all foodstuffs are subject to physiological, chemical, biochemical and microbial decay. In general, the most common form of deterioration of foodstuffs is that caused by microorganisms; but enormous losses are also caused by desiccation, so adequate packaging is very important.

Various preservation methods have been developed over the years in order to prevent microbial decay.
Recently, in addition to the usual methods such as heating, cooling, addition of chemicals, etc., ionizing radiation has also been used, especially in the medical industry. This method of preservation is gaining more and more ground in the food industry because the application of radiation offers certain prospects. Every preservation method has its own specific properties and applications. This applies also to preservation by means of ionizing radiation.

2. PROPERTIES OF RADIATION

For food preservation and irradiation of non-foods only gamma rays and electrons are used, produced by Cobalt-60 sources and electron generators respectively. Gamma rays form part of the electro-magnetic spectrum, which is shown in Fig. 1. In this spectrum the waves of various kind of rays become shorter from left to right.

In addition to UV rays there are röntgen (X) and gamma rays. The shorter the waves, the more penetrating the radiation, due to the higher energy (often expressed as eV).

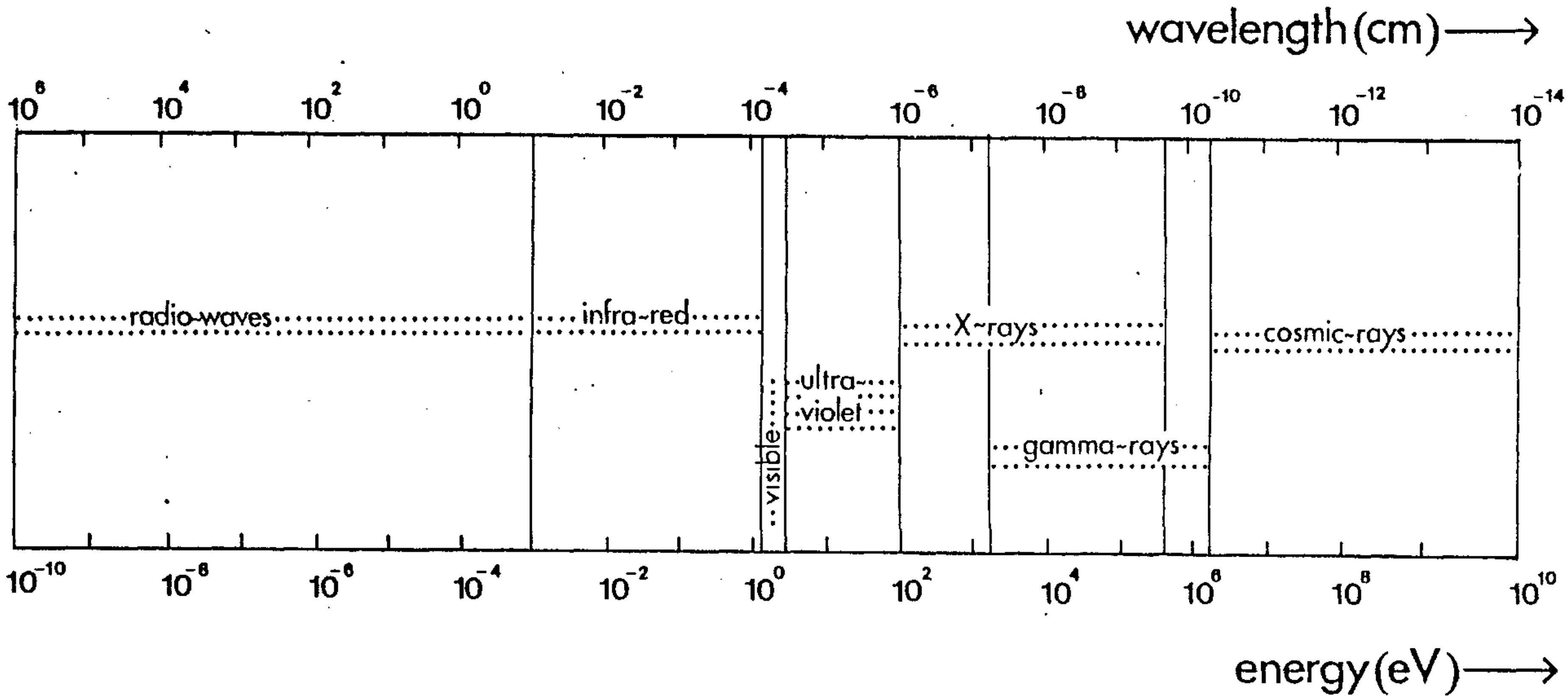

FIG. 1. Electro-magnetic spectrum.

Whereas UV rays cannot penetrate glass (they are absorbed), X-rays and gamma rays penetrate both glass and packaging. The penetrating qualities of gamma rays through packaging are dependent on the following factors:

- the energy of rays;
- the specific mass of the packing material;
- the density of the packed product.

The density of the packed product is usually the most important factor. The dimensions of the packaging intended for an irradiation treatment also depend, in addition to the density of the packed product, on the required uniformity of radiation dose in the packaging: the D_{max}/D_{min} ratio, as shown in Fig. 2. D_{max} is the highest absorbed dose in the packaging and D_{min} the lowest[1].

Uniformity is increased by irradiating the product on two sides. If the product requires great uniformity of radiation dose, i.e. small D_{max}/D_{min} ratio, then the dimensions of the packaging must be adapted. If the product allows a large D_{max}/D_{min} ratio, e.g. 3, as is the case when onions are irradiated to prevent sprouting, then it is possible to use bulk bins with a content of 1 m^3 measuring 1 m x 1 m x 1 m. The required uniformity is determined by the sensitivity of the product to irradiation. In the case of a large difference in D_{max} and D_{min} non-acceptable taste, odour and colour differences can arise in this same packaging. Because of this, irradia-tion in pallet packaging is not always possible. The D_{max}/D_{min} relationship is, therefore, related to the quality requirements of the product.

Not only gamma rays but also electrons are used in food preservation. In general they are less penetrating than gamma rays and are, therefore, only used for products of limited thickness or for surface irradiation. The penetration of electrons into the material takes place according to the Bragg curve.

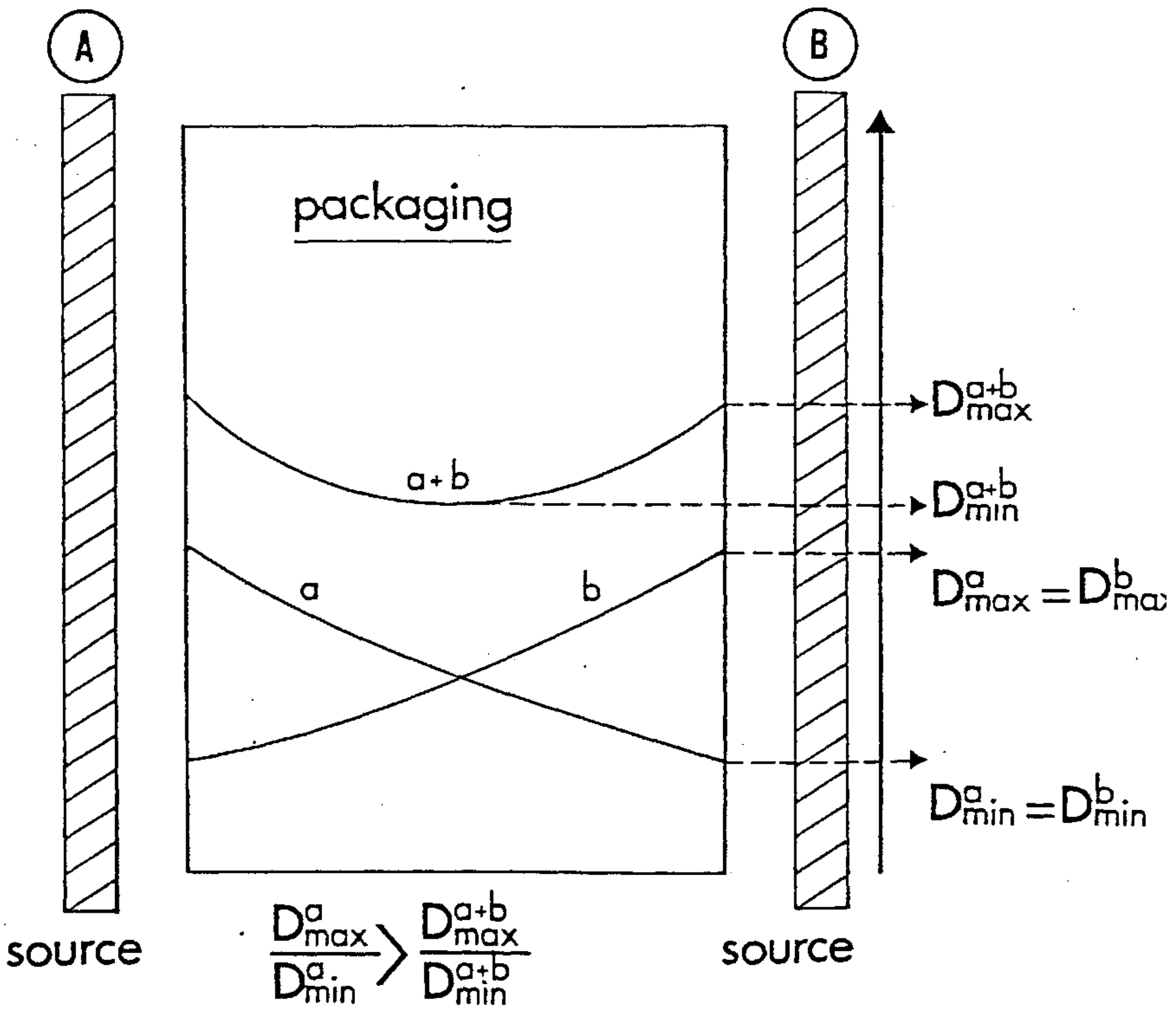

FIG. 2. Penetration curve and dose curve of a double-sided gamma irradiation.

TABLE 1. THE PENETRATION DEPTH OF ELECTRONS IN MATERIAL WITH A DENSITY OF 1, WITH A SINGLE-SIDED AND A DOUBLE-SIDED IRRADIATION

Energy (MeV)	Maximum depth (cm)	Effective packaging thickness (cm)	
		single-sided	double-sided
1	0.5	0.3	0.9
2	1.0	0.6	1.7
4	2.0	1.2	3.5
6	3.0	1.9	5.1
8	4.0	2.5	7.0
10	5.0	3.1	8.9

The penetration of electrons is also determined by the energy of the rays and the density of the material. Because dose distribution runs from 100 to 0%, the concept of effective packaging thickness is incorporated; this is 3/5 of the maximum depth of penetration. With a double-sided irradiation, this packaging thickness is increased[2]. An outline of the penetration depth of electrons with varying energies is given in Table 1.
Table 1 shows that, in comparison with gamma rays, the packaging thickness with electrons, even with high energies, is limited. For bulk packaging, therefore, only gamma rays are suitable.

2.1 Dose

As with heating or cooling treatments, a unit is used for the dose of radiation given. The former unit was the rad (radiation absorbed dose): 1 rad = 100 erg absorbed energy per gram of tissue; 1000 rad = 1 krad; 1000 krad = 1 Mrad. Since the adoption of the new Sl units, the Gy (gray) is used: 1 Gy = 1 Joule/kg = 100 rad.

2.2 The effect of radiation

As far as food preservation is concerned, ionizing radiation has the following three effects:

1. (Micro)biological effect. Radiation can destroy (micro) organisms. Depending on the dose, radiation can

- desinfest (inactivation of insects, larvae, eggs);
- decontaminate (pathogen-free: elimination of non-sporulating pathogenic microorganisms);
- pasteurize (lowering of the bacterial count, shelf-life extension);
- sterilize (destruction of all microorganisms, more or less unlimited shelf-life).

2. Physiological effect. By influencing biochem-ical processes in the product, radiation can produce the following effects:

- inhibition of sprouting (potatoes, onions, carrots);
- delay of growth and ripeness (mushrooms, fruits).

3. Physical effect. Changes in permeability of cell walls (shortening of drying and cooking times in dried vegetables).

How radiation brings about the above-mentioned effects is very complicated. It is assumed that the absorbed energy produces very small molecular changes in tissue, whereby certain biochem-ical processes can be decreased or increased.

How does irradiation influence the shelf-life of fruits and vegetables compared with other preservation methods? This can be shown with the help of Table 2 which compares the effects of cooling, heating, irradiation and food additives on components which govern the shelf-life and quality of fruits and vegetables. These components are:

- the number of microorganisms in and upon the product;
- biochemical processes in the product (senescense, respiration);
- desiccation.

Table 2 shows that cooling does not kill microorganisms, but only delays their growth. The rate of senescence (dissimilation) is delayed by cooling according to the Q_{10} rule. Cooling, however, promotes desiccation because open packaging is necessary to allow the cold to penetrate. The fresh character of a product is maintained by cooling. A heat treatment kills the microorganisms, arrests senescence by the inactivation of enzymes, and promotes desiccation (loss of weight). The product is completely changed by a heat treatment; the fresh character disappears.

TABLE 2. EFFECT OF VARIOUS PRESERVATION METHODS ON THE COMPONENTS GOVERNING SHELF-LIFE AND QUALITY

Components	Preservation methods			
	Cooling[1]	Heating	Radiation[2]	Additives
Microorganisms	±	+	+	+
Senescence	+	+	±	0
Desiccation	−	−	+	0
Product	0	−	0	0 (±)

+ = positive; − = negative; ± = moderate; 0 = no effect.

1. Cooling to 0°C.

2. Dose lower than 5 kGy.

Like heating, an irradiation treatment inactivates most of the microorganisms. It also has a delaying effect on senescence (ripening) by reducing the enzyme activity in the product. The effect of irradiation on senescence is, however, less radical than that of cold or heat. A combination of irradiation with a moderate cooling treatment is, therefore, usually necessary.
No extra desiccation appears with irradiation; it is even possible to irradiate a fresh product in sealed packaging. In such packaging, a modified air composition (low O_2 and high CO_2 content) can develop from the respiratory activity of the product. This kind of gas storage delays senescence, thus giving a longer shelf-life. Like cooling, an irradiation treatment does not change the fresh character of the product (no temperature increase occurs!). So far, no harmful substances have been shown in products which have been preserved by irradiation.

Food additives diminish the number of microorganisms, but generally have no effect on senescence, on desiccation or on the product itself. The application of chemicals, however, leaves residues in and on the product, which may be harmful.

3. POSSIBILITIES OF IRRADIATION

It has been shown that irradiation offers a number of specific possibilities in food preservation, because of the preserving effect without considerable temperature increase. An absorption dose of 10 kGy per hour is equal to 10^4 J kg^{-1} h^{-1}, resulting in an increase in temperature of 2.78°C.

TABLE 3. A SUMMARY OF RADIATION APPLICATION IN FOOD PRESERVATION

Product	Dose (kGy)	Aim
Tuber, bulb and root vegetables	0.02-0.15	inhibition
Grains, grain products, dried fruit	0.2-0.5	desinfestation
Pome and stone fruit, tropical fruit	0.25-1.0[1]	delay of rotting, ripening and storage disease
Pre-packed vegetables	0.5-2.0	prolonged shelf-life
Soft fruit	2.0-2.5	prolonged shelf-life
Canned products	2-10	sterilization (radiation + heat)
Deep-frozen, dried products (raw material)	5-10	decontamination
Non-food	10-50	sterilization

1. Combined with heat (40-55°C).

In the past, irradiation has often been applied as a substitute for cooling. Irradiation, however, requires its own specific technology. In fact, irradiation should be considered as being supplementary to or an improvement of an existing preservation method. It may only totally or partially replace such a method (e.g. refrigeration) if the product does not tolerate that particular treatment (alternative).
Over the years a wide range of possibilities has been developed by irradiation research (see Table 3).

4. CONDITIONS FOR A CORRECT IRRADIATION TREATMENT

To achieve optimal results with the application of irradiation it is desirable to know the marginal conditions. For "living" products such as agricultural and horticultural products, the following factors are important.

- The initial quality of the product (irradiation cannot convert a bad product into a good one).
- Ripening stage: the ripening of a product can only be delayed by irradiation when the fruit is in the preclimacteric stage. In controlling decay, irradiation of ripe fruits is more successful, because in unripe fruits the natural resistance to decay can be reduced by irradiation.

TABLE 4. DECIMAL REDUCTION (D_{10} VALUE) FOR SOME MICROORGANISMS[3]

Species	Dose (kGy)
Pseudomonas spp.	0.10 - 0.20
Escherichia coli (aerobic	0.12 - 0.35
Escherichia coli (anaerobic)	0.20 - 0.45
Salmonella spp.	0.20 - 0.50
Streptococcus faecalis	0.50 - 1.00
Fungus spores (Penicillium, Aspergillus, etc.)	0.50 - 0.70
Bacillus pumilus (spores)	ca. 1.70
Clostridium sporogenes	1.60 - 2.20
Clostridium botulinum	1.50 - 2.50
Micrococcus sodonensis	ca. 1.95
Micrococcus radiodurans	>5.00

- The initial contamination: to apply the optimal dose, knowledge of type and level of the contamination is important. From Table 4 it can be seen that microorganisms have different resistances with regard to irradiation. This resistance is expressed as a D_{10} value (the irradiation dose corresponding with a decimal reduction).

When level and type of contamination are known, it is theoretically possible to calculate a dose at which all microorganisms are inactivated.

- Time of irradiation: for physiological and microbiological reasons the product should be irradiated as soon as possible after harvesting. Investigations have shown that, with ageing of the product, irradiation is less effective. Also, after harvesting, the number of microorganisms increases very rapidly and it is also possible that the microorganisms become more resistant with storage, resulting in the necessity of a higher dose, with all the consequences.
- The packaging must be adapted to the irradiation procedure. Because irradiation does not prevent desiccation, sealed packaging is usually recommended; the product is then also protected against external influences (re-infection).
- Storage and transport conditions. These must also be adapted to both the product and the irradiation procedure. In combination with irradiation a too low storage temperature can stimulate tissue damage.

In "dead" products, such as raw materials, in which few or no enzyme activities are present, the moisture content in the product plays an important role. In the case of a low moisture content, the effect of irradiation on the product and the inactivation of microorganisms is less than when the moisture content is high. In general, a high O_2 content promotes the inactivation of microorganisms by irradiation. However, under anaerobic conditions a higher dose is required for the same microorganisms.

5. APPLICATIONS IN AGRICULTURE

It is impossible to discuss this for all products; a few examples will be given for some fields of application.

5.1 Desinfestation

Grain and grain products, especially from tropical countries, are often infested with insects, larvae and eggs. This causes enormous losses and the countries importing the grain demand stringent quality requirements.

Controlling these pests by means of insecticides such as methylbromide and ethylene dibromide is possible. They are usually introduced into the silos or sprayed onto products packed in jute sacks. This, however, means that re-infestation can occur. The ideal packing for grain and grain products is polypropylene, because it cannot be eaten by insects and the product itself is also protected from damp, etc. Because these bags are impermeable to gases they cannot be gassed with insecticides, but can be treated with gamma rays because these rays can penetrate straight through the packing and the product. Because the packing remains sealed, no re-infestation can occur.
Another advantage of irradiation is that it can control moulds which sometimes cause rotting and produce mycotoxins that are dangerous to health. Desinfestation by radiation is also a "clean" treatment; it leaves no residues as is the case with insecticides.

5.2 Decontamination

Frozen products from animal origin are often contaminated with pathogens such as Salmonella. Frozen vegetables and fruit are often contaminated with yeasts and other bacteria that cause rotting. Because of the more stringent quality requirements, these contaminated products are no longer accepted for either export or consumption. Decontamination is, therefore, essential. Until now the only possibility was heating, but the product loses its fresh character and the quality of the product is seriously diminished (e.g. consistency, colour and taste). Also, heating requires much energy, because the product has to be thawed and re-frozen.

In addition to deep-frozen products, microbial contamination also occurs in dried products such as fruit powders, dried vegetables, herbs, spices and raw materials.
These products form a source of infection during further processing. Decontamination by ethylene oxide is possible, but this is toxic, leaves residues in the product and is forbidden in many countries. Decontamination by gamma rays is, therefore, the simplest solution. An example of this is given in Table 5.

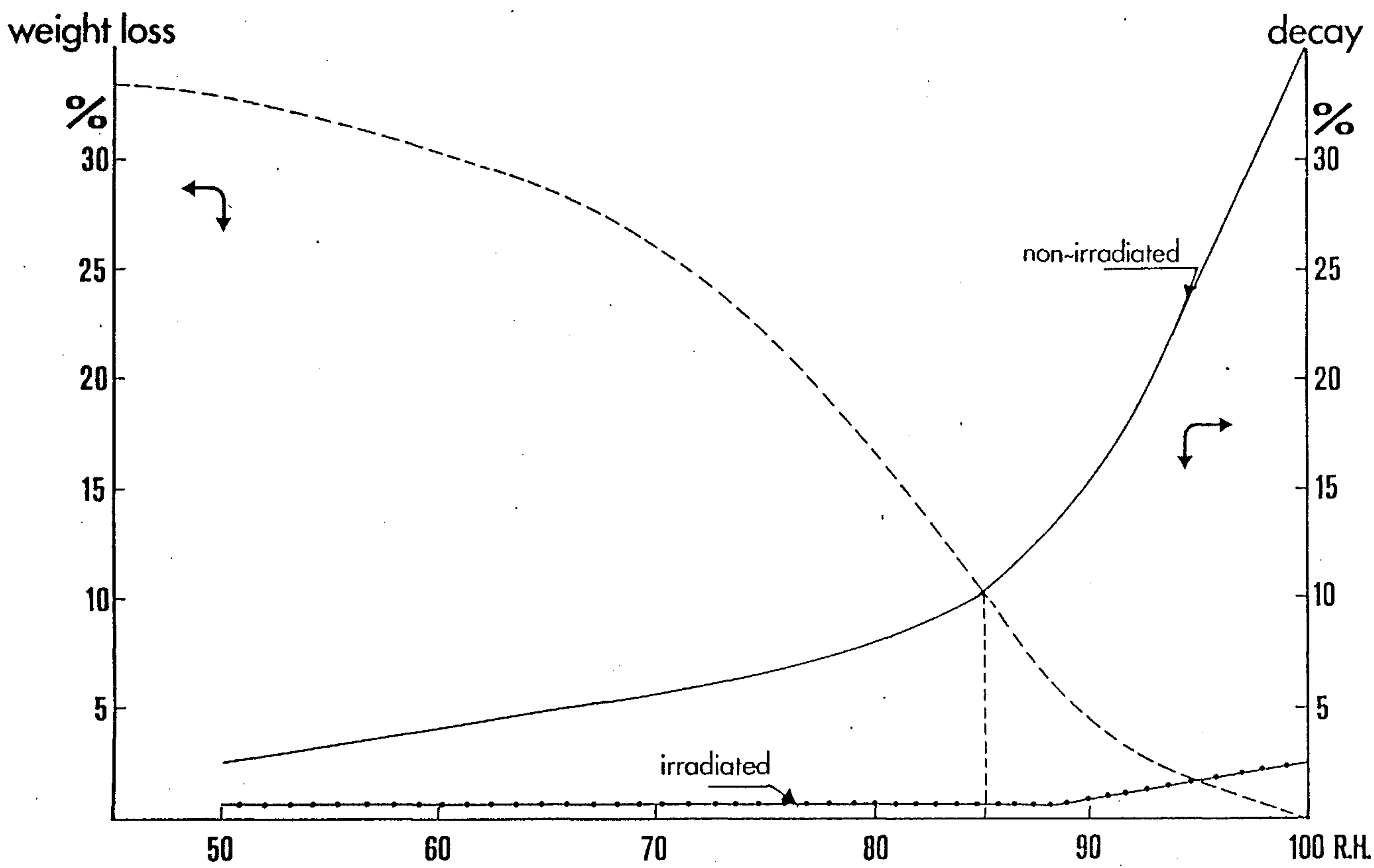

FIG. 3. Effect of relative humidity and irradiation on weight loss and

TABLE 5. EFFECT OF IRRADIATION ON THE MICROBIAL QUALITY OF NON-BLANCHED SILVERSKIN ONIONS. AVERAGE COUNT PER GRAM OF 3 SAMPLES[4].

Dose (kGy)	Viable count	Entero-bacteri-aceae	*Escherichia coli*	*Staphylococcus aureus*	Yeast and moulds
0	7.3×10^{6}	3.2×10^{4}	neg.	<10	2.4×10^{3}
0.9	1.7×10^{6}	2.0×10^{2}	neg.	<10	2.4×10^{3}
1.4	3.8×10^{5}	3.7×10^{1}	neg.	<10	<10
1.8	4.4×10^{5}	<10	neg.	<10	<10
2.7	2.8×10^{3}	<10	neg.	<10	<10

In relation to decontamination, irradiation offers the following advantages:

- treatment in the original packaging
- no re-contamination
- maintenance of fresh or deep-frozen character because there is no temperature rise during irradiation (cold pasteurization)
- no loss of quality
- no residues, as with gassing
- saving of material (no re-packing)
- saving of energy.

5.3 Pasteurization

Most horticultural products deteriorate during storage, transportation and distribution/marketing, due to microbial decay and desiccation. Irradiation can control microbial decay, but not desiccation.
Losses due to desiccation can reach 10 to 30%. This weight loss can largely be prevented by storage in high humidity (Fig. 3). Because during transportation and marketing the humidity is often low, adequate packaging of horticultural products is very important. Various plastics can be used, such as polythene, polypropylene, polyvinyl chloride (pvc), polystyrene and polyvinylidene chlorides (pvdc).

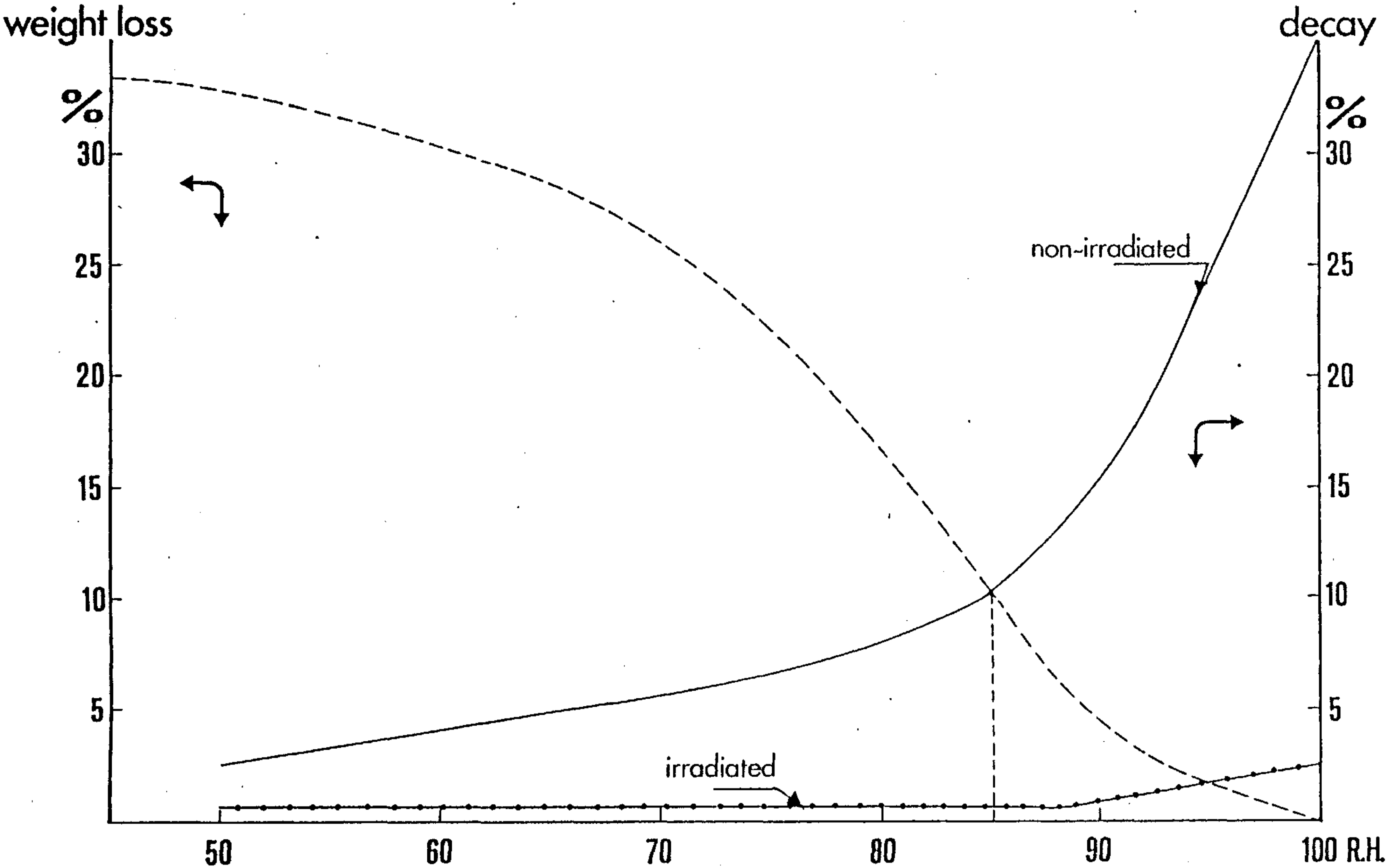

FIG. 3. Effect of relative humidity and irradiation on weight loss and decay of vegetables.

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1.8	4.4×10^5	<10	neg.	<10	<10
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Losses due to desiccation can reach 10 to 30%. This weight loss can largely be prevented by storage in high humidity (Fig. 3). Because during transportation and marketing the humidity is often low, adequate packaging of horticultural products is very important. Various plastics can be used, such as polythene, polypropylene, polyvinyl chloride (pvc), polystyrene and polyvinylidene chlorides (pvdc).

The most commonly used foil is polythene (low density). Due to the low permeability of the packing and water vapour from the product, a microclimate with a high humidity is present so that weight loss is limited. But a high humidity also has disadvantages: it stimulates, for example, decay by microorganisms.

Figure 3 shows the relationship between relative humidity and decay. To prevent decay, therefore, holes are made in the packaging so that the rela-tive humidity cannot rise above 85 to 90%. The ideal relative humidity is, however, more than 95%. This is only possible when it is combined with radiation, because then microbial decay is reduced even with a high humidity (see Fig. 3).

In addition to a high relative humidity, sealed packaging has the advantage that, as a result of respiration (dissimilation) of the product, the air composition inside the packing is altered.
During respiration, carbohydrates in the planttissue are oxidized.
This is represented by the following formula:

$$C_6H_{12}O_6 + 6\ O_2 \rightleftharpoons 6\ CO_2 + 6\ H_2O + \text{energy}.$$

Horticultural products, therefore, take up O_2 and produce CO_2, whereby the O_2 percentage decreases and the CO_2 percentage increases in the packing.
This alteration in air composition has a delaying effect on the respiration process (ageing) of the product, thus giving a prolonged shelf-life. There is, therefore, a sort of miniature gas storage in the packing.

With an unirradiated product, sealed packaging is impossible because, due to microorganisms, fermentation exists in the packing[5,6].
For this reason the use of sealed packaging is only possible in combination with irradiation.

Another example of a different method of packing in combination with irradiation, is the packing of soft fruit such as strawberries, raspberries and blackberries.

Soft fruit generally has a limited shelf-life because it is very susceptible to desiccation, transportation damage and rotting. Closed packaging offers good protection but is impossible because the high humidity causes rapid rotting. Only in combination with radiation can closed packaging be used.

5.4 Sterilization

Metal packaging is usually used for the sterilization of food. The dimensions depend on whether the product belongs to the convection or conduction type. With the conduction type, especially, the dimensions must be limited, otherwise the product has to be heated for too long in order to achieve the desired sterility. Flexible, synthetic materials have also been used for sterilization for some years now, the so-called retort packaging, mainly consisting of laminates of nylon, aluminium and polypropylene. Because heat sterilization occurs at 121°C, the qualities required of the plastic packaging are very high; the number of plastics suitable for heat sterilization is, therefore, limited.

When sterilization is combined with irradiation, however, it is possible to reduce the heat treatment, expressed as an Fo value (Fo value is the process value = number of minutes necessary to sterilize a product at 121°C), by 50% of the original value[7]. This results in either a shorter heat treatment, or sterilization at a lower temperature, e.g. 100°C. Table 6 gives a clear view of a shorter heat treatment.

Because of these shorter or lower heat treatments less stringent demands are made upon the plastic material. The combination of heat and irradiation for the sterilization of foodstuffs offers the following perspectives:

- packaging in large units, especially important for conduction types;
- greater choice of packing material, which means it can be cheaper;
- saving of fossil energy because the treatment is either shorter or is done at a lower temperature;
- better quality of the product.

TABLE 6. EFFECT OF COMBINED TREATMENT ON THE Fo VALUE (SEE TEXT) AND QUALITY WITH REGARD TO A SINGLE HEAT TREATMENT

Product	Heat Fo value	Heat + irradiation		Quality improvement[1]		
		Fo value	dose (kGy)	colour	taste	textu
Strawberries	3.2 min/ 85°C	0.9 min/ 85°C	<1	+	±	+
Pears	10.0 min/ 85°C	7.2 min/ 85°C	<3	+	±	+
Asparagus	19.3 min/115°c	8.0 min/115°C	<3	+	±	+
Spinach	4.7 min/121°C	0.04 min/121°C	>3	±	±	±
French beans	17.5 min/121°C	7.4 min/121°C	<3	±	±	+
Peas	18.0 min/121°C	6.0 min/121°C	<5	±	±	+

1. + = clear; ± = slight.

5.5 Sprout inhibition

Tuber, bulb and root vegetables will produce sprouts during storage, which results in deteriation of their quality. Sprouting can partly be prevented by storing the vegetables at low temperature or by making proper use of chemical inhibitors. Particularly under (semi) tropical conditions adequate cooling is often not available and the chemicals used are not always effective against sprouting. A good alternative is the use of ionizing radiation. With a dose of 0.02 to 0.15 kGy sprouting can be completely prevented, provided that the treatment is carried out when the product is in its dormancy period.

For this reason onions should be irradiated as soon as possible after harvesting. The relationship between percentage of sprouted bulbs and delay in weeks between harvest and irradiation is demonstrated by the following formula:

$$y = 0.44 x^2 + 0.36 x + 3.41$$

in which y is the percentage of sprouting and x the delay in weeks[8].

The results are shown in Figure 4.

A disadvantage of the irradiation of potatoes is that it decreases the natural resistance of the tubers to fungi, resulting in a higher percentage of rot.

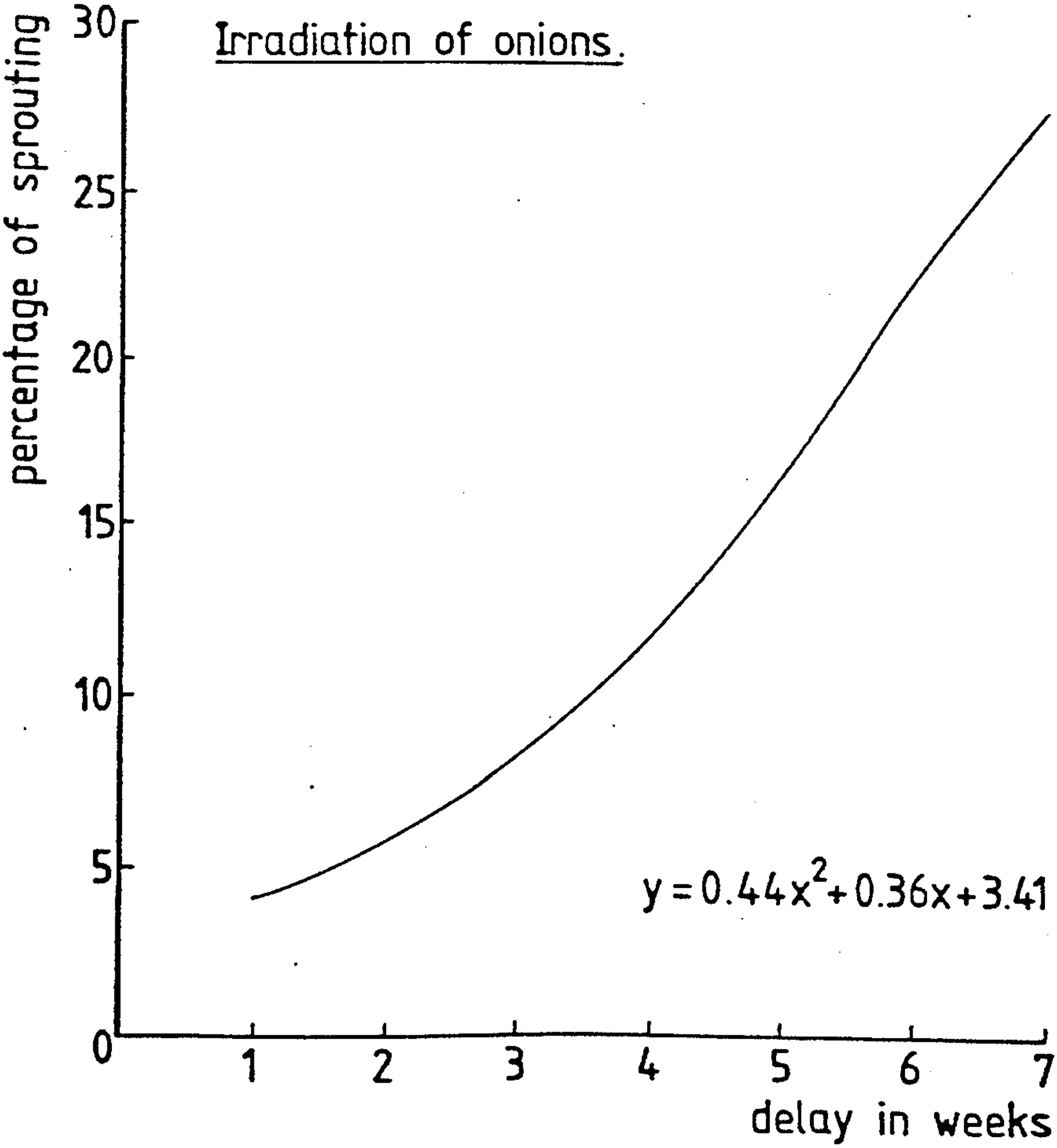


FIG. 4. Relation between sprouted bulb and delay between harvest and irradiation.

The losses can be reduced by paying due regard to various factors: good quality product, careful handling, adequate curing period before irradiation and proper ventilation during storage. Another problem in the irradiation of potatoes is the after-cooking discoloration (greyness) and the darkening of the processed product (chips, crisps, etc.), probably by an induced increase in sugar content. Reconditioning after storage at temperatures higher than 15°C may help diminish the extent of discoloration[9].

5.6 Delay of growth and ripeness

A number of vegetables, such as asparagus and mushrooms, continue growing after being harvested. The result is a decrease in quality. Also, most fruits are ripened artificially after picking, and subsequently go through a senescence process. These phenomena can be delayed by cooling. However, tropical and subtropical fruits will not stand storage at temperatures lower than 10°C, because at these temperatures abnormalities are caused in their physiology (stress). This disorder manifests itself in discoloration, failure to ripen, and chill injury of the tissue. Most tropical fruits have to be stored at temperatures above 12°C. At these temperatures, however, the ripening process (senescence) is stimulated and microbial decay sets in, resulting in a decrease in shelf-life. Instead of cooling the products they can be given an irradiation treatment, provided that this is carried out immediately after harvesting. A delay in ripening only occurs in climacteric fruits such as mangoes, papayas, avocados, bananas, tomatoes etc. Radiation should take place when the fruits are in the preclimacteric (mature green) stage and relatively low doses (< 1 kGy) should be given in order to prevent damage to tissue[10]. Since these low doses are insufficient to control mould growth on the fruits, a combined treatment should be given (see 5.7).

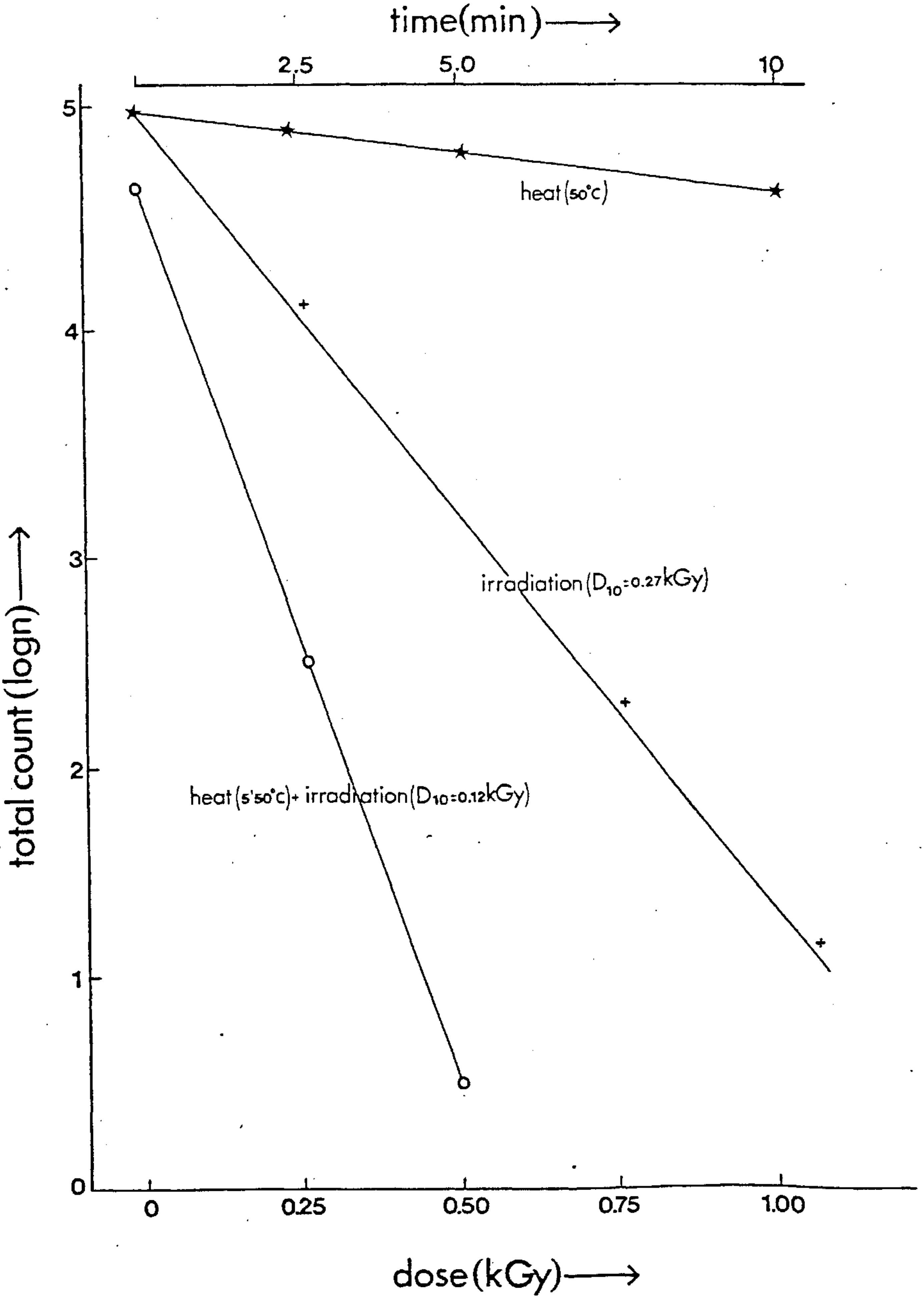
5.7 Disadvantages of irradiation

As every preservation method, food irradiation has disadvantages as well as advantages. When too high a dose is given, texture and colour losses can occur. Also, some aromas and flavourings are sensitive to radiation so that an "off-flavour" can occur that is analogous to a "deep-freeze taste" or a "tin taste". This can occur especially in foods with a high protein or fat content.

Where these difficulties could exist, radiation is done in combination with other preservation methods, for example with moderate cooling, a mild heat treatment or under vacuum. Colour, taste and odour changes can also be prevented by irradiation under vacuum or at a very low temperature (e.g. -80°C).
A combination of a mild heat treatment with irradiation is very effective in controlling moulds on products which are very sensitive to heat or high doses.
The above-mentioned combination gives a synergistic effect: the combination has a greater effect on the inactivation of fungi than the sum of the separate treatments (see Fig. 5). Consequently, a lower heat treatment and a lower irradiation dose can be applied with no adverse effects on the product.
The development and application of this combined treatment is still being intensively studied. However, practical applications have already been started with tropical products such as mangoes, and papayas[11] and avocados[12]. Instead of a fungicide, a combined heat and irradiation treatment is used, which prevents decay and delays ripening. In the case of the mango, the mango weevil is also controlled at the same time. Furthermore, this combined treatment now offers the possibility of transporting the product by ship instead of by aeroplane, resulting in a lowering of transport costs by a factor 3.

6. CONCLUSIONS

This review shows that irradiation has its restrictions, but also a wide spectrum of application possibilities. We can, therefore, expect irradiation to claim its place in the field of food preservation, especially where the conventional techniques are inadequate or too expensive through lack of fossil energy (oil). Actual introduction of irradiated food, however, needs to be done very carefully. Consequently, supporting research is permanently necessary. The speed at which the procedure comes onto the market depends largely on regulatory policies. Furthermore, information and advice to both producer and consumer are extremely important.


time(min)⟶
2,5
5,0
10
5
4
3
2
1
0
heat (50°c)
irradiation (D_{10}=0.27kGy)
heat (5'50°c)+ irradiation (D_{10}=0.12kGy)
total count (logn)⟶
0
0.25
0.50
0.75
1.00
dose(kGy)⟶

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