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Effect of wound healing period and temperature, irradiation and post irradiation storage temperature on the keeping quality of potatoes

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ABSTRACT

Effect of wound healing period and temperature, irradiation and post irradiation storage temperature on the keeping quality of potatoes.

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36 figures, 7 tables, 27 references.

Losses during storage in potatoes are mainly due to sprouting and rotting. It has indicated that irradiation by low dose (50 to 100 Gy) during the dormancy period is most effective for sprout inhibition. During storage at 10 and 20 °C the dormancy period was 5 and 2 weeks respectively. A dose of 75 and 100 Gy reduced the loss of weight and gave a complete sprout inhibition to the end of a 27 weeks storage period. For a complete wound healing a period of at least 2 weeks at 15 to 20 °C was necessary. In this experiment the percentage of rot did not increase due to an irradiation treatment. An irradiation treatment reduced the vitamin C content, but did not affect the dehydro ascorbic acid content. No relation was found between the start of sprouting and an increase of dehydro ascorbic acid content. An irradiation treatment increased the reducing sugar content in deep fat fried potatoes, resulting in a darker colour, especially at potatoes prior frying stored at 10 °C. The increased sugar content did not affect the taste of the deep fat fried potatoes.

Key words: ascorbic acid, bulb products, dehydro ascorbic acid, irradiation, potatoes, sprout inhibition, vitamin C, wound healing.

CONTENT Page

SUMMARY

Potatoes are important, as a source of nutrition, all over the world. The losses in potato tubers during storage are mainly due to sprouting and rot. This is a common problem in most countries especially in the tropical countries. The effect of irradiation doses, wound healing temperature, post harvest irradiation time (wound healing period) and storage temperature on a number of quality parameters such as loss of weight, sprout inhibition and rot incidence, chemical parameters such as sugar and vitamin C content, sensory parameters taste and colour and also wound healing ability were investigated. The potatoes were irradiated with a dose range of 50 to 100 Gy, after a wound healing period varying from 0 to 6 weeks at 15 or 20 °C. The product was stored at 10 and 20 °C and 90% relative humidity.
It appeared from the results that a dose of 75 and 100 Gy reduced the loss of weight and gave a complete sprout inhibition to the end of the storage period. A dose of 50 Gy was not effective to the end and increased the number of sprouts per potato. A treatment within 2 weeks after harvest gives the best results. The primary suberization started 1 week after injury and was independent of storage temperature. The secundary suberization was very sensitive to low temperature (10 °C) and radiation. For a complete wound healing a storage period of 2 weeks at 15 to 20 °C was necessary. The effect of dose, wound healing period and temperature on the rot incidence was not measurable because the percentages infected potatoes were too low and the spread too large for finding significant differences.
The vitamin C content was at 20 °C higher than at 10 °C. No effect of wound healing period was found in the vitamin C content, however, irradiation reduced, immediately after treatment, the vitamin C content, but after some weeks a restoration occurred. An irradiation treatment did not affect the dehydro ascorbic acid content. No relation was found between the start of sprouting and an increase of dehydro ascorbic acid content. The reducing sugars in deep fat fried potatoes increased by an irradiation treatment and a storage at 10 °C, resulting in a darker colour of the fried potatoes. During storage the effect of irradiation on the reducing sugars disappeared. In contrast with the reducing sugar, the non-reducing sugar content was for the product

stored at 20 ^{o}C higher than at 10 ^{o}C. On the end of the storage period this content increased, especially at the irradiated samples. No effect of irradiation or storage temperature on the taste was found.

1 INTRODUCTION

The losses in potato tubers during storage are mainly due to sprouting and rot. This is a common problem in most countries especially in the tropical countries. One of the most promissing applications to inhibit the sprouting and to extend of the storage life of potatoes is a treatment with gamma-rays. Also the mould attack, resulting in rot, can be reduced by irradiation (Levis & Mathur 1963; Nair et al. 1973). On the other hand other authors mentioned that an irradiation treatment induces some unfavorable side effects e.g. enhancement of storage rot and discolouration after boiling. Rot incidence is associated with the decrease in the resistance of tubers to phytopathogenic micro-organisms, caused by an irradiation treatment (Burton & Hannan 1957; Langerak et al. 1986). The development of rot in potatoes, however, depends not only on the irradiation dose but also on the wound healing period and temperature, post-harvest irradiation time and storage temperature (Langerak et al. 1986). In several studies it has indicated that, during the dormancy period, irradiation at low doses (50 to 100 Gy) is most effective for sprout control (Levis & Mathur 1963; Nair et al. 1973; Langerak et al. 1986). On the other hand the doses should not exceed 100 Gy to avoid unnecessary side effects of irradiation due to damage of the wound healing ability (Metlitsky et al. 1968). An irradiation dose over 150 Gy decreases the wound healing ability, increases the storage rot, spoilage and sweetening and decreases the vitamin C content (Brownell et al. 1957; Cloutier et al. 1959; Metlitsky et al. 1968). Also this dose could bring changes in chemical composition which did not disappear during subsequent storage (Metlitsky et al. 1968).

Sparenberg (1974) reported that irradiation of potatoes immediately after harvest strongly suppresed sprout formation. Irradiation gave less good results after 2 weeks. Langerak et al. (1986) also proved that an irradiation treatment within 2 weeks after harvest gave the best results concerning sprout inhibition and rot incidence. Roushdy et al. (1977) advised to irradiate as soon as possible after harvest and curing, preferable within 4 weeks.

It is known that wound healing before irradiation can reduce rotting during subsequent storage. Because the wound healingability of potato tubers is reduced by irradiation (Brownell et al. 1957) the tubers should be kept first 2 weeks at ambient temperature to ensure the healing of tissue damage by harvesting and handling (Metlitsky et al. 1968).

The pre-irradiation temperature and relative humidity plays a very important role at the wound healing. To complete the wound healing process, curing at about 15 to 20 °C with high humidity (not less than 85 %) under good air condition for 1 to 2 weeks is necessary (Workman et al. 1950; Radatz 1967; Wigginton 1974). The formation of wound periderm is delayed not only at low temperature but also at high temperature (Wigginton 1974). During the curing period the storage temperature must not be allowed to exceed 22 °C (Meijers 1981).

Irradiation of potatoes with sprout inhibition dose can give some change in chemical and sensorical properties. Many studies showed that both reducing and non-reducing sugars, in potatoes, increased immediatly after irradiation and decreased to the normal level after some time again (Burton & de Jong 1959; Ussuf & Nair 1972; Langerak et al. 1986). This temporary rise in reducing sugar content was independent of storage temperature and irradiation dose, but dependent upon the post-harvest irradiation period, the longer this period the larger the increase of reducing sugar as a result of irradiation (Matsuyama & Umeda 1983). In contrast with reducing sugars, the sucrose content increased stronger with rising dose and was independent of the post-harvest irradiation period (Burton 1975; Schwimmer et al. 1957; Langerak et al. 1986). These effects level off during storage dependent on the storage temperature. Schwimmer et al. (1958) observed that irradiation increased the accumulation of sucrose during storage at 4 °C and has also showed that starch phosphorylase was activated in irradiated potatoes stored at 21 °C. These results suggested that the sucrose accumulation was not caused by direct chemical reaction but biochemical reactions. Increase in sugar content is a disadvantage, especially for processing. The conversion of sugar to starch took place by reconditioning.

There was no significant effect on the starch content of potatoes owing to reconditioning (Atomic 1962; Moor et al. 1963; Tanako et al. 1972; Umeda 1978).

Irradiation of potato tubers caused some slight loss of total

vitamin C, especially ascorbic acid (Schwimmer et al. 1958; Langerak et al. 1986). This loss depended on the storage temperature; a lower temperature increases the losses. Research in Hungary with onions indicated that on the end of the dormancy period the dehydro ascorbic acid content in onions increased (oral information). This phenomenon can may be serve as a test for the break of dormancy period.
In relation to the above mentioned problems the following factors were studied:

- Effect of wound healing period and temperature, irradiation dose and storage temperature on the external quality;
- Relation between irradiation dose, sugar content and sensory evaluation;
- Relation between dehydro ascorbic acid (DHAA) content and break of dormancy period;
- Effect of irradiation dose, post-harvest irradiation time and temperature on the wound healing process.

2 MATERIALS AND METHODS

The experiment was set op on the following conditions:

- Wound healing: at 15 ^{o}C (ambient temperature) and at 20 ^{o}C (tropical condition);
- Wound healing period: at 15 ^{o}C for 0, 2, 4 and 6 weeks and at 20 ^{o}C for 0, 1 and 2 weeks;
- Irradiation with a dose of 0, 50, 75 and 100 Gy (dose rate 108 $Gy.h^{-1}$);
- Post-irradiation storage: at 10 ^{o}C (mild cooling) and at 20 ^{o}C (tropical condition).

The external and internal quality was studied on the following parameters:

- Inspection: loss of weight, percentage of sprouted tubers, length of sprouts, rot incidence and general appearance;
- Chemical analysis: dehydro ascorbic acid, total vitamin C, glucose, fructose and sucrose content;
- Sensory evaluation: taste, colour;
- Brightness measured by physical instrument;
- Histology evaluation: inspection of wound periderm.

The experiment was carried out with potatoes variety "Bintje". The sample material was purchased from "proefboerderij De Bouwing" lokated in Randwijk, the Netherlands.

2.1 Inspection

For each treatment 125 potatoes, divided in 5 samples of 25 potatoes stored in wooden boxes, were taken.
The loss of weight in potato tubers was estimated by weighting the whole boxes of potatoes. The loss of weight was calculated as percentage loss as compared with the initial weight.
Potatoes with at least one sprout longer than 0,5 cm were considered as to be sprouted. The percentage of sprouted potatoes was estimated by counting all sprouted potatoes in each box.
During the storage the length of sprouts was estimated by individualy measuring all sprouts per potato. For the study of the estimation of the sprout activity in very early state in this review also the sprouts smaller than 0,5 cm are involved. The length of sprouts was registred using the following class distribution: class 1 = 0 to 0,5 cm, class 2 = 0,5 to 5,0 cm and class 3 = more than 5,0 cm
The rot incidence was estimated by individualy observing all potatoes. The rotten tubers were not removed in order to imitate the practice. The general appearance was estimated by observing the whole box using the following score grade: 5 = excelent, 4 = good, 3 = moderate (just marketable), 2 = poor (not acceptable) and 1 = very poor.

2.2 Chemical analysis

Chemical analyses were carried out on potatoes for wound healing stored at 15 ^{o}C. The determation of vitamin C and dehydro ascorbic acid were carried out with a frequency of 4 weeks. The sugar determination was carried out on potatoes stored at a wound healing temperature of 15 ^{o}C and for a wound healing period of 4 weeks. The sugar analyses were repeated on raw as well as fried potatoes every 8 weeks, parallel with the sensory tests.
The determination of the dehydro ascorbic acid content was carried out according to an internal high performance liquid chromatographic

(HPLC) method developed by RIKILT and described in IFFIT report 68 (Quan et al. 1988).
The total vitamin C content determination was carried according to an internal fluorometric method (A-119) and also described in IFFIT report 68.
The glucose, fructose and sucrose contents were determinated according to the enzymatic method of Boehringer (1986).

2.3 Sensory evaluation

The sensory evaluation was carried out by the method described by ASTM (American 1969).
Analysis of variance with F-testings (probability 5%, double-sided) were used for estimation of significance.

2.4 Brightness measurement by physical instrument

The brightness was estimated using the method as described by Quan et al. (1988).

2.5 Histological examination

The samples were examined according to a method developed by RIKILT and described in IFFIT report 68 (Quan et al. 1988).

3 RESULTS AND DISCUSSION

Because of the large amount of data only the most representative figures are given.
All in this report mentioned standard errors (SE) are defined as standard error of the mean (standard deviation devided by square root of number of replicates).

3.1 Inspection

3.1.1 Loss of weight

The average loss of weight percentages of potatoes, irradiated and unirradiated are mentioned in figures 1 to 4.
The potatoes stored at 20 °C showed a significant higher loss of weight than the potatoes stored at 10 °C. The effect of wound healing temperature on the loss of weight was negligible. In the beginning of the storage period the difference in loss of weight between irradiated and unirradiated samples was small.
On the end of the storage period, however, the loss of weight in the control and with 50 Gy irradiated samples was mostly significant higher than in the other samples, probably due to sprouting. This difference was larger for the product stored at 20 °C than at 10 °C. This is in agreement with previous studies of Langerak et al. (1986).

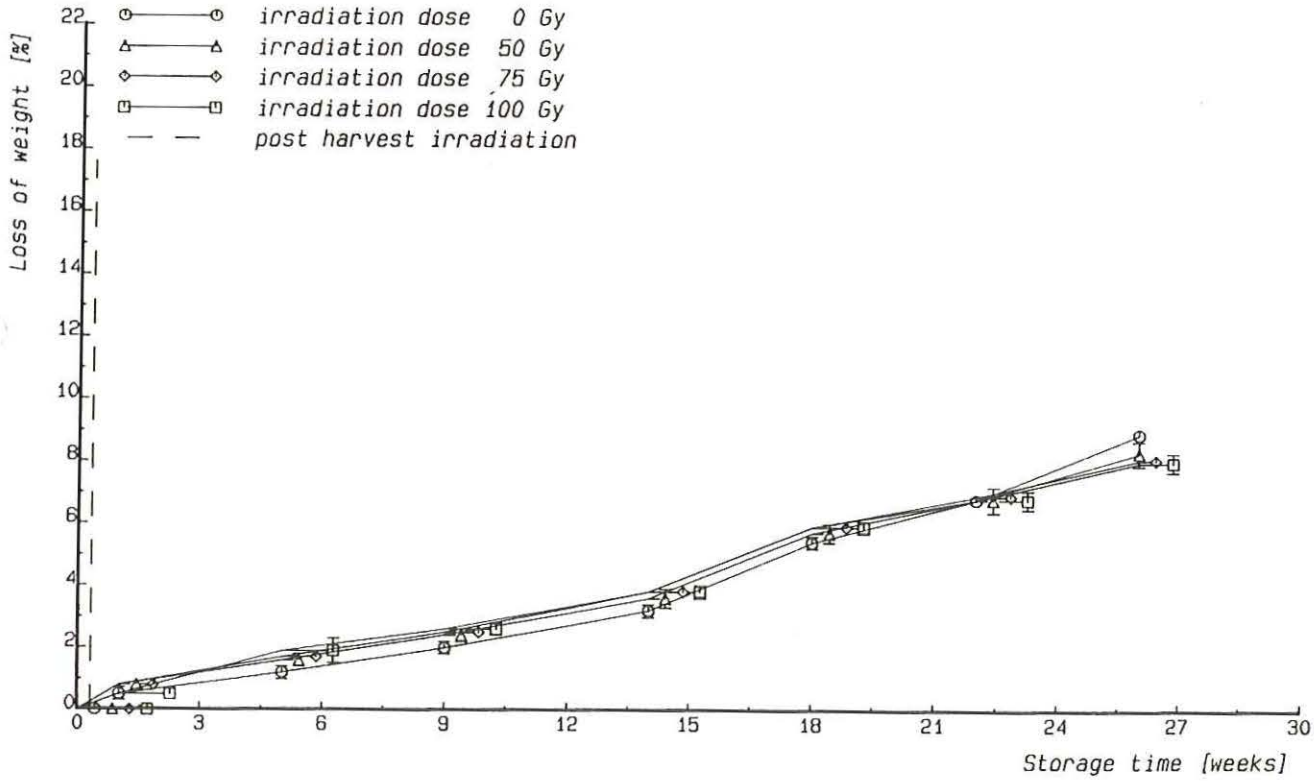

Figure 1: Average loss of weight ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 10 °C.

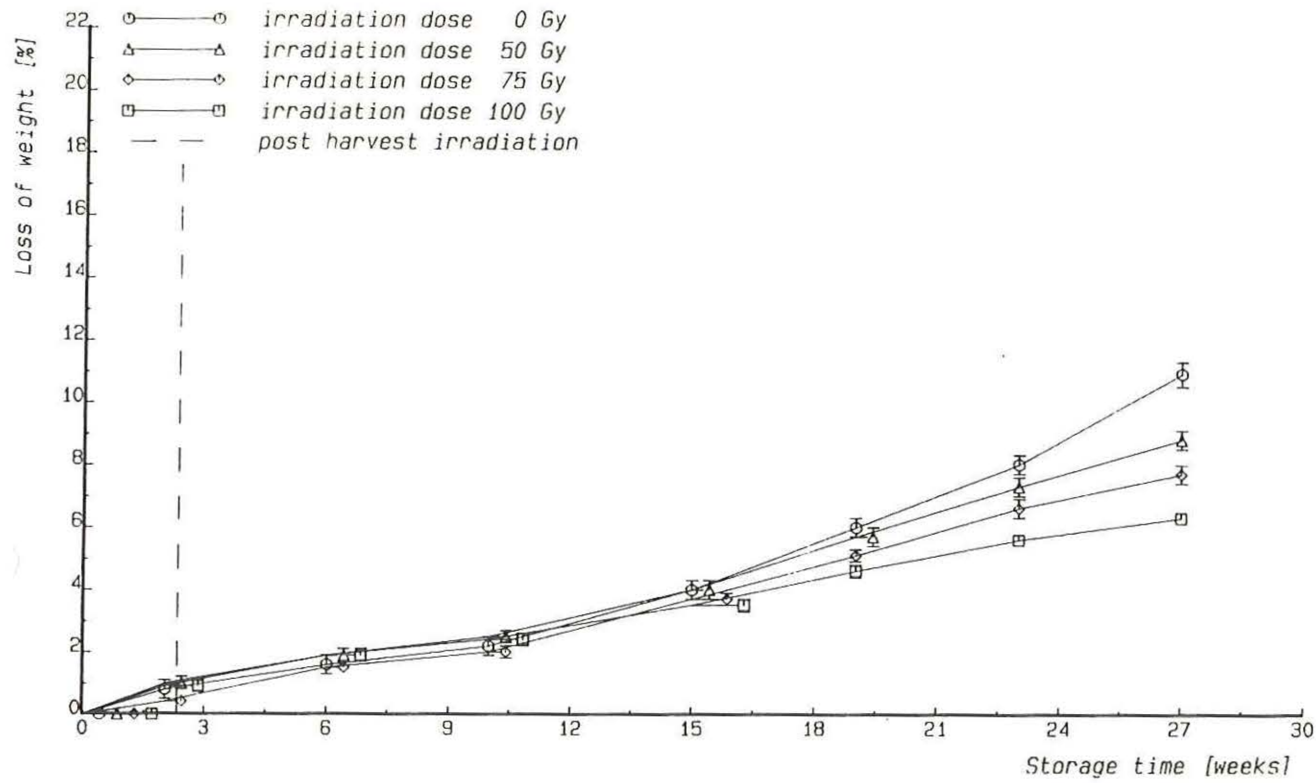

Figure 2: Average loss of weight ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 10 °C.

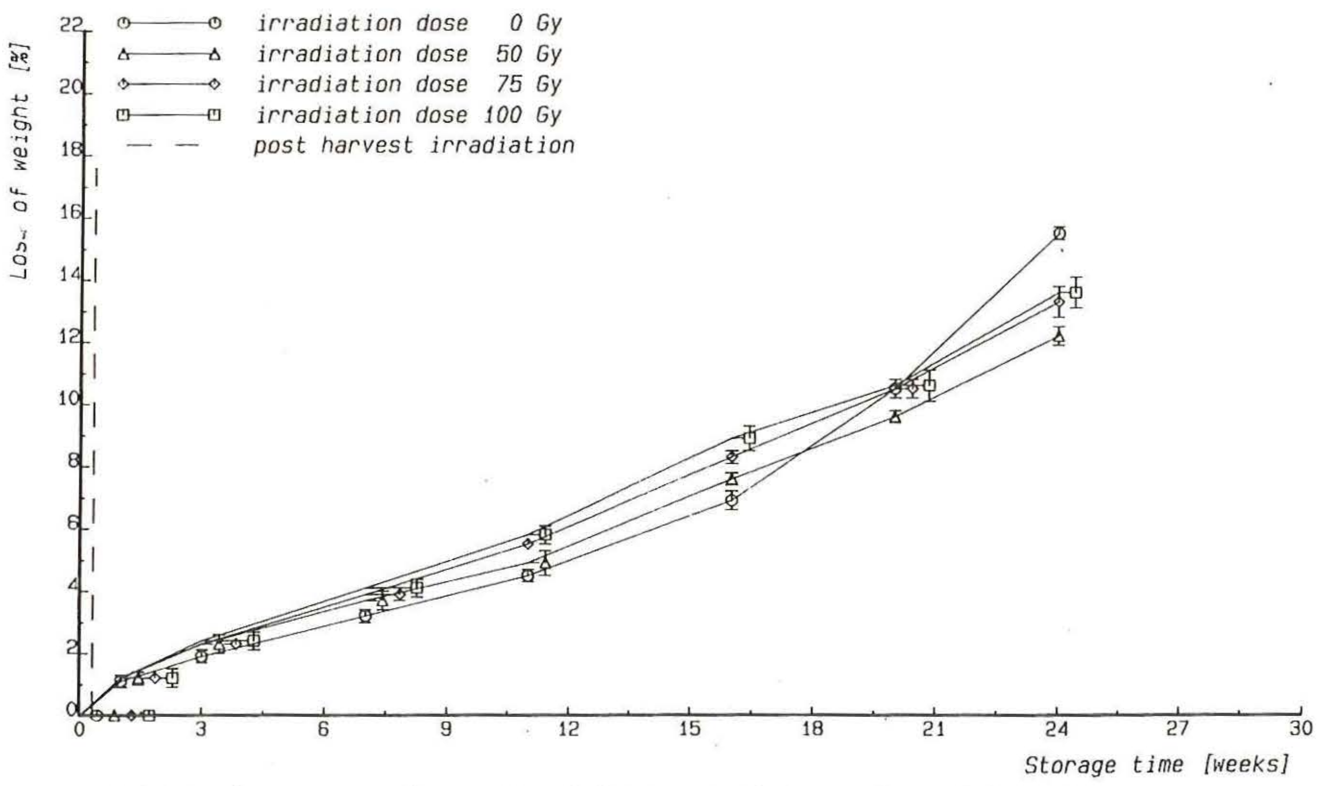

Figure 3: Average loss of weight ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

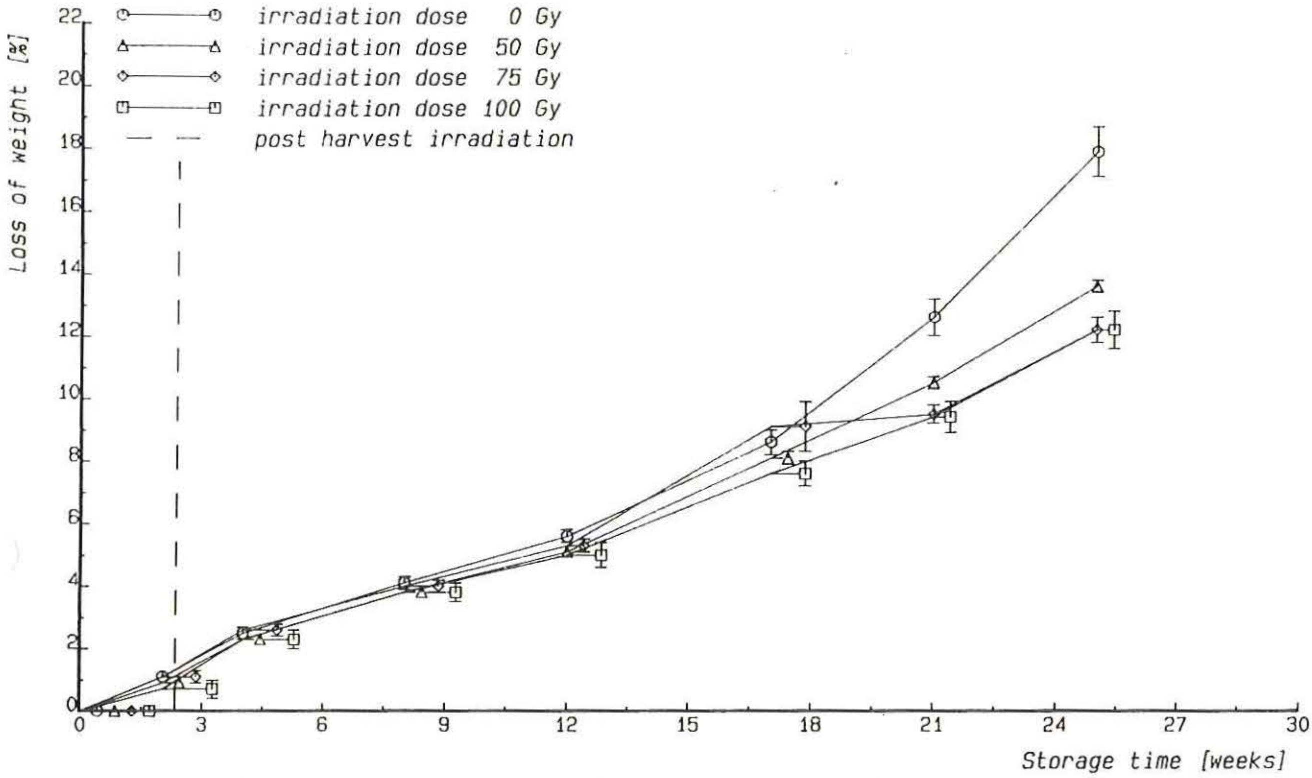

Figure 4: Average loss of weight ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 20 °C.

3.1.2 Percentage of sprouted potatoes

The average percentages of sprouted potatoes are mentioned in figures 5 to 8.
The potatoes stored at 10 and 20 °C started to sprout after 5 and 2 weeks respectively, so this season the dormancy period was rather short, probably due to a dry period during growing.
The dormancy period at 10 °C was shortened by a post-harvest irradiation period (PHI) at 15 or 20 °C. At 20 °C, however, the dormancy period was lengthened by a PHI period at 15 °C.
The effect of an irradiation treatment on the percentage of sprouted potatoes was estimated by the following factors:
- irradiation dose;
- storage temperature;
- postponed irradiation treatment.

For potatoes stored at 10 °C an irradiation dose of 50 Gy was almost sufficient for sprout inhibition, but for a storage period longer than

22 weeks a dose of 75 Gy was necessary. At 20 °C a dose of 50 Gy was not effective; for a complete sprout inhibition till the end of the storage period a dose of 100 Gy has to be applied. It proves from this experiment that a post-harvest irradiation period of 2 to 6 weeks at 15 or 20 °C for wound healing shortened the dormancy period and enhanced the percentage of sprouted potatoes when stored at 10 °C. This is in agreement with previous studies from sparenberg (1974), Roushdy et al. (1977) and Langerak et al. (1986). An irradiation treatment applied immediately after harvest was the most effective concerning sprout inhibition.

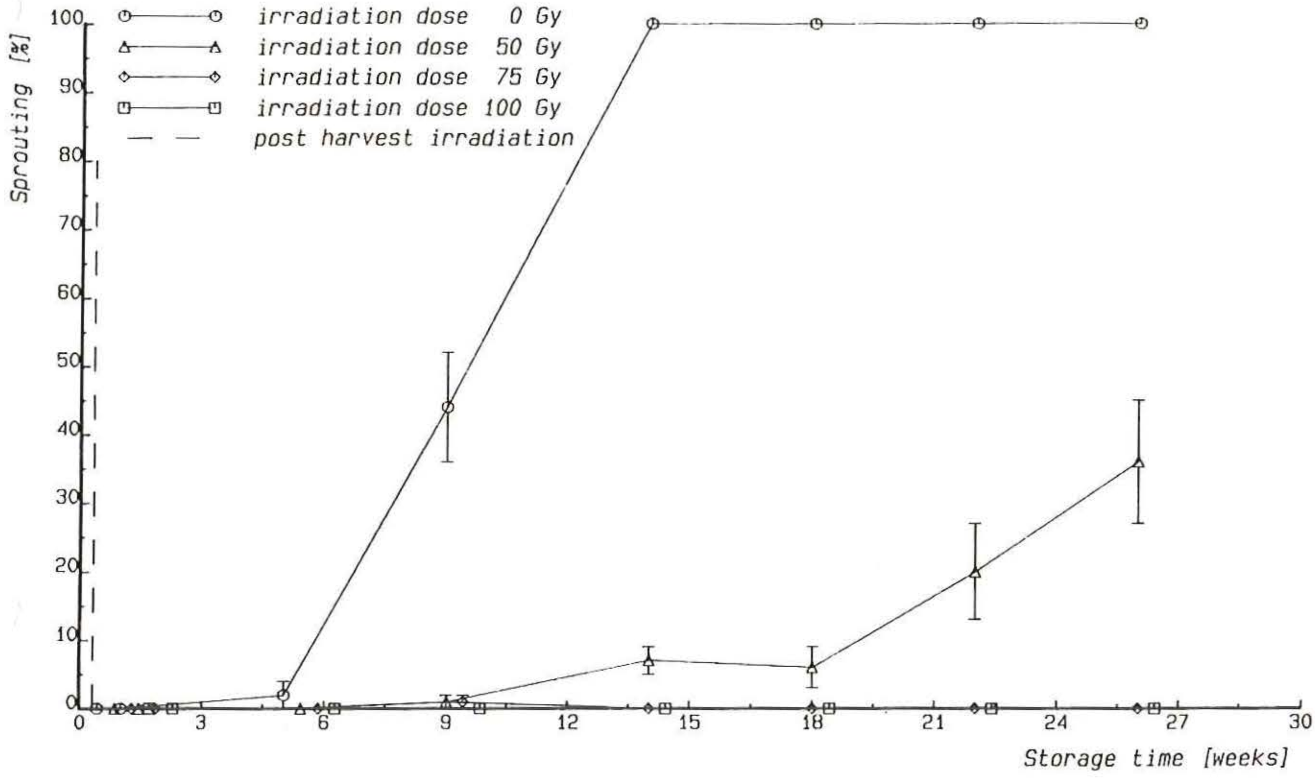

Figure 5: Average percentage sprouted potatoes ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 10 °C.

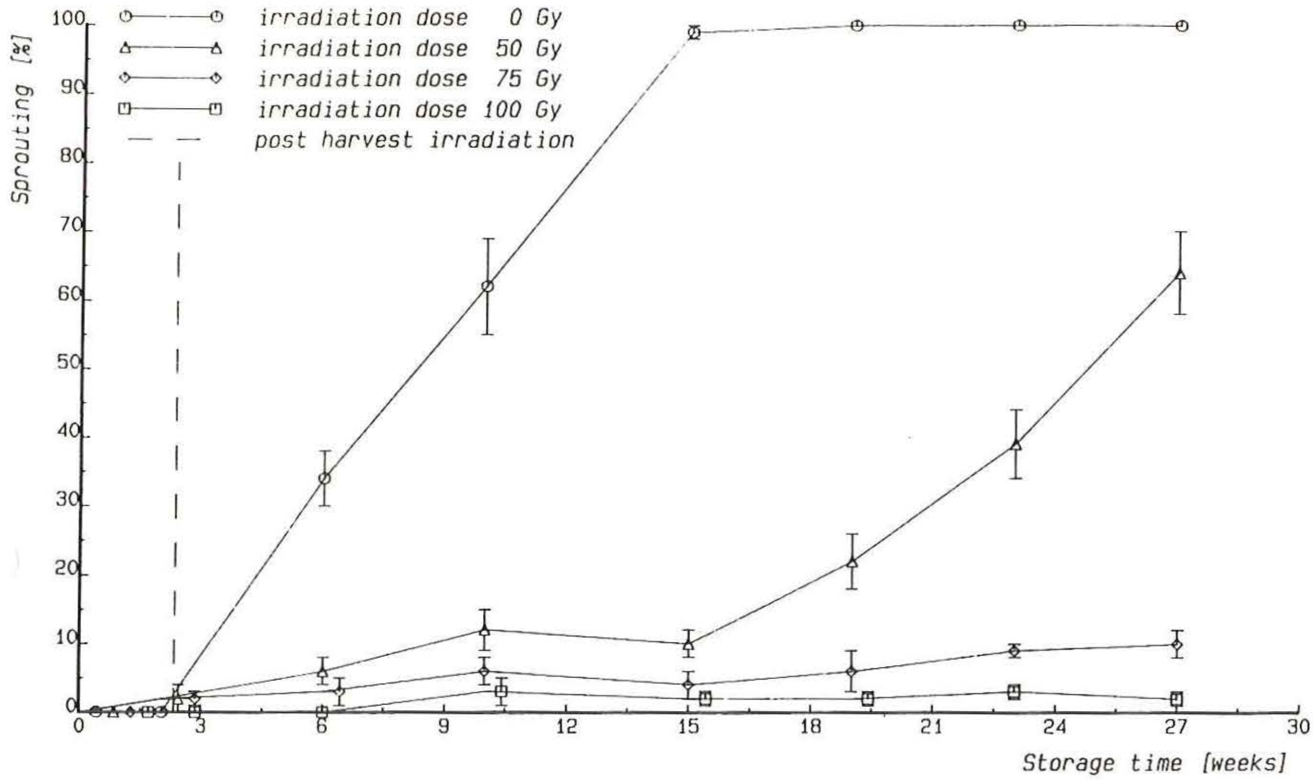

Figure 6: Average percentage sprouted potatoes ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 10 °C.

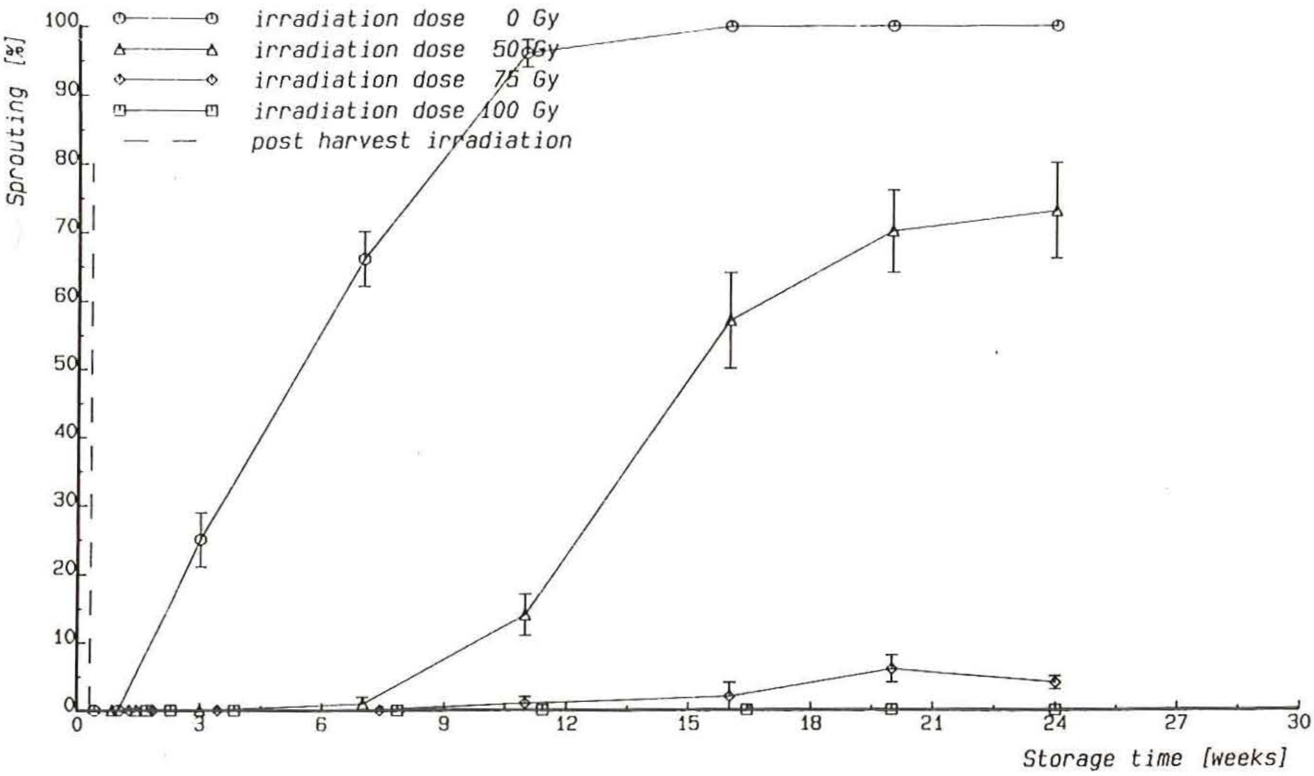

Figure 7: Average percentage sprouted potatoes ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

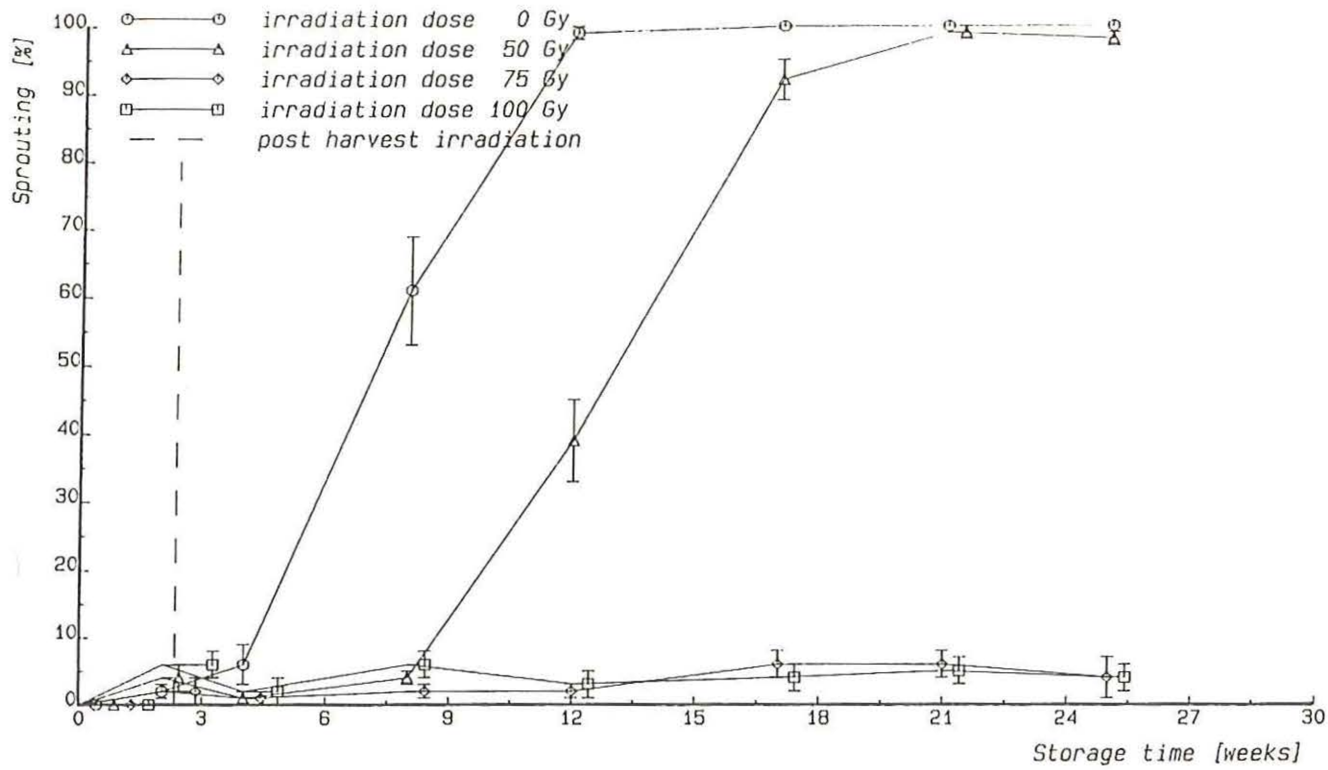

Figure 8: Average percentage sprouted potatoes ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 20 °C.

3.1.3 Length of sprouts

The average number of sprouts and frequency distribution of sprout lenght of irradiated and unirradiated potatoes are mentioned in figures 9 to 12.

These results shown that in general an irradiation treatment effectively inhibits sprouting of potatoes, except when irradiated with a dose of 50 Gy. The potatoes irradiated with 50 Gy often showed a larger number of sprouts in class 1 (< 0,5 cm) than the unirradiated samples, because the adventive eyes were activated, probably as a reaction to stress. During the storage the growth was delayed and only a part of the sprouts reached class 2 (0,5 to 5,0 cm) and seldom class 3 (> 5,0 cm). As compared with the control the sprouts of the irradiated samples were thin and weak and broke of by touching.

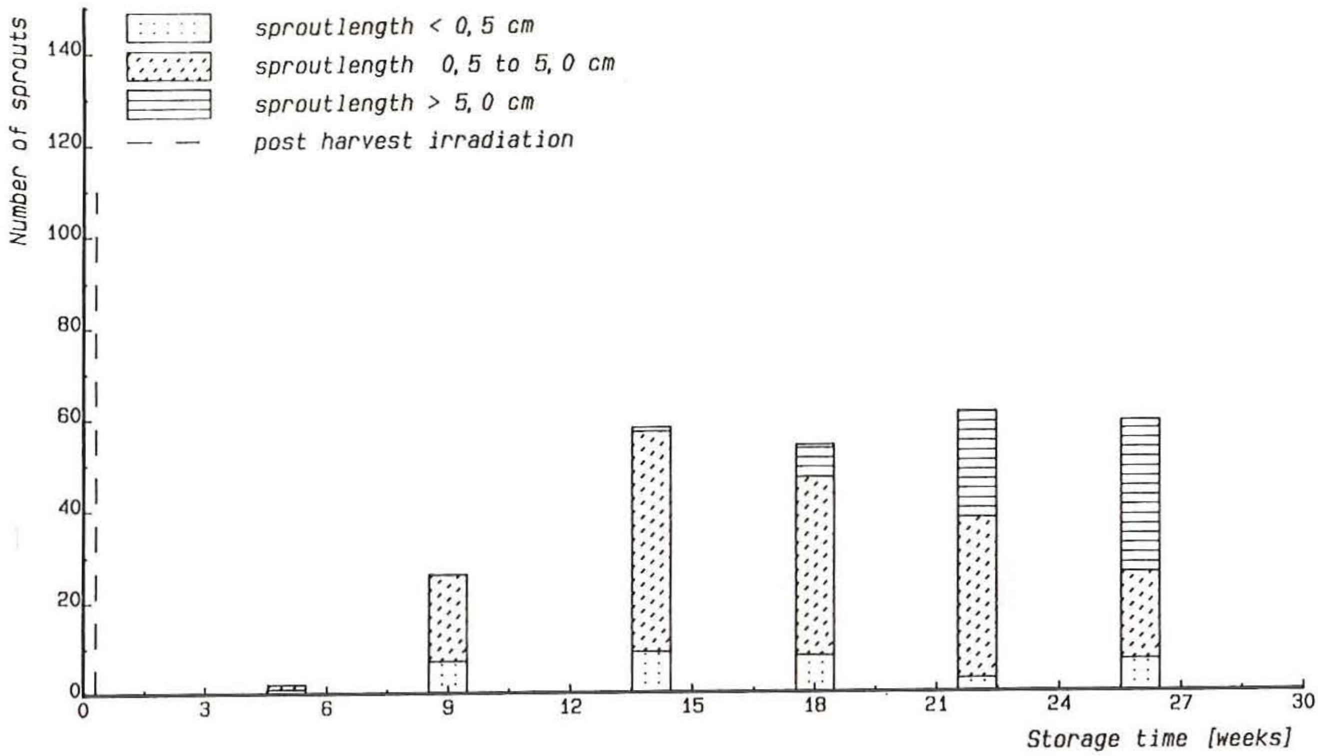

Figure 9: Average number of sprouts and frequency distribution of sprout length of 5 samples of 25 potatoes, post-harvest irradiated with 0 Gy after 0 weeks storage at 15 ^{o}C and subsequently stored at 10 ^{o}C.

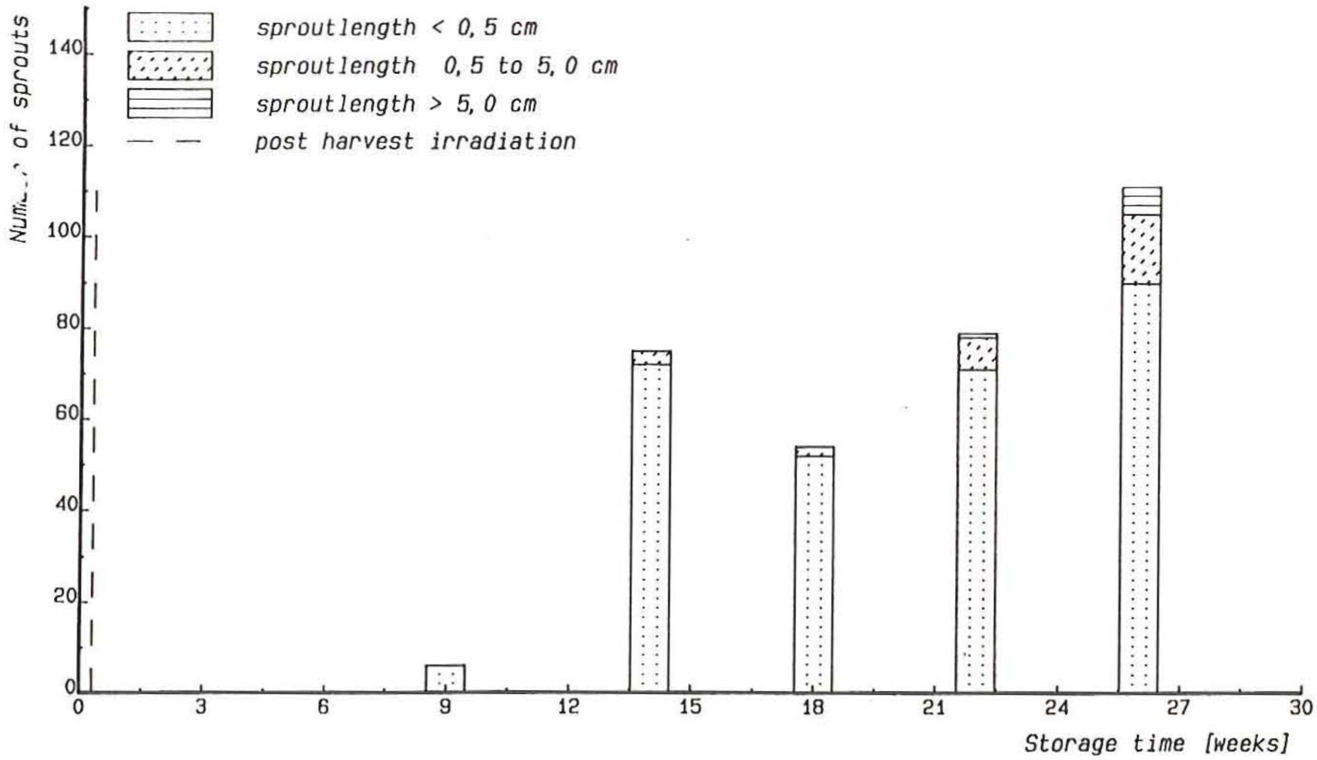

Figure 10: Average number of sprouts and frequency distribution of sprout length of 5 samples of 25 potatoes, post-harvest irradiated with 50 Gy after 0 weeks storage at 15 ^{o}C and subsequently stored at 10 ^{o}C.

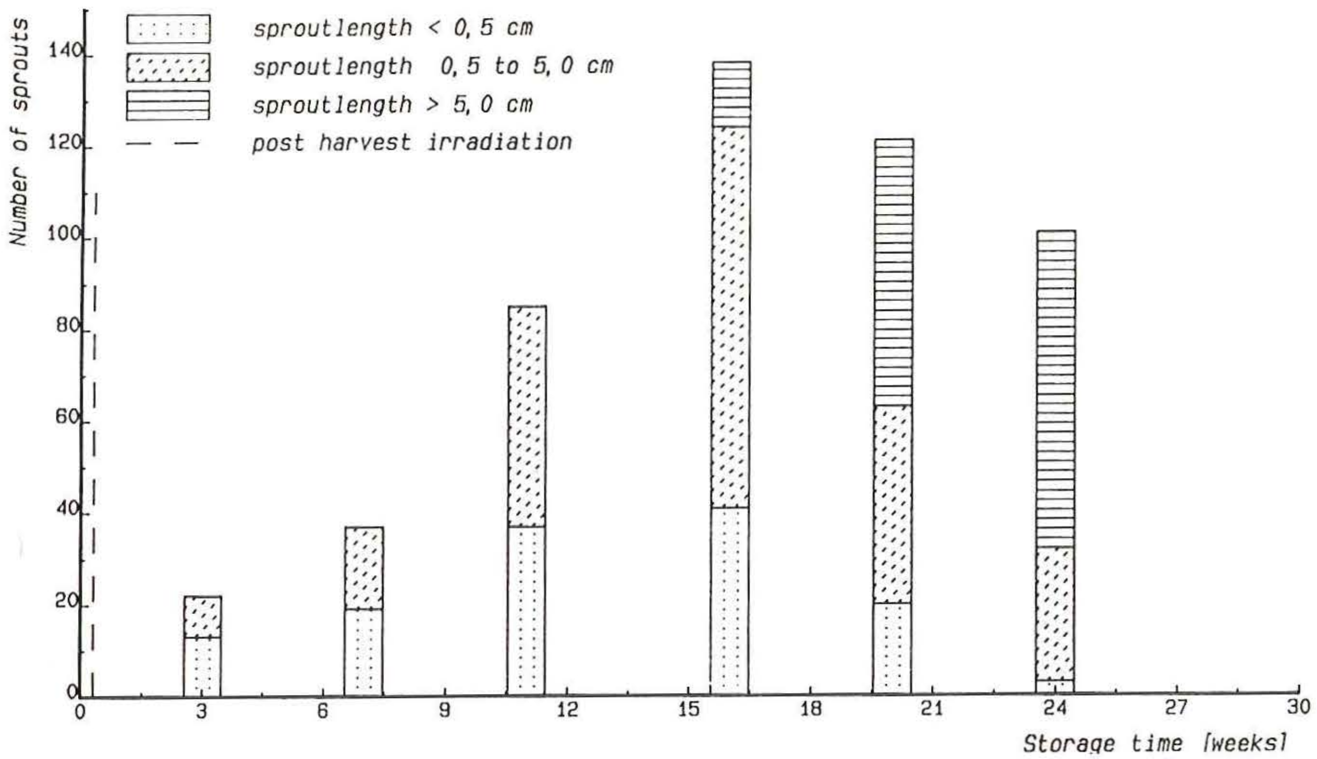

Figure 11: Average number of sprouts and frequency disribution of sprout length of 5 samples of 25 potatoes, post-harvest irradiated with 0 Gy after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

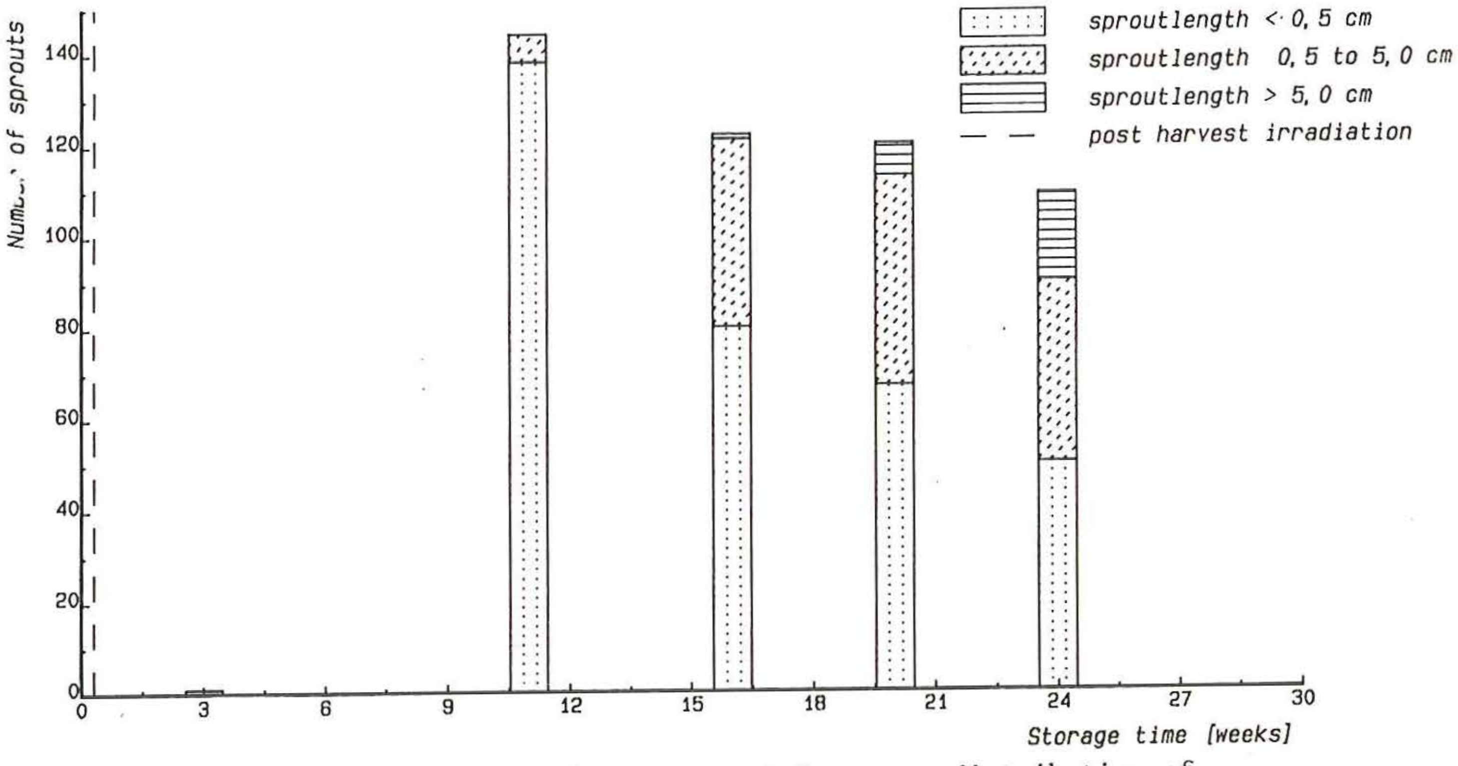

Figure 12: Average number of sprouts and frequency distribution of sprout length of 5 samples of 25 potatoes, post-harvest irradiated with 50 Gy after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

3.1.4 Rot incidence

The results of the estimation of rot incidence are mentioned in tables 1 to 4.
This tables indicate that that during storage at 10 °C hardly any rot incidence was found in all samples. An irradiation treatment applied immediately after harvest, even with a dose of 100 Gy did not increase the percentage of rotten potatoes, altough it proves from parallel experiment that a wound healing process needs at least 7 days before it has finished.
Because of the absence of rot, it was not possible to study the effect of different wound healing temperatures on the development of rot. A small increase of rot incidence was noticed in the objects, stored at 20 °C and irradiated with 50 Gy and 100 Gy immediately after harvest. After a wound healing period of 2 and 4 weeks at 15 °C the percentage of rot was negligible. However a very small amount of rot was found by a dose of 100 Gy applied after a wound healing period of 2 weeks at 20 °C. The spread in the samples was too large for finding a significant difference between the different treatments.

Table 1: Average percentage rot incidence ± SE of 5 samples of 25 potatoes, post-harvest irradiated after different periods at 15 °C and subsequently stored at 10 °C.

WP [weeks]	ST [°C]	SP [weeks]	irradiation dose [Gy] 0	50	75	100
0	15	0	0,0	0,0	0,0	0,0
		***				
		1	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0
		18	0,0	0,0	0,0	0,8 ± 0,8
		22	0,0	0,0	0,0	0,8 ± 0,8
		26	0,0	0,0	0,0	0,8 ± 0,8
2	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0
		***				
	10	6	0,0	0,0	0,0	0,0
		10	0,0	0,0	0,0	0,0
		15	0,0	0,0	0,0	0,0
		19	0,0	0,0	0,0	0,0
		23	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0
4	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0
		***				
	10	6	0,0	0,0	0,0	0,0
		10	0,0	0,0	0,0	0,0
		15	0,0	0,0	0,0	0,8 ± 0,8
		19	0,0	0,0	0,0	0,8 ± 0,8
		23	0,0	0,0	0,0	0,8 ± 0,8
		27	0,0	0,0	0,0	0,8 ± 0,8
6	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0
		6	0,0	0,0	0,0	0,0
		***				
	10	10	0,0	0,0	0,0	0,0
		15	0,0	0,0	0,0	0,0
		19	0,0	0,0	0,0	0,0
		23	0,0	0,0	0,0	0,0
		27	0,0	0,0	0,0	0,0

WP = wound healing period (before irradiation)
ST = storage temperature (before and after irradiation)
SP = total storage period (before and after irradiation)
*** = time of irradiation

Table 2: Average percentage rot incidence ± SE of 5 samples of 25 potatoes, post-harvest irradiated after different periods at 20 °C and subsequently stored at 10 °C.

WP [weeks]	ST [°C]	SP [weeks]	irradiation dose [Gy] 0	50	75	100
0	20	0	0,0	0,0	0,0	0,0
		***				
	10	1	0,0	0,0	0,0	0,0
		5	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0
		18	0,0	0,0	0,0	0,8 ± 0,8
		22	0,0	0,0	0,0	0,8 ± 0,8
		26	0,0	0,0	0,0	0,8 ± 0,8
1	20	0	0,0	0,0	0,0	0,0
		1	0,0	0,0	0,0	0,0
		***				
	10	5	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0
		18	0,0	0,0	0,0	0,0
		22	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0
2	20	0	0,0	0,0	0,0	0,0
		1	0,0	0,0	0,0	0,0
		***				
	10	5	0,0	0,0	0,0	0,0
		9	0,0	0,0	0,0	0,0
		14	0,0	0,0	0,0	0,0
		18	0,0	0,0	0,0	0,0
		22	0,0	0,0	0,0	0,0
		26	0,0	0,0	0,0	0,0

WP = wound healing period (before irradiation)
ST = storage temperature (before and after irradiation)
SP = total storage period (before and after irradiation)
*** = time of irradiation

Table 3: Average percentage rot incidence ± SE of 5 samples of 25 potatoes, post-harvest irradiated after different periods at 15 °C and subsequently stored at 20 °C.

WP [weeks]	ST [°C]	SP [weeks]	irradiation dose [Gy] 0	50	75	100
0	15	0	0,0	0,0	0,0	0,0
		***				
	20	1	0,0	0,0	0,0	0,0
		3	0,0	0,0	0,0	0,0
		7	0,8 ± 0,8	0,0	0,0	0,0
		11	1,6 ± 1,0	0,0	0,0	0,0
		16	1,6 ± 1,0	0,0	0,0	0,0
		20	1,6 ± 1,0	0,8 ± 0,8	0,8 ± 0,8	0,0
		24	1,6 ± 1,0	1,6 ± 1,0	1,6 ± 1,0	0,8 ± 0,8
2	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0
		***				
	20	4	0,0	0,0	0,0	0,0
		8	0,0	0,0	0,0	0,0
		12	0,8 ± 0,8	0,0	0,0	0,0
		17	0,8 ± 0,8	0,0	0,0	0,0
		21	0,8 ± 0,8	0,0	0,0	0,0
		25	0,8 ± 0,8	0,0	0,0	0,0
4	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,0	0,0
		4	0,0	0,0	0,0	0,0
		***				
	20	8	0,0	0,0	0,0	0,0
		12	0,0	0,0	0,8 ± 0,8	0,0
		17	0,0	0,0	0,8 ± 0,8	0,0
		21	0,0	0,0	0,8 ± 0,8	0,0
		25	0,0	0,0	0,8 ± 0,8	0,0
6	15	0	0,0	0,0	0,0	0,0
		2	0,0	0,0	0,8 ± 0,8	0,0
		4	0,0	0,0	0,8 ± 0,8	0,0
		***				
	20	8	0,0	0,0	0,8 ± 0,8	0,0
		12	0,0	0,0	0,8 ± 0,8	0,0
		17	0,0	0,0	0,8 ± 0,8	0,0
		21	0,0	0,0	0,8 ± 0,8	0,0
		25	0,0	0,0	0,8 ± 0,8	0,0

WP = wound healing period (before irradiation)
ST = storage temperature (before and after irradiation)
SP = total storage period (before and after irradiation)
*** = time of irradiation

Table 4: Average percentage rot incidence ± SE of 5 samples of 25 potatoes, post-harvest irradiated after different periods at 20 °C and subsequently stored at 20 °C.

WP [weeks]	ST [°C]	SP [weeks]	irradiation dose [Gy] 0	50	75	100
0	20	0	0,0	0,0	0,0	0,0
		***				
	20	1	0,0	0,0	0,0	0,0
		3	0,0	0,0	0,0	0,0
		7	0,8 ± 0,8	0,0	0,0	0,0
		11	1,6 ± 1,0	0,0	0,0	0,0
		16	1,6 ± 1,0	0,0	0,0	0,0
		20	1,6 ± 1,0	0,8 ± 0,8	0,8 ± 0,8	0,0
		24	1,6 ± 1,0	1,6 ± 1,0	1,6 ± 1,0	0,8 ± 0,8
1	20	0	0,0	0,0	0,0	0,0
		1	0,0	0,0	0,0	0,0
		***				
	20	3	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,0	0,0
		11	0,0	0,0	0,0	0,0
		16	0,0	0,0	0,0	0,8 ± 0,8
		20	0,0	0,0	0,0	0,8 ± 0,8
		24	0,0	1,6 ± 1,0	0,0	0,8 ± 0,8
2	20	0	0,0	0,0	0,0	0,0
		1	0,0	0,0	0,0	0,0
		***				
	20	3	0,0	0,0	0,0	0,0
		7	0,0	0,0	0,8 ± 0,8	0,0
		11	0,0	0,0	0,8 ± 0,8	0,0
		16	0,0	0,0	0,8 ± 0,8	0,0
		20	0,0	0,0	0,8 ± 0,8	0,0
		24	0,0	0,0	1,6 ± 1,0	0,0

WP = wound healing period (before irradiation)
ST = storage temperature (before and after irradiation)
SP = total storage period (before and after irradiation)
*** = time of irradiation

3.1.5 General appearance

The average general appearance scores are presented in figures 13 to 16.

In general an irradiation treatment applied immediately after harvest with doses over 50 Gy gave the highest quality scores. After harvest a postponed irradiation treatment lowered the quality score for all objects. The unirradiated samples stored at 10 and 20 °C were just marketable (score 3) after 18 and 16 weeks respectively. An irradiation dose of 50 gave an extension of 4 weeks, while potatoes irradiated with doses of 75 and 100 Gy were qualified in general as good (score 4) till the end of the storage period (27 weeks).

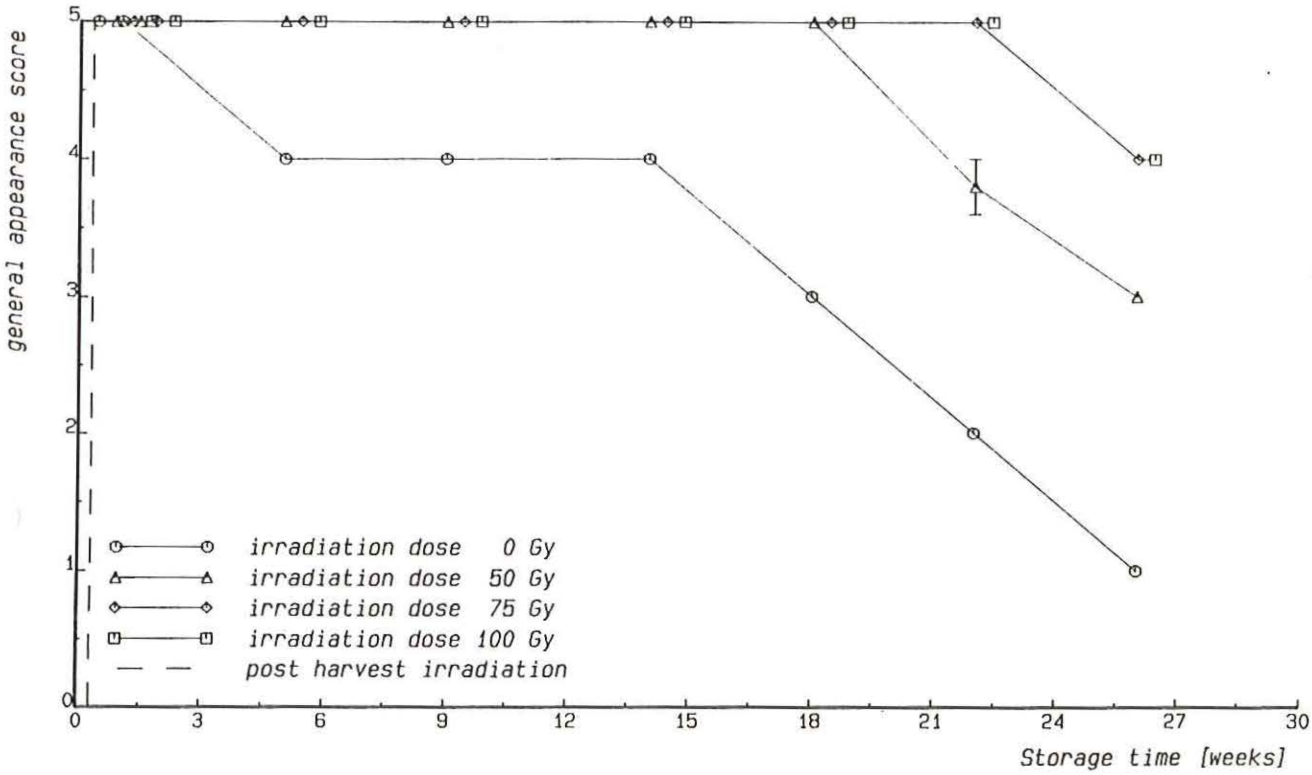

Figure 13: Average general appearance ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 10 °C.

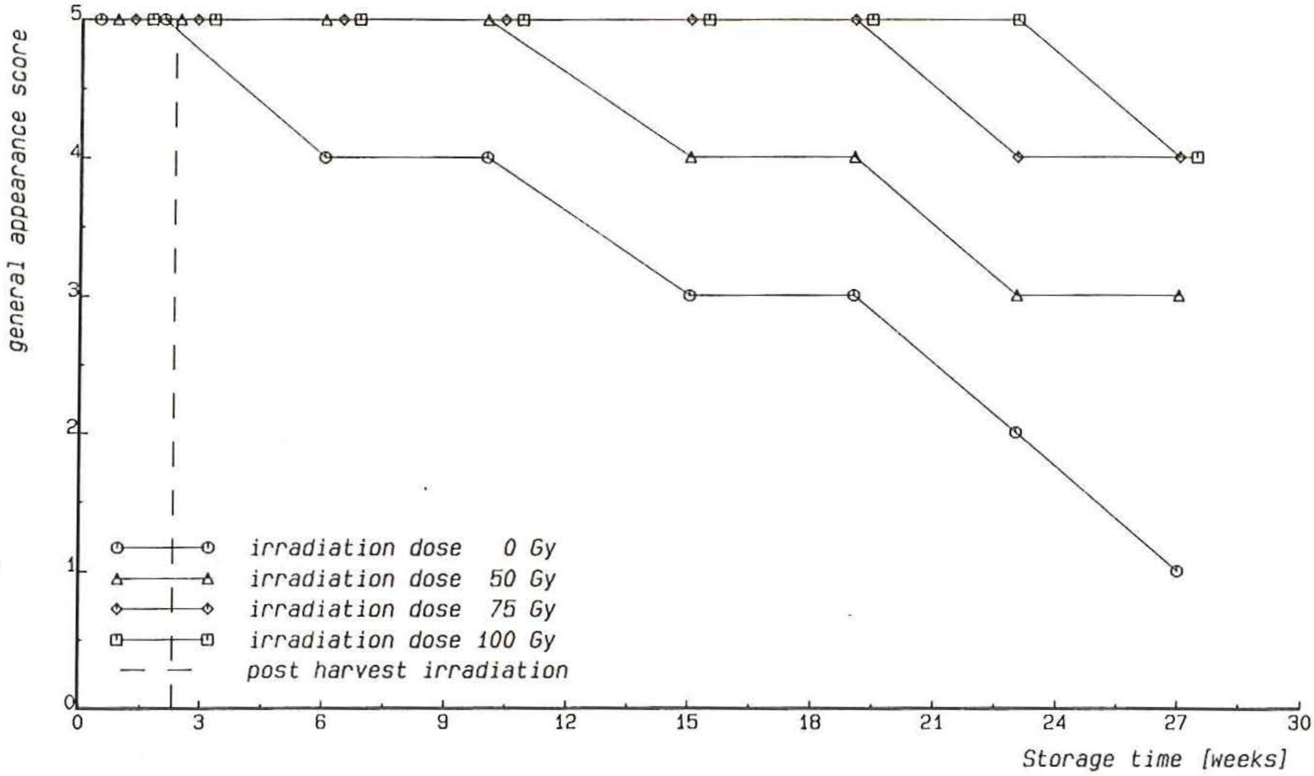

Figure 14: Average general appearance ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 10 °C.

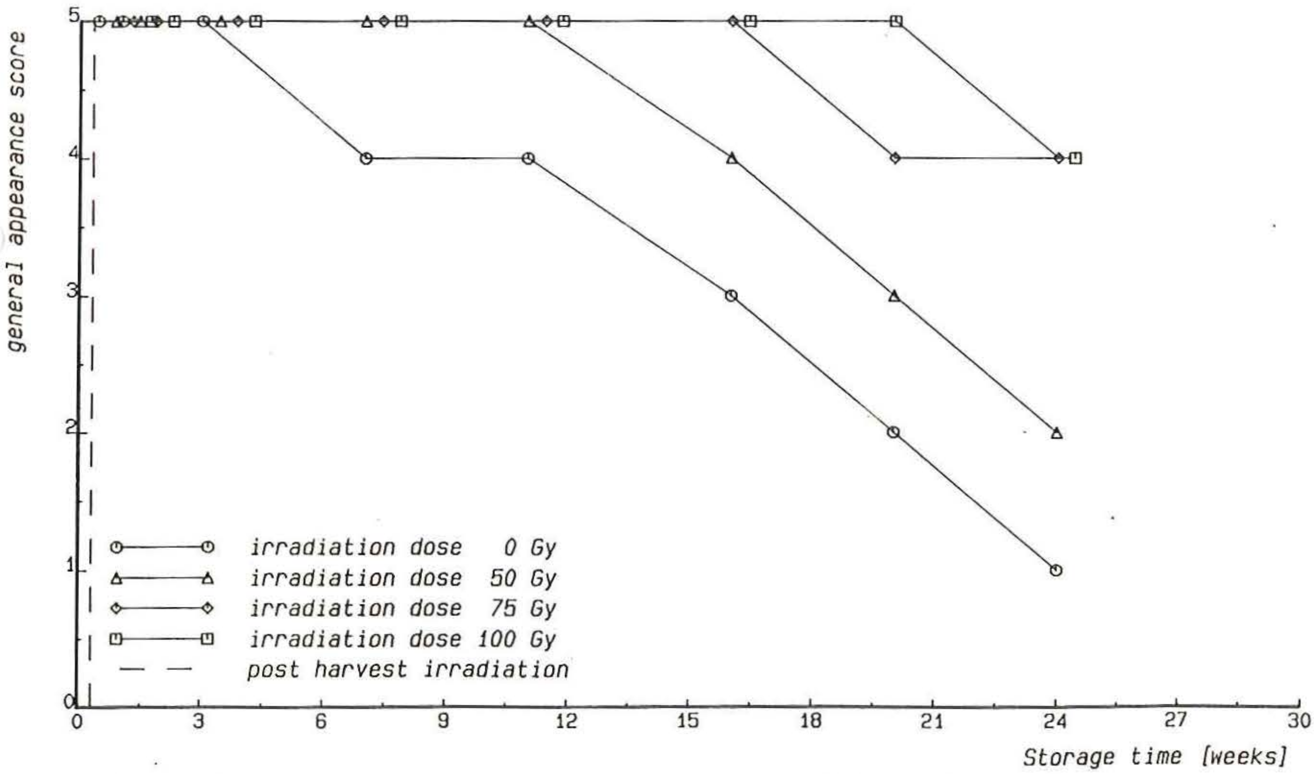

Figure 15: Average general appearance ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

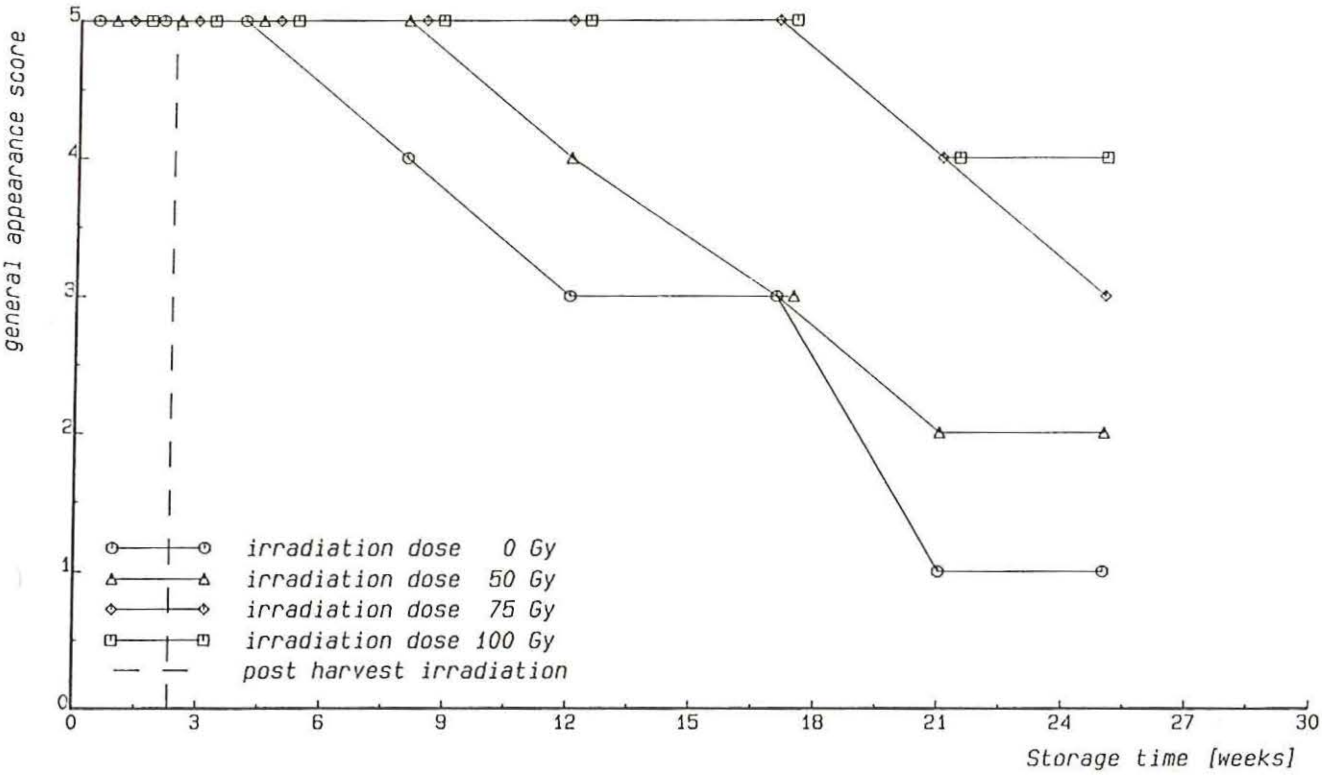

Figure 16: Average general appearance ± SE of 5 samples of 25 potatoes, post-harvest irradiated after 2 weeks storage at 15 °C and subsequently stored at 20 °C.

3.2 Chemical analyses

3.2.1 Vitamin C content

The results of the dehydro ascorbic acid (DHAA) and total vitamin C content determinations are presented in figures 17 to 20.

It proves from the results that the effect of a wound healing period and a irradiation dose on the DHAA content is not clear, because the variation (spread) in the same objects is larger than the difference between the treatments.

In general the DHAA content was higher for the product stored at 10 °C, than at 20 °C. No relation was stated between the start of sprouting and an increase of DHAA content as was expected. So this chemical parameter was not suited for the determination of the break of dormancy period.

In contrast with the DHAA content the vitamin C content was considerable higher for the product stored at 20 °C than at 10 °C. This proves that storage of products at too low temperatures causes stress.

An irradiation treatment with doses of 50, 75 and 100 Gy reduces the vitamin C retention with 15, 20 and 24% repectively. Also after a postponed irradiation treatment of 2, 4 and 6 weeks (wound healing period) a reduction of vitamin C was determined, so irradiation has a direct effect. This direct effect disappeared during storage. The restoration of the vitamin C content was considerably quicker for the product stored at 20 °C than at 10 °C. In the first experiment (Langerak et al. 1986) it seemed that, for the product stored at 20 °C, the vitamin C content was already equal to the control after 2 weeks. For the product stored at 10 °C this same level was reached after 6 weeks. However, in the 2nd experiment the effect of irradiation on the vitamin C content, in the product stored at 10 °C, was measurable to the end of the storage period.
On the end of the storage period of this 2nd experiment the vitamin C content of the treated samples stored at 20 °C was also higher than of the control.

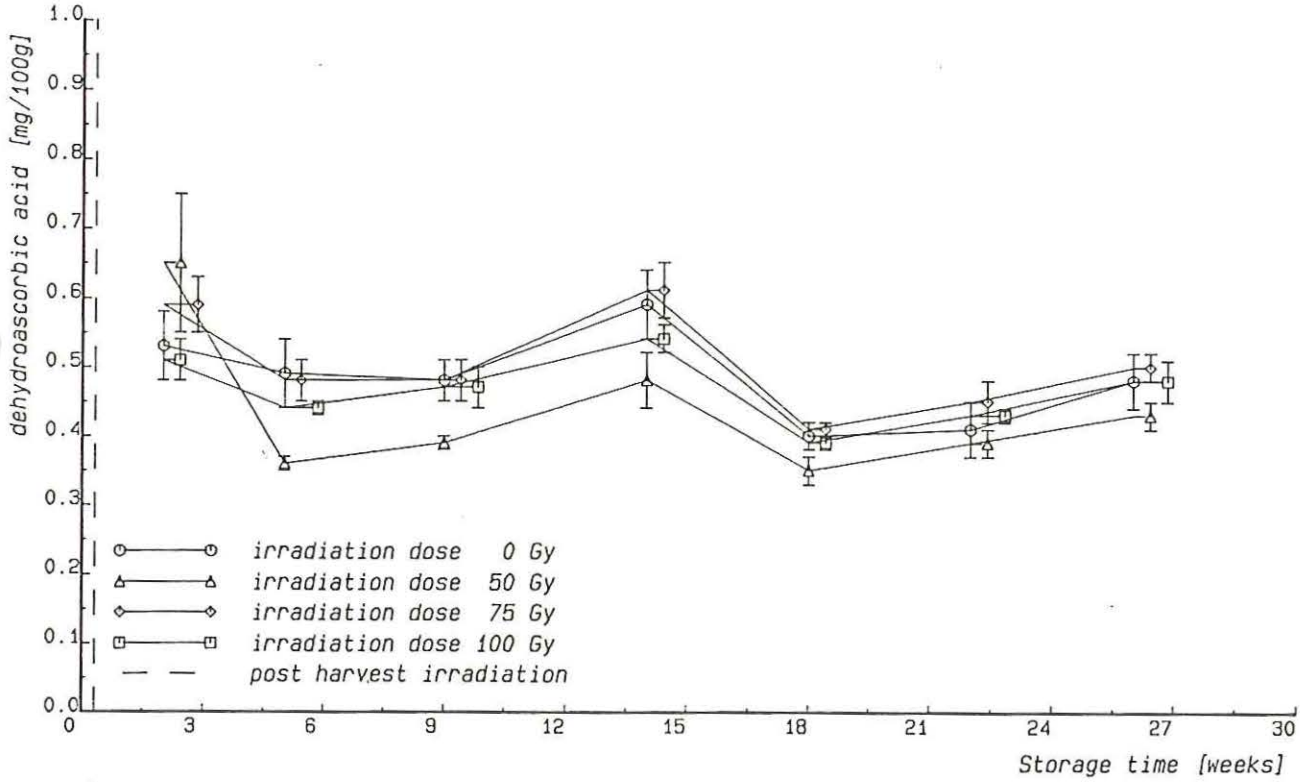

Figure 17: Average dehydro ascorbic acid content ± SE of 5 samples of 10 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 10 °C.

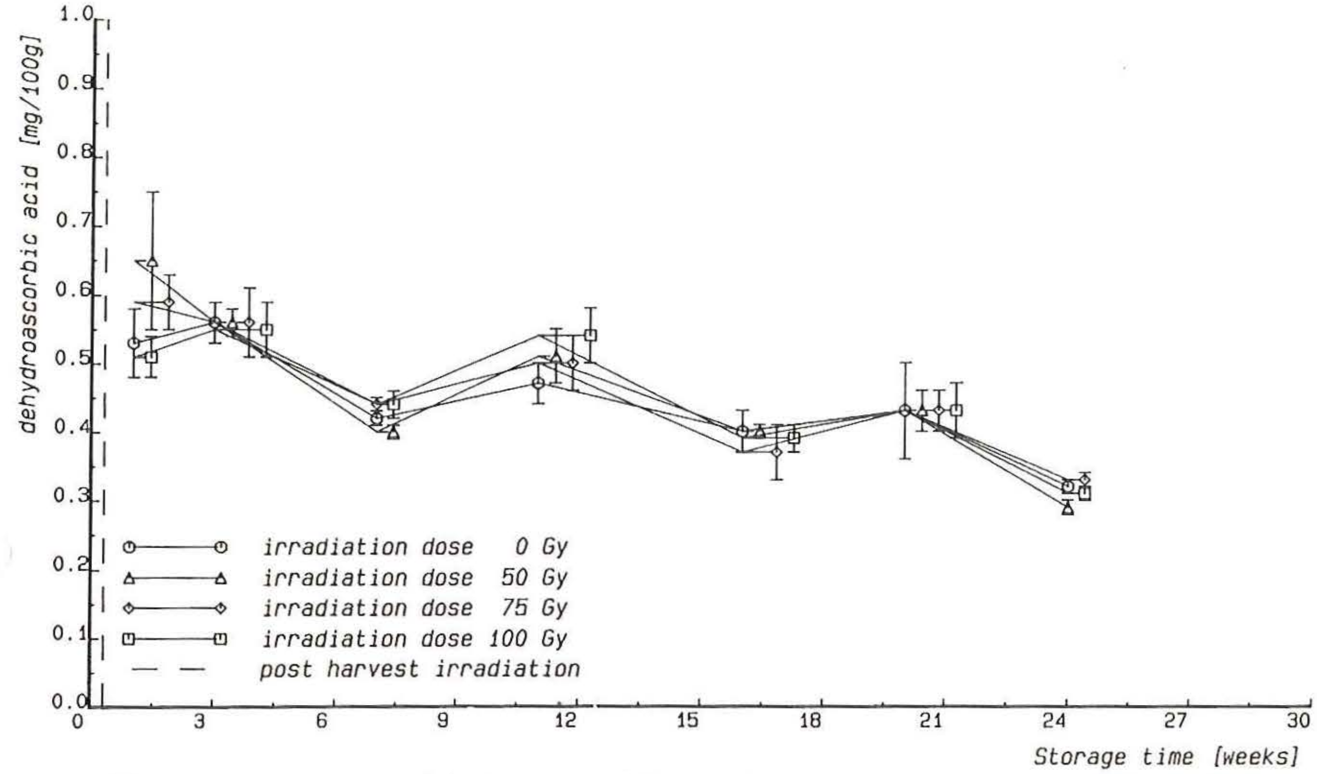

Figure 18: Average dehydro ascorbic acid content ± SE of 5 samples of 10 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

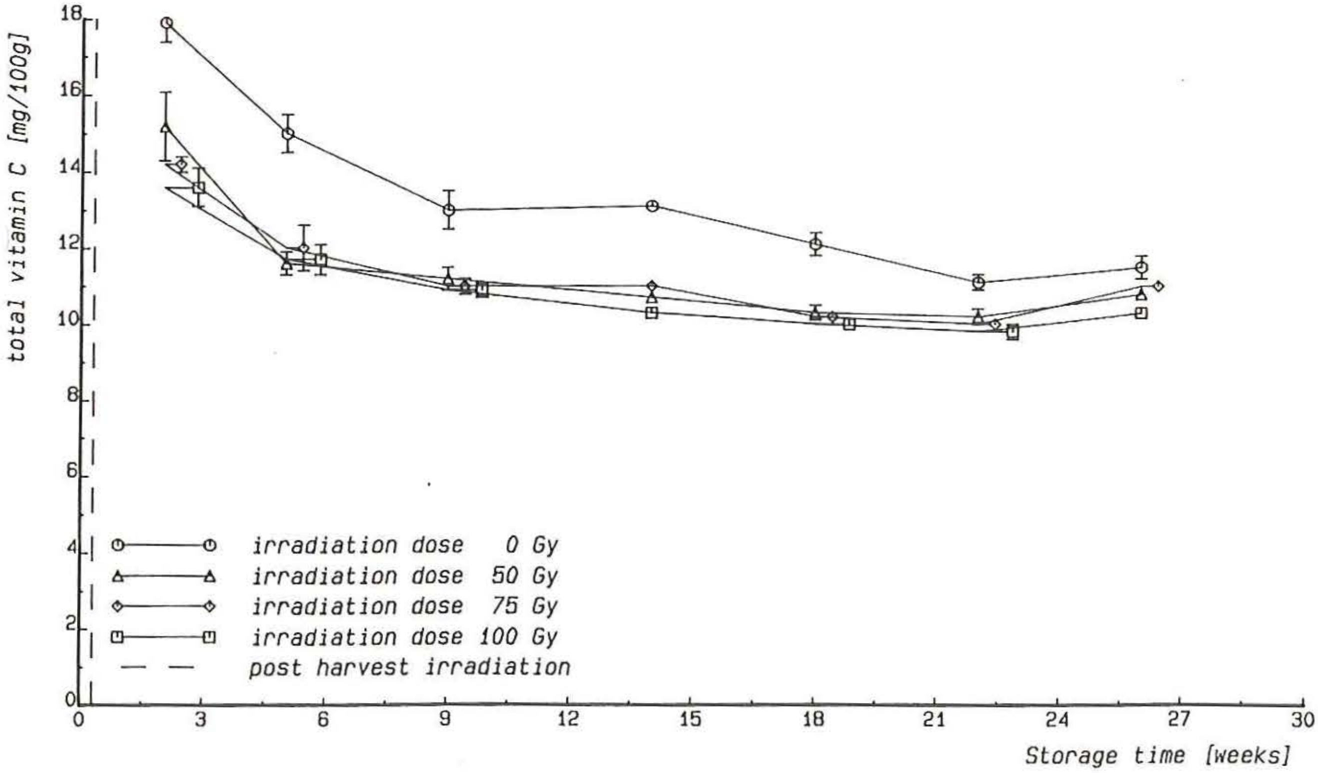

Figure 19: Average total vitamin C content ± SE of 5 samples of 10 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 10 °C.

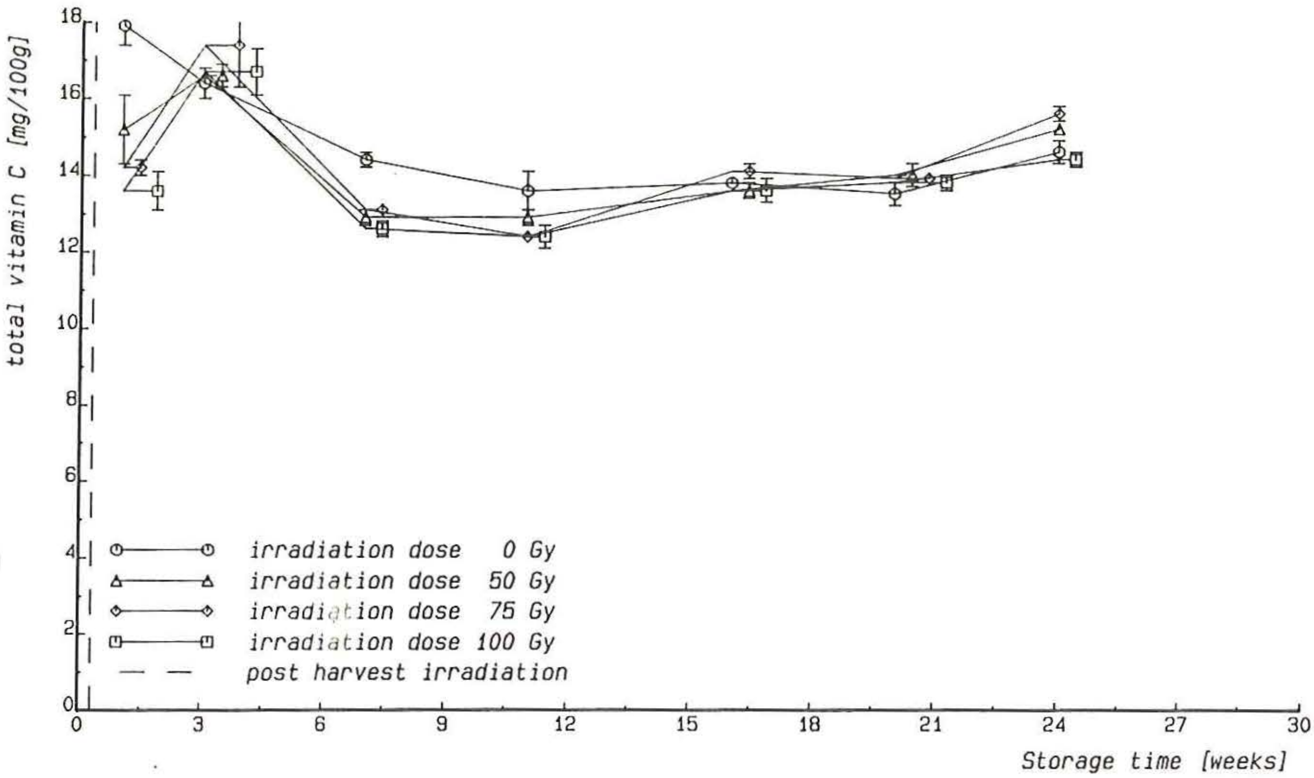

Figure 20: Average total vitamin C content ± SE of 5 samples of 10 potatoes, post-harvest irradiated after 0 weeks storage at 15 °C and subsequently stored at 20 °C.

3.2.2 Sugar content

The sugar content for the raw as well as deep fat fried potatoes are presented in figures 21 to 32.

Since the analysis were carried out as much as possible together with the sensory evaluation, only a rough impression of the effect of irradiation on reducing and non-reducing sugars can be given.

Also in conformity with the 1st experiment (Langerak 1986) it proves that the reducing sugar content (glucose and fructose) of potatoes stored at 10 °C was higher than at 20 °C. An irradiation treatment increased the reducing sugar content after treatment, but this amount leveled down during storage, resulting in a lower content than the control at the end of the storage period.

In general the glucose content was higher than the fructose content.

In contrast with the reducing sugars the non-reducing sugar content (sucrose) was for the product stored at 20 °C higher than at 10 °C, probably related to a higher respiration activity.

At the end of the storage period at 20 °C the sucrose content of the control was lower than the sucrose content of the irradiated samples due to sprouting activity consuming energy. This was also in agreement with research carried out on potatoes treated with chemical sprout inhibitors. In the untreated potatoes the sucrose content was lower than in the chemical treated samples related to a higher energy consumption of the sprouted potatoes (van Es & Hartmans 1981).
In deep fat fried potatoes the reducing sugar content was, in the potatoes stored before frying at 10 °C, considerably higher than in potatoes stored at 20 °C. An irradiation treatment enhanced the sugar content and that was reflected also in a browner colour of the fried product as compared with the control. In agreement with the results in raw potatoes, also in deep fat fried potatoes the sucrose content was, in potatoes stored at 20 °C, higher than in the potatoes stored at 10 °C. At the end of the storage period this content increases faster in the irradiation treated samples than in the control.

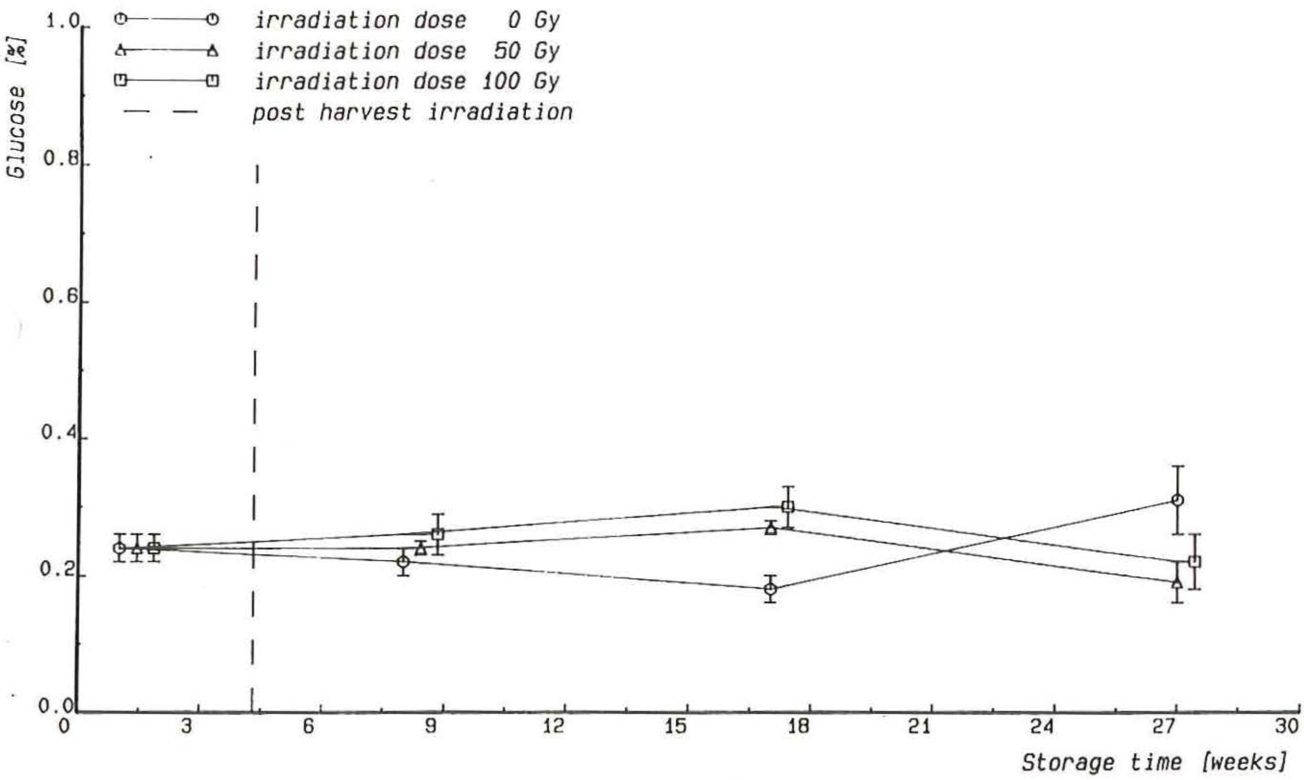

Figure 21: Average glucose content ± SE of 5 samples of 10 raw potatoes, post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

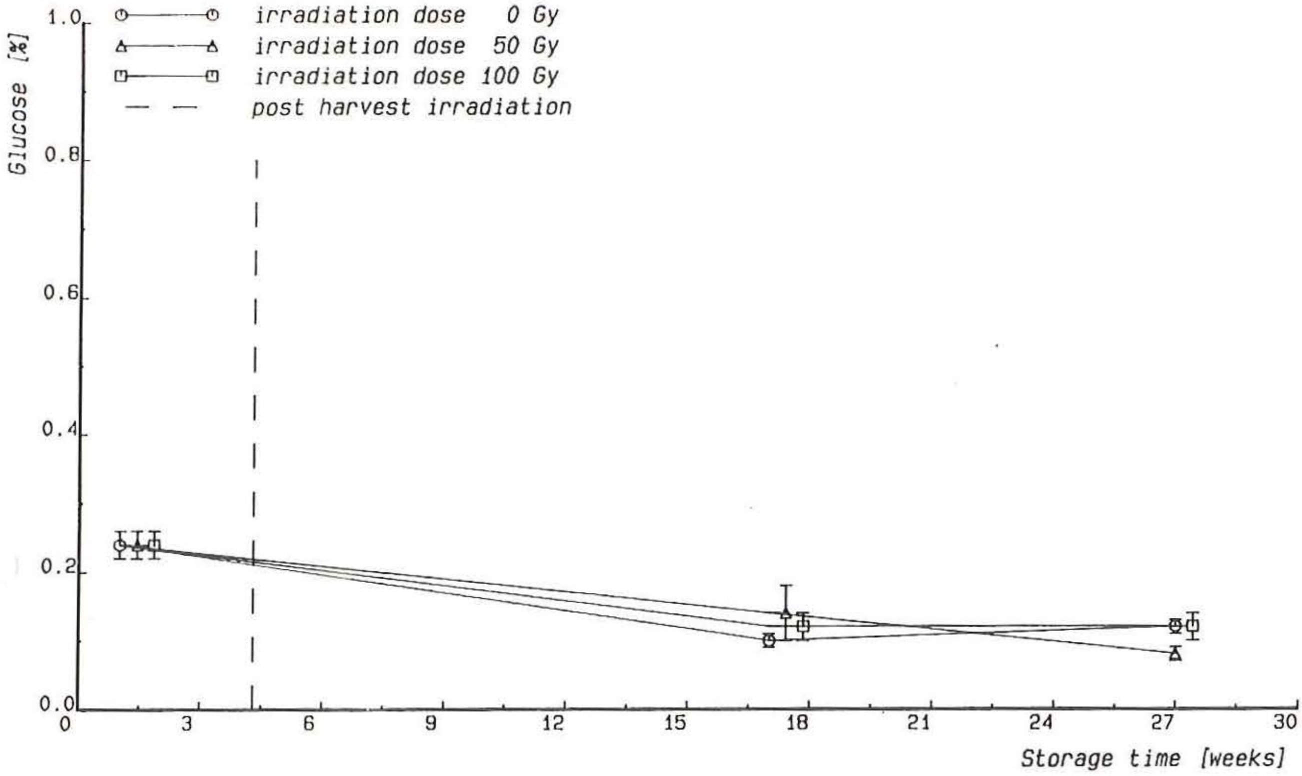

Figure 22: Average glucose content ± SE of 5 samples of 10 raw potatoes, post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

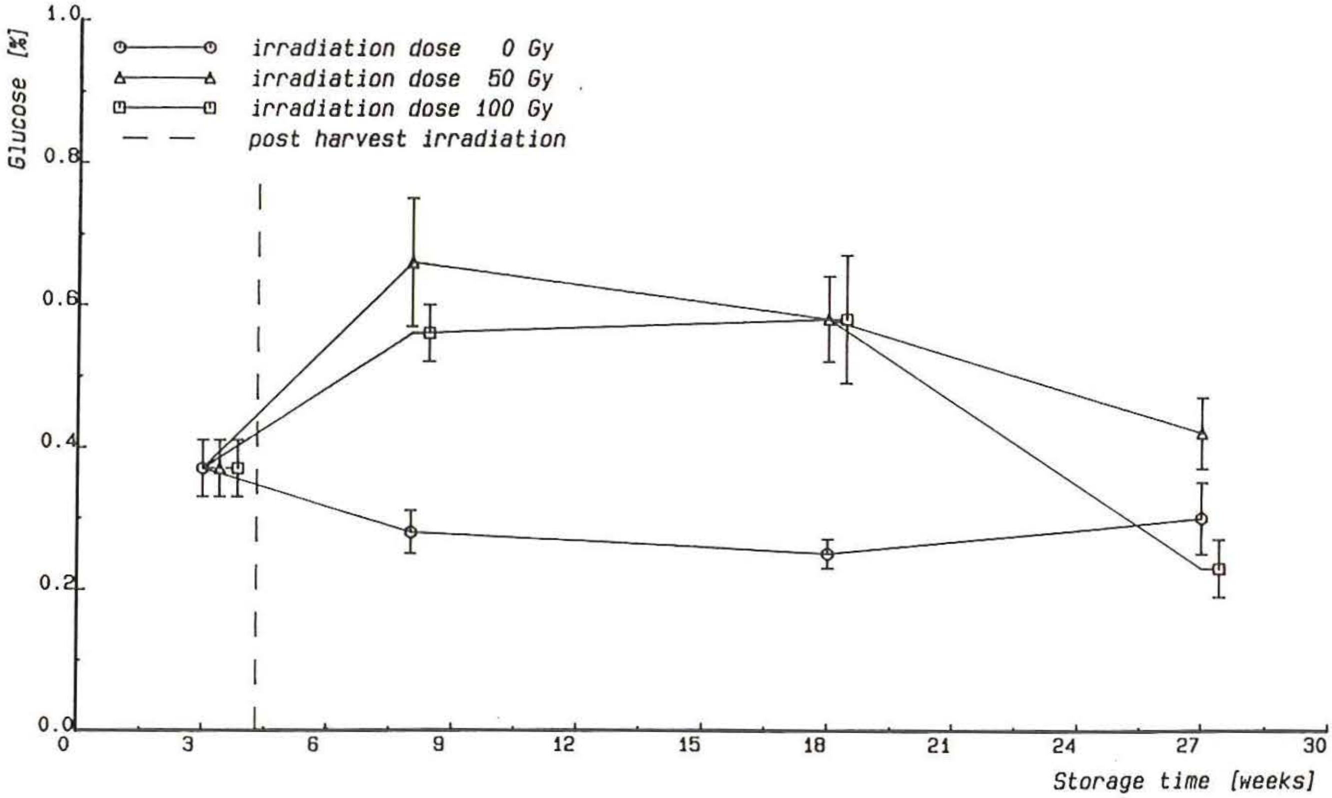

Figure 23: Average glucose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

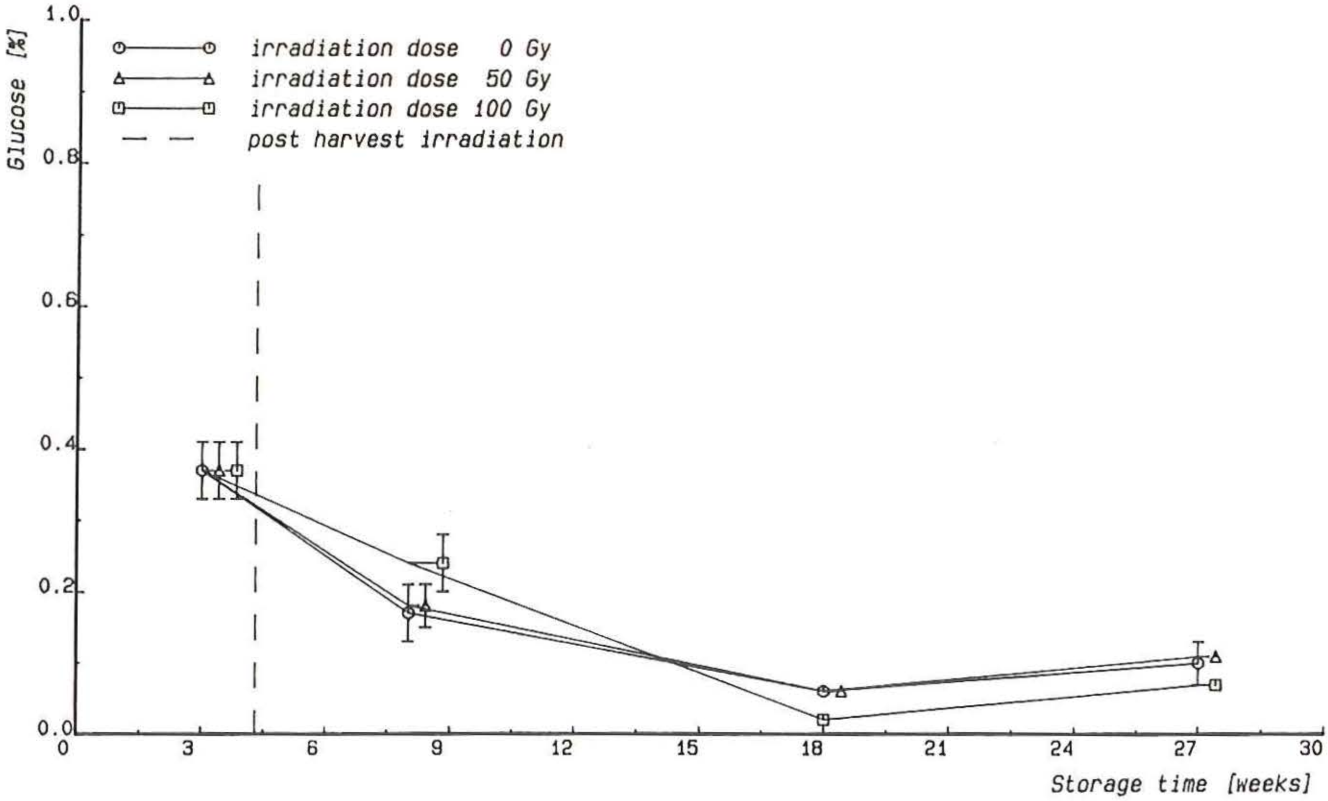

Figure 24: Average glucose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

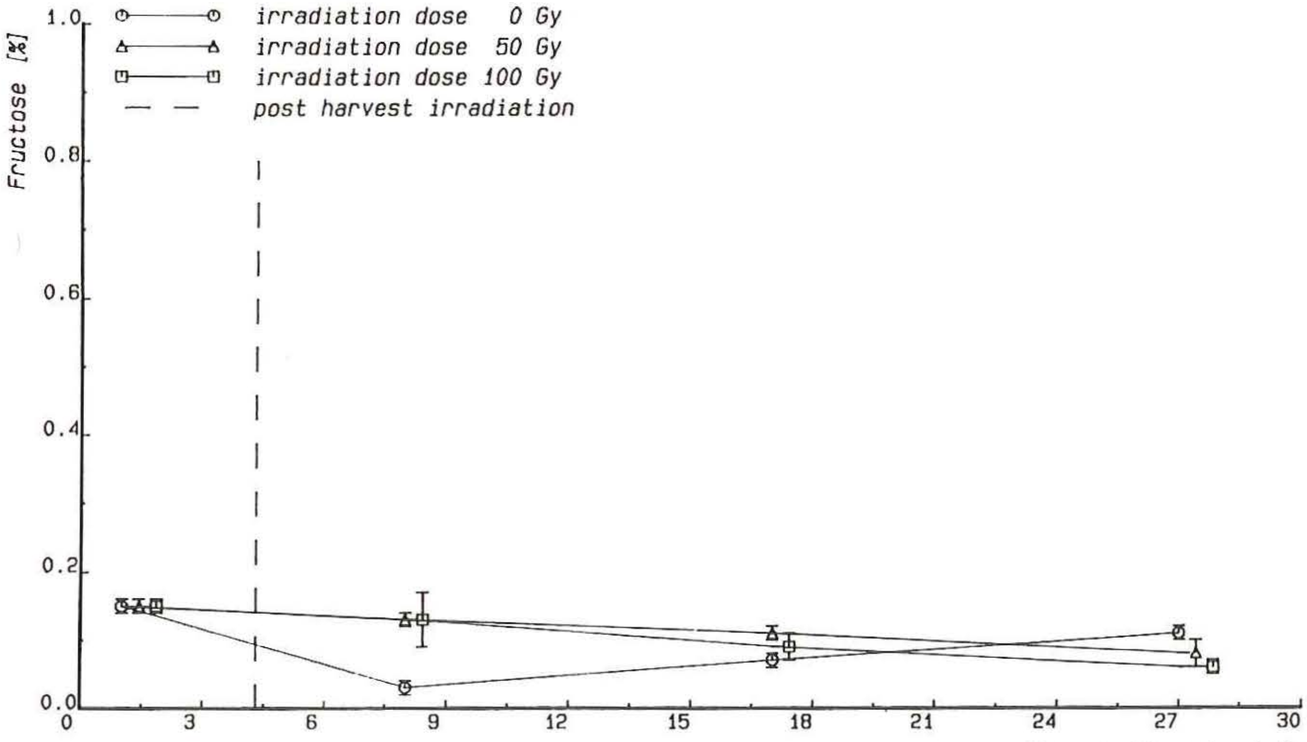

Figure 25: Average fructose content ± SE of 5 samples of 10 raw potatoes, post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

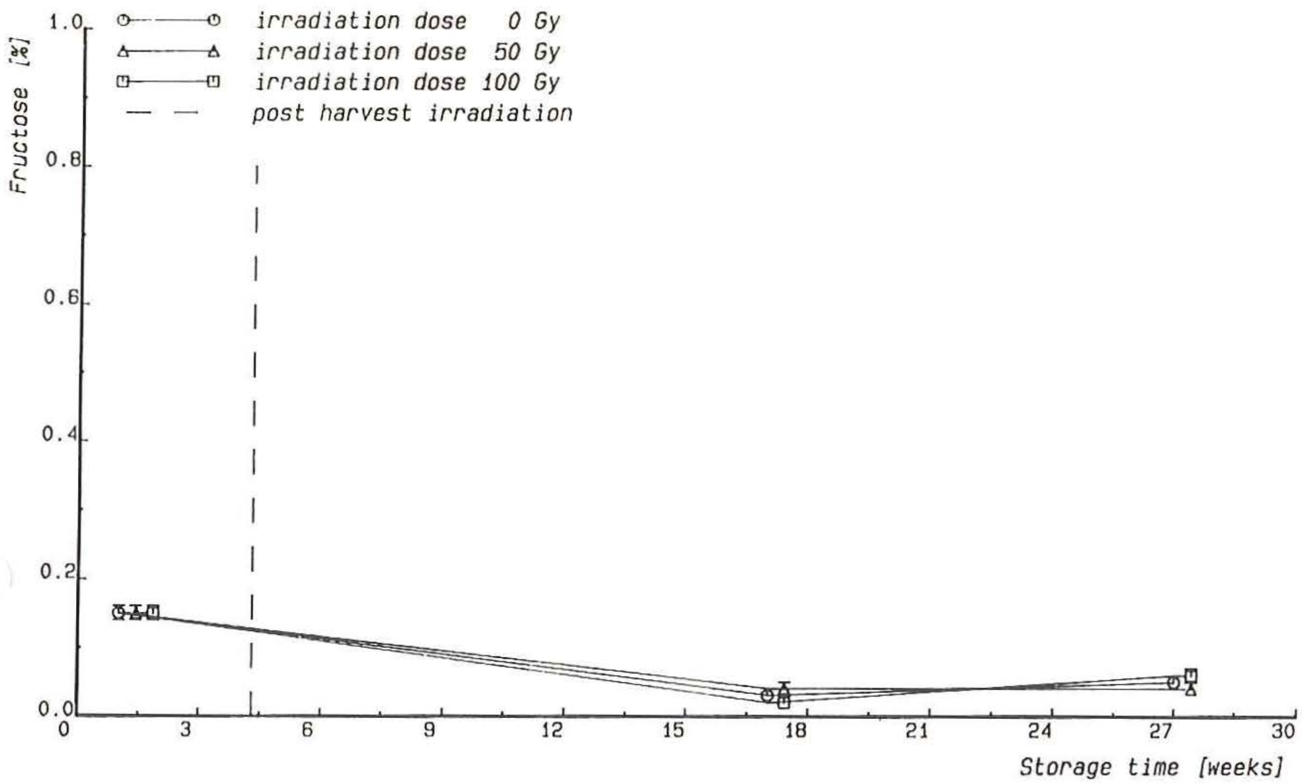

Figure 26: Average fructose content ± SE of 5 samples of 10 raw potatoes post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

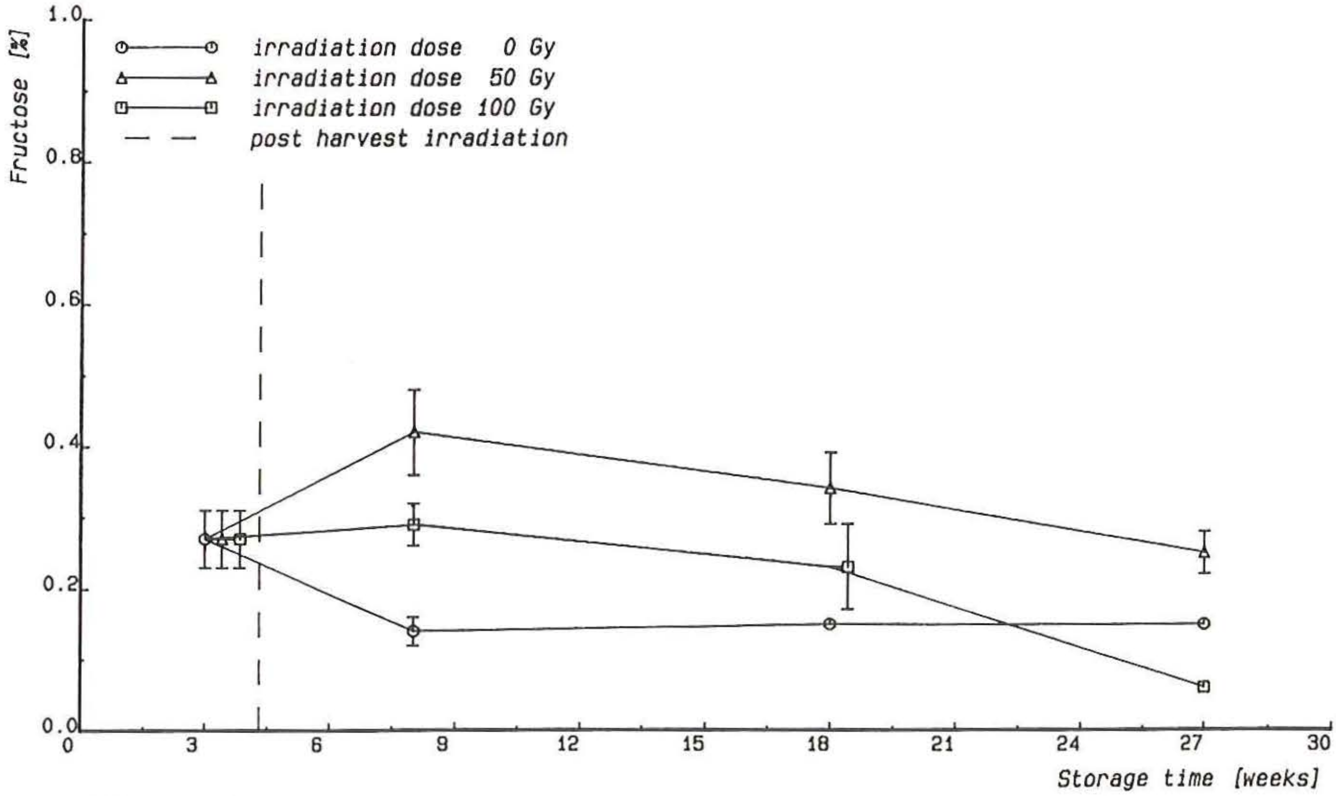

Figure 27: Average fructose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

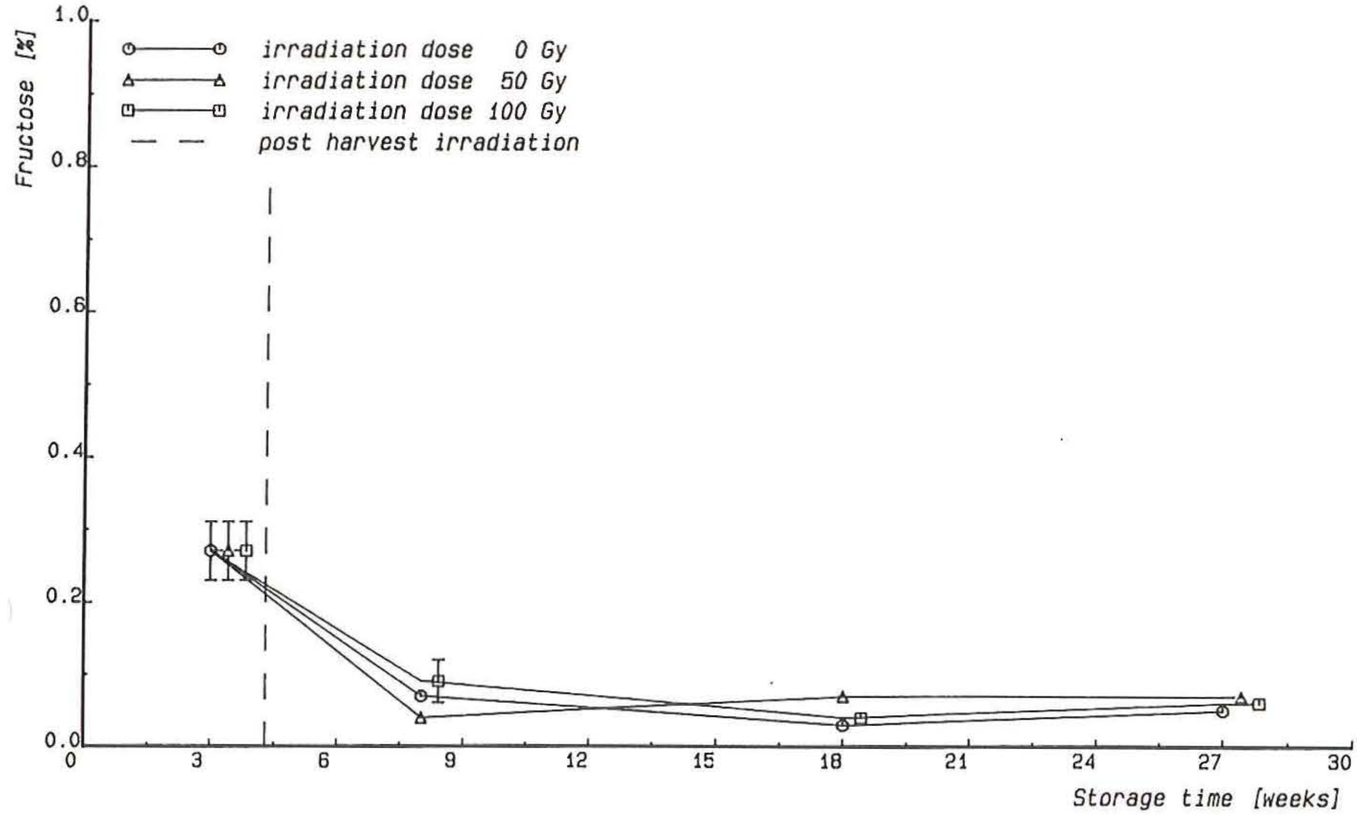

Figure 28: Average fructose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

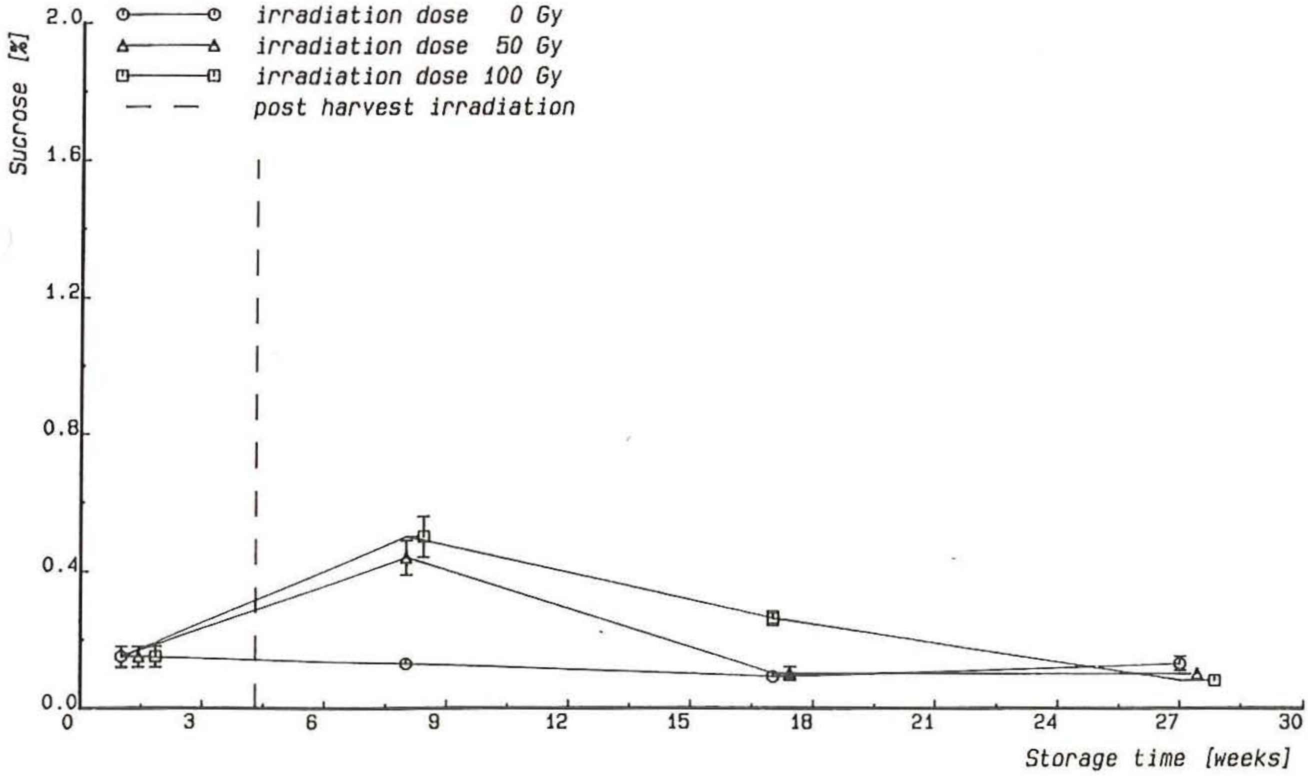

Figure 29: Average sucrose content ± SE of 5 samples of 10 raw potatoes, post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

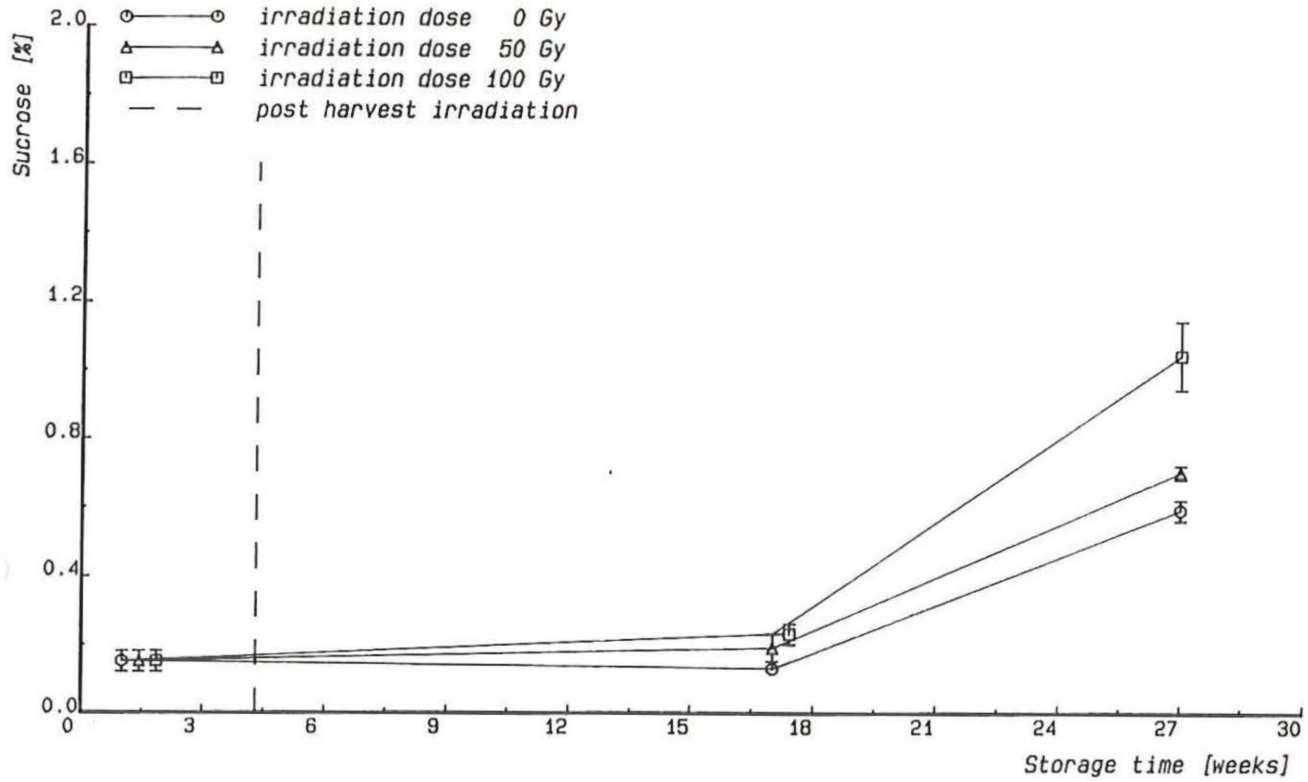

Figure 30: Average sucrose content ± SE of 5 samples of 10 raw potatoes post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

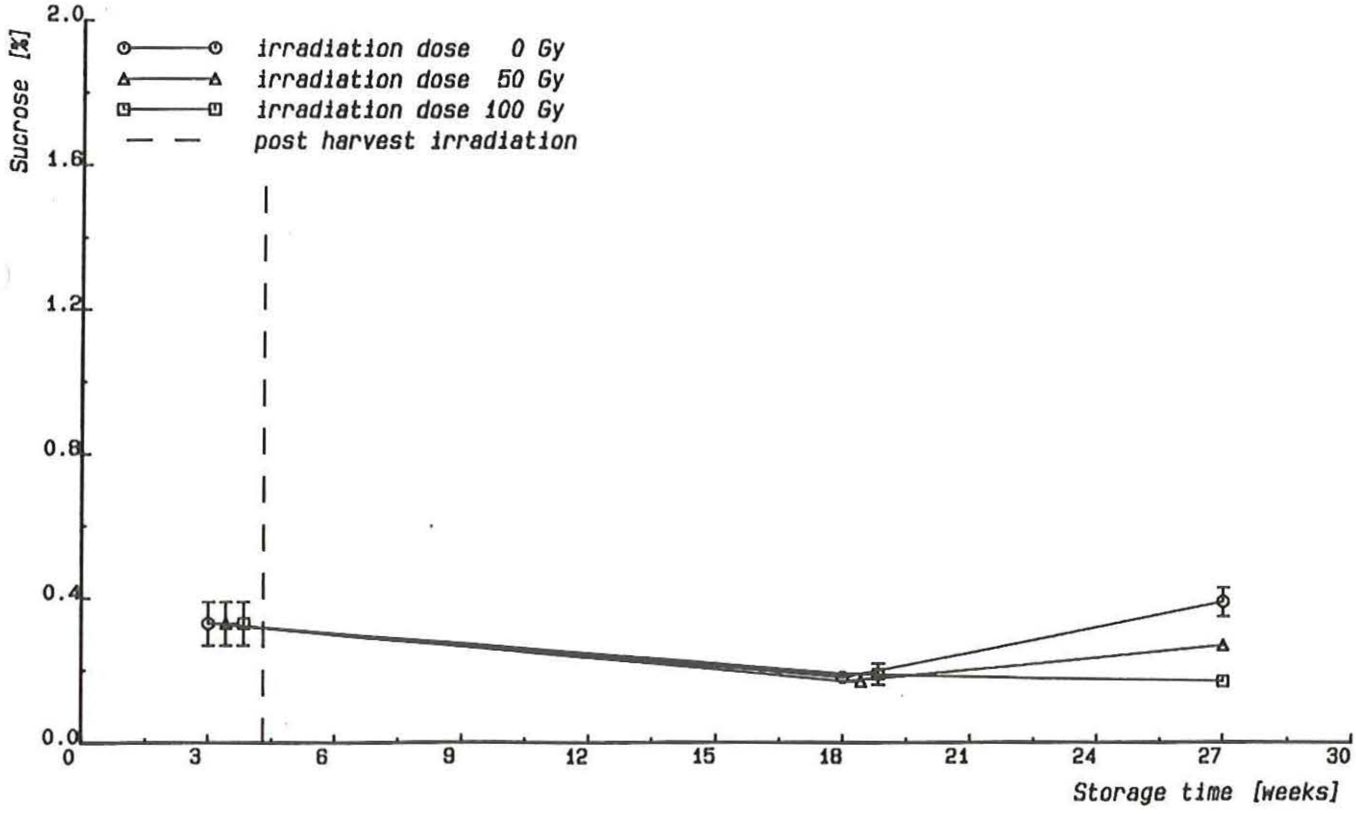

Figure 31: Average sucrose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 10 °C.

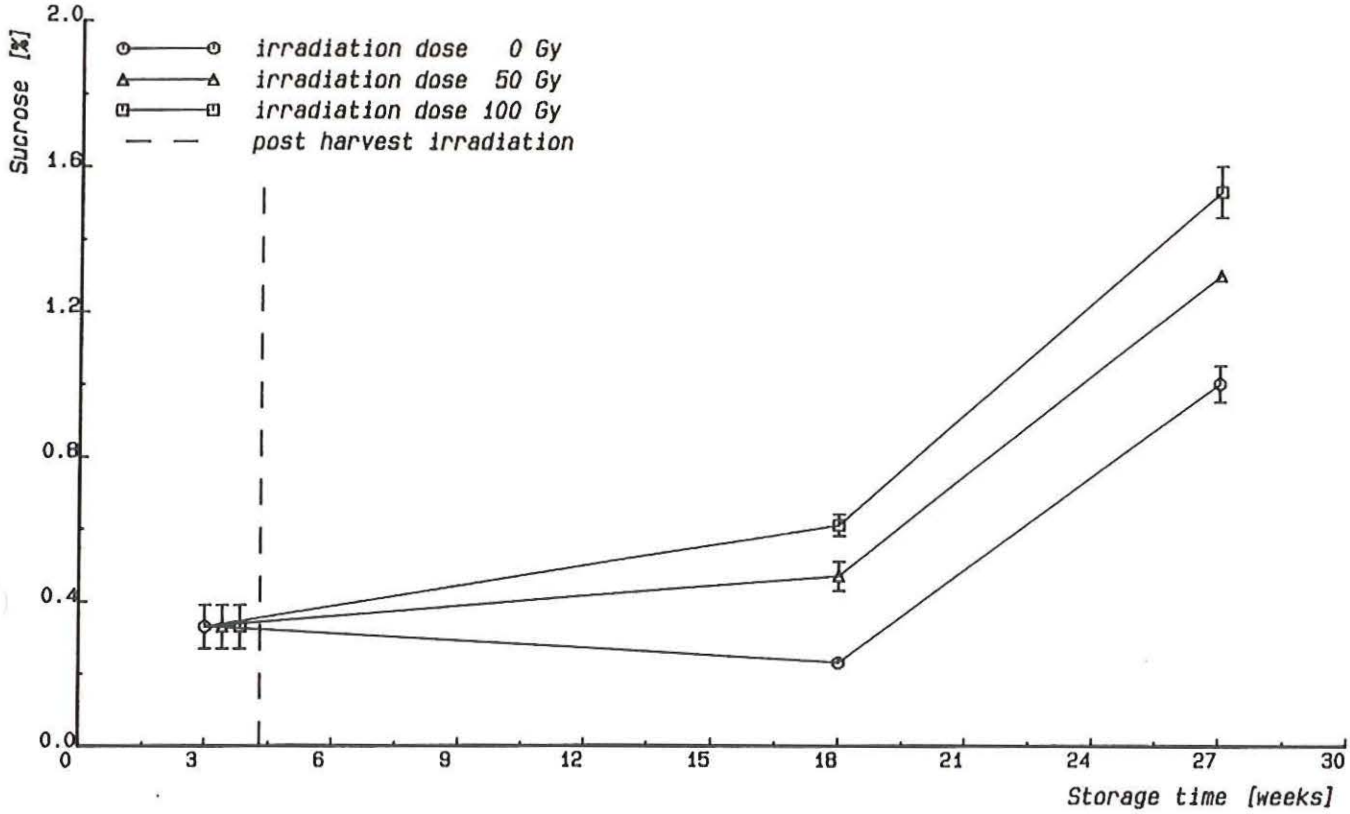

Figure 32: Average sucrose content ± SE of 5 samples of deep fat fried potatoes. Prior frying the product was post-harvest irradiated after 4 weeks storage at 15 °C and subsequently stored at 20 °C.

3.3 Sensory evaluation

In table 5 are given the colour values (light = lower value, dark = higher value). Table 6 shows the differences between the control and irradiated samples.

It proves from the results that an irradiation treatment significantly influenced the colour of deep fat fried potatoes when the product was stored at 10 °C before frying. The colour of the treated potatoes was browner than the control as a consequence of the Maillard reaction. This discolouration was the largest 4 weeks after the irradiation treatment and decreased during storage. A dose effect (50 or 100 Gy) was not clear.

From the potatoes stored at 20 °C prior irradiation, the discolouration was consequently smaller than in the product stored at 10 °C. The colour was very close to the control.

In general the colour of deep fat fried potatoes stored before frying at 20 °C was lighter than potatoes stored at 10 °C, due to a lower reducing sugar content.

The taste of deep fat fried potatoes was not significantly affected by the storage temperature nor by an irradiation treatment. Only in the product stored at 10 ^{o}C a small difference was found at 100 Gy, 4 weeks after applying irradiation.

Table 5: Average sensory value [mm] ± SE of potatoes, post-harvest irradiated after 4 weeks storage at 15 ^{o}C, subsequently stored at different temperatures deep fat fried and tested by 18 panel members on colour and taste.

storage temp [^{o}C]	storage period [weeks]	colour irradiation dose [Gy]			taste irradiation dose [Gy]		
		0	50	100	0	50	100
15	***						
10	4	44 ± 2	54 ± 2	49 ± 2	35 ± 2	39 ± 2	30 ± 2
	8	34 ± 2	60 ± 2	64 ± 1	33 ± 2	37 ± 2	42 ± 2
	17	35 ± 2	57 ± 1	53 ± 2	40 ± 2	40 ± 2	34 ± 2
	27	32 ± 2	47 ± 2	39 ± 2	34 ± 2	34 ± 2	28 ± 2
15	***						
20	4	44 ± 2	54 ± 2	49 ± 2	35 ± 2	39 ± 2	30 ± 2
	8	36 ± 2	33 ± 2	40 ± 2	38 ± 2	35 ± 2	36 ± 2
	17	18 ± 2	25 ± 2	22 ± 1	35 ± 2	38 ± 2	30 ± 2
	27	21 ± 2	24 ± 2	37 ± 1	38 ± 2	40 ± 2	43 ± 2

*** = time of irradiation

Table 6: Average sensory value, relative as compared with the control, [mm] ± SE of potatoes, post-harvest irradiated after 4 weeks storage at 15 ^{o}C, subsequently stored at different temperatures deep fat fried and tested by 18 panel members on colour and taste.

storage temp [^{o}C]	storage period [weeks]	colour irradiation dose [Gy]			taste irradiation dose [Gy]		
		0	50	100	0	50	100
15	***						
10	4	0 ± 2	10* ± 2	5 ± 2	0 ± 2	4 ± 2	-5 ± 2
	8	0 ± 2	26* ± 2	30* ± 1	0 ± 2	4 ± 2	9* ± 2
	17	0 ± 2	22* ± 1	18* ± 2	0 ± 2	0 ± 2	-6 ± 2
	27	0 ± 2	15* ± 2	7* ± 2	0 ± 2	0 ± 2	-6 ± 2
15	***						
20	4	0 ± 2	10* ± 2	5 ± 2	0 ± 2	4 ± 2	-5 ± 2
	8	0 ± 2	-3 ± 2	4 ± 2	0 ± 2	-3 ± 2	-2 ± 2
	17	0 ± 2	7+ ± 2	4 ± 1	0 ± 2	3 ± 2	-5 ± 2
	27	0 ± 2	3 ± 2	16* ± 1	0 ± 2	2 ± 2	5 ± 2

*** = time of irradiation
\+ = significant, as compared with control, at probability 5%
* = significant, as compared with control, at probability 1%

3.4 Brightness measurement by physical instrument

The results of the measurements are collected in table 7. A higher reflection results in a brighter colour (yellower).
It proved from the data that the brightness of deep fat fried potatoes depends on the irradiation dose, the storage temperature and storage time.
In general the brightness of the product decreased with an increased dose; the difference between 50 and 100 Gy was, however, small. The colour of the potatoes stored at 20 °C prior frying was brighter than the product stored at 10 °C. Also the differences in colour between the control and irradiated samples was at 20 °C smaller than at 10 °C. These results were in agreement with the findings of the sensory evaluation; the product stored at 10 °C was browner than at 20 °C, as a consequence of the higher sucrose content (Maillard reaction).
In general the brightness of deep fat fried potatoes declined on the end of the storage period.

Table 7: Result of physical measurement of brightness [% reflection] of potatoes post-harvest irradiated after 4 weeks of storage at 15 °C and subsequently stored at different temperatures, fried at 180 °C.

storage temp. [°C]	period [weeks]	irradiation dose [Gy] 0	50	100
15	***			
10	4	50,7	51,1	50,5
	8	58,5	50,7	48,2
	17	53,0	45,6	44,0
	27	49,3	45,7	44,8
15	***			
20	4	50,7	51,1	50,5
	8	53,6	52,4	50,2
	17	53,7	49,7	47,8
	27	52,9	48,1	48,0

*** = time of irradiation

3.5 Histological examination

In figures 33 to 36 are given the results of the histological examination. The results show a clear effect of temperature, wound healing period and irradiation treatment on the suberization of injured potatoes. The primary suberization started within 1 week after injury and

was completed in approximately 2 weeks, independant of the temperature. The primary wound periderm formation was slightly delayed by an increased irradiation dose.
The secundary suberization, however, was dependant of the temperature and also very sensitive to irradiation. For the product stored at 10 °C the secundary suberization started 1 week after injury and was completed after 6 weeks. For potatoes stored at 15 and 20 °C the secundary suberization was completed after approximately 2 weeks. An irradiation treatment applied immediately after injury of potatoes destroyed the possibility of secundary suberization. Even after 6 weeks no secundary wound periderm was formed.
It proves from above mentioned data that for a complete primary and secundary suberization a wound healing period of at least 2 weeks at 15 or 20 °C is necessary. In general a wound healing period at 20 °C gave the best results.

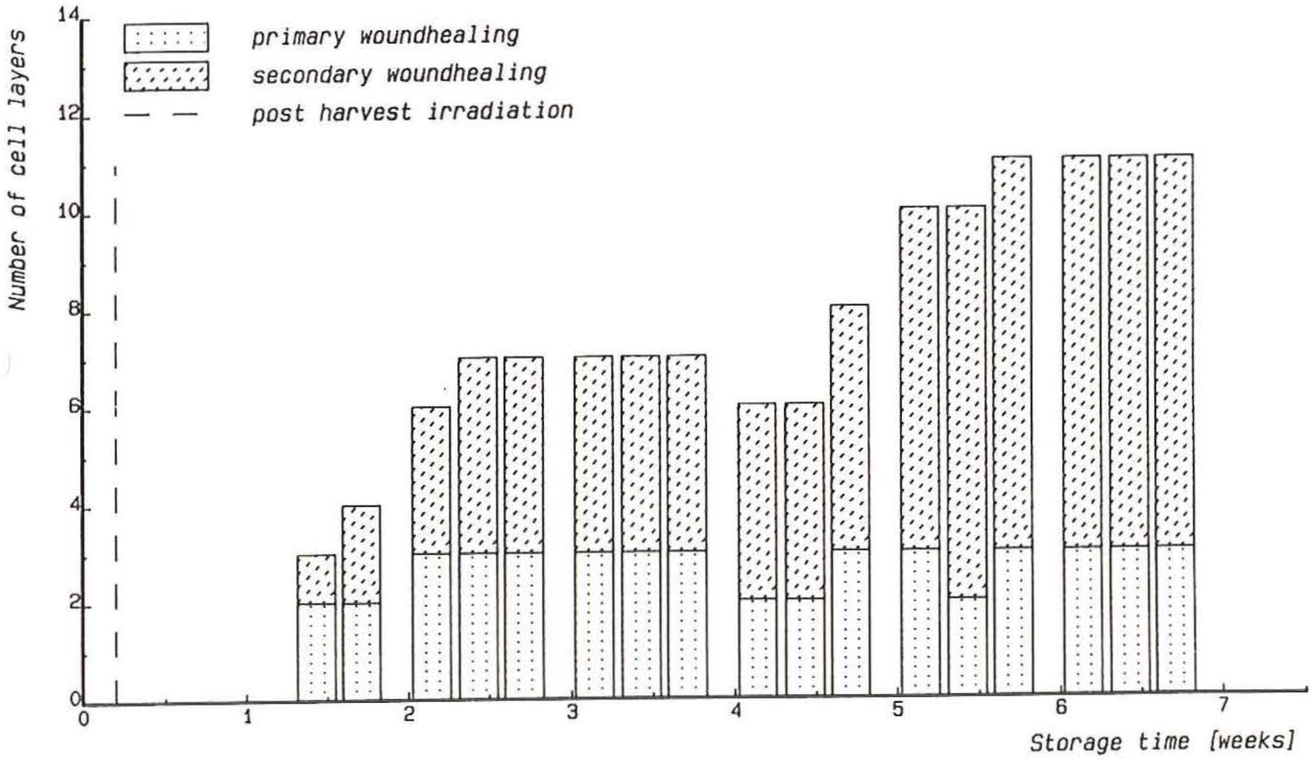

Figure 33: Number of cell layers in artificially injured potatoes, post-harvest irradiated with 0 Gy after 0 weeks storage at 15 °C and subsequently stored at 10 °C up to a total of 7 weeks.

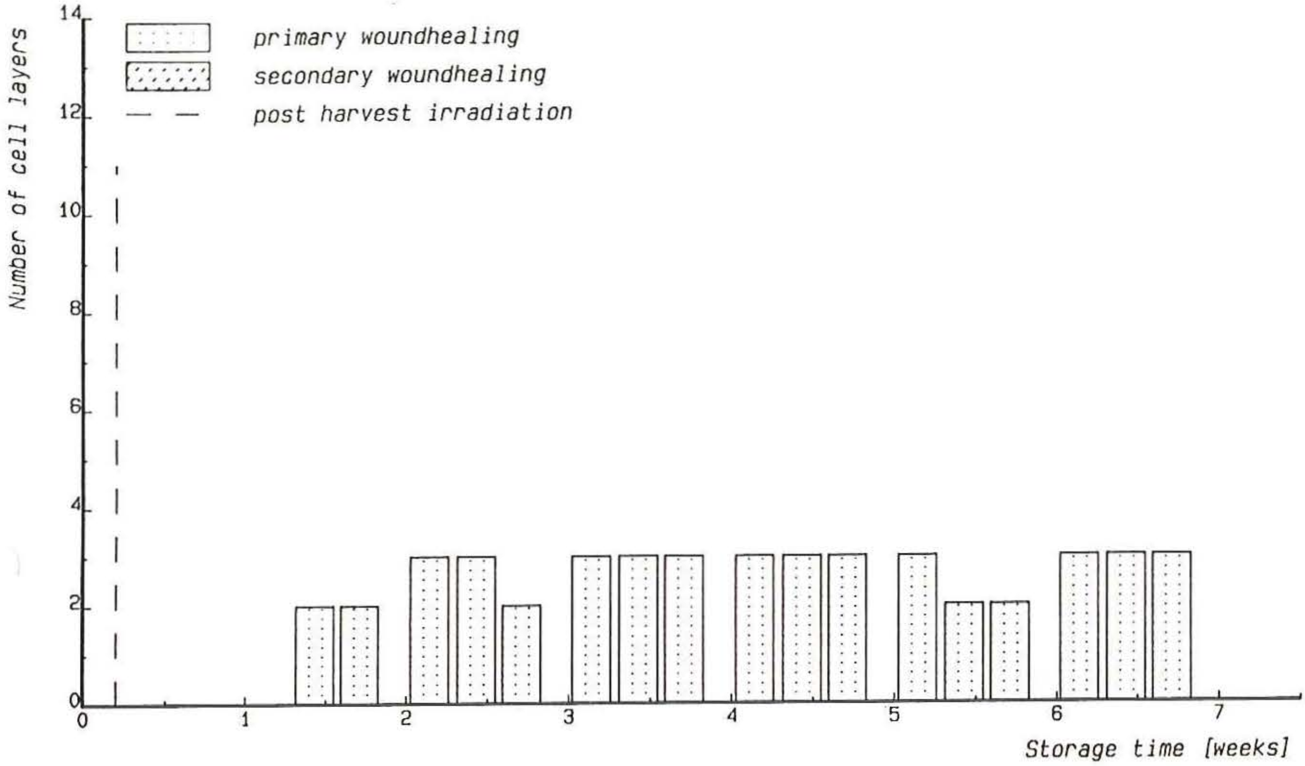

Figure 34: Number of cell layers in artificially injured potatoes, post-harvest irradiated with 50 Gy after 0 weeks storage at 15 °C and subsequently stored at 10 °C up to a total of 7 weeks.

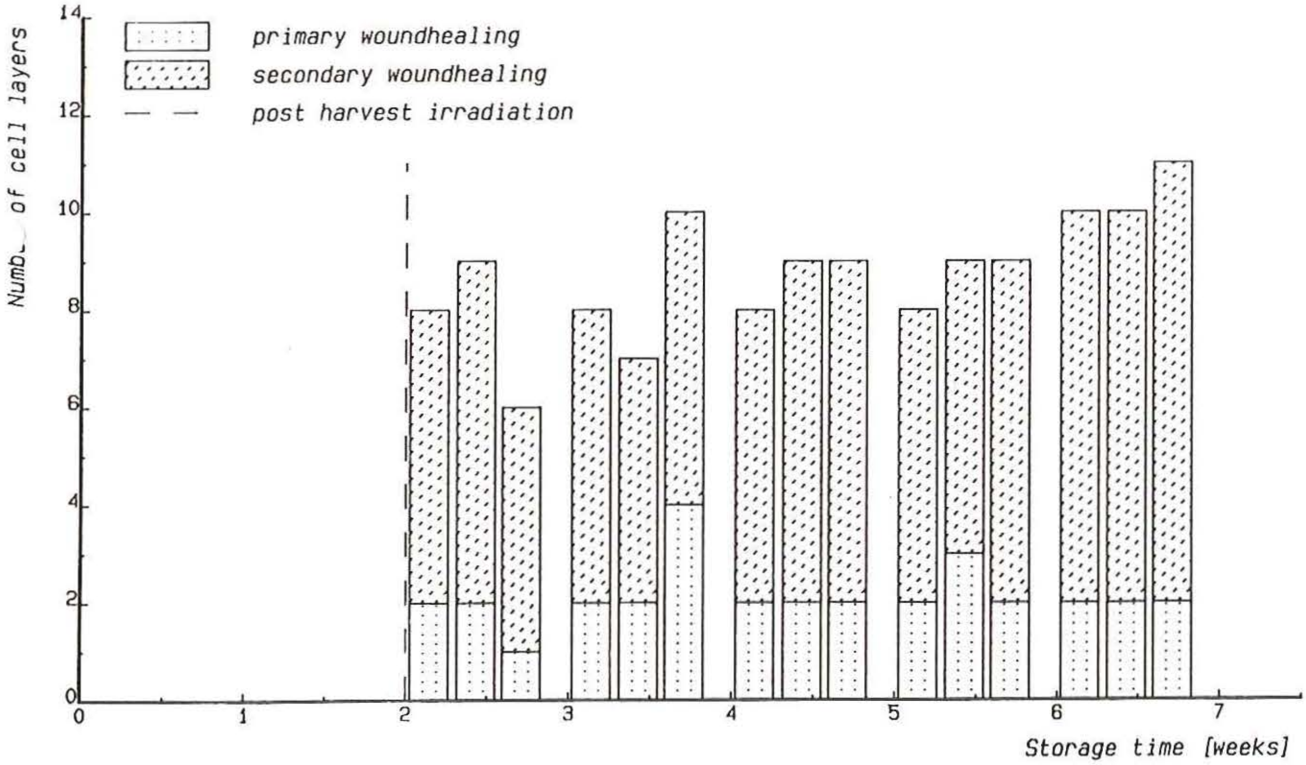

Figure 35: Number of cell layers in artificially injured potatoes, post-harvest irradiated with 0 Gy after 2 weeks storage at 15 °C and subsequently stored at 10 °C up to a total of 7 weeks.

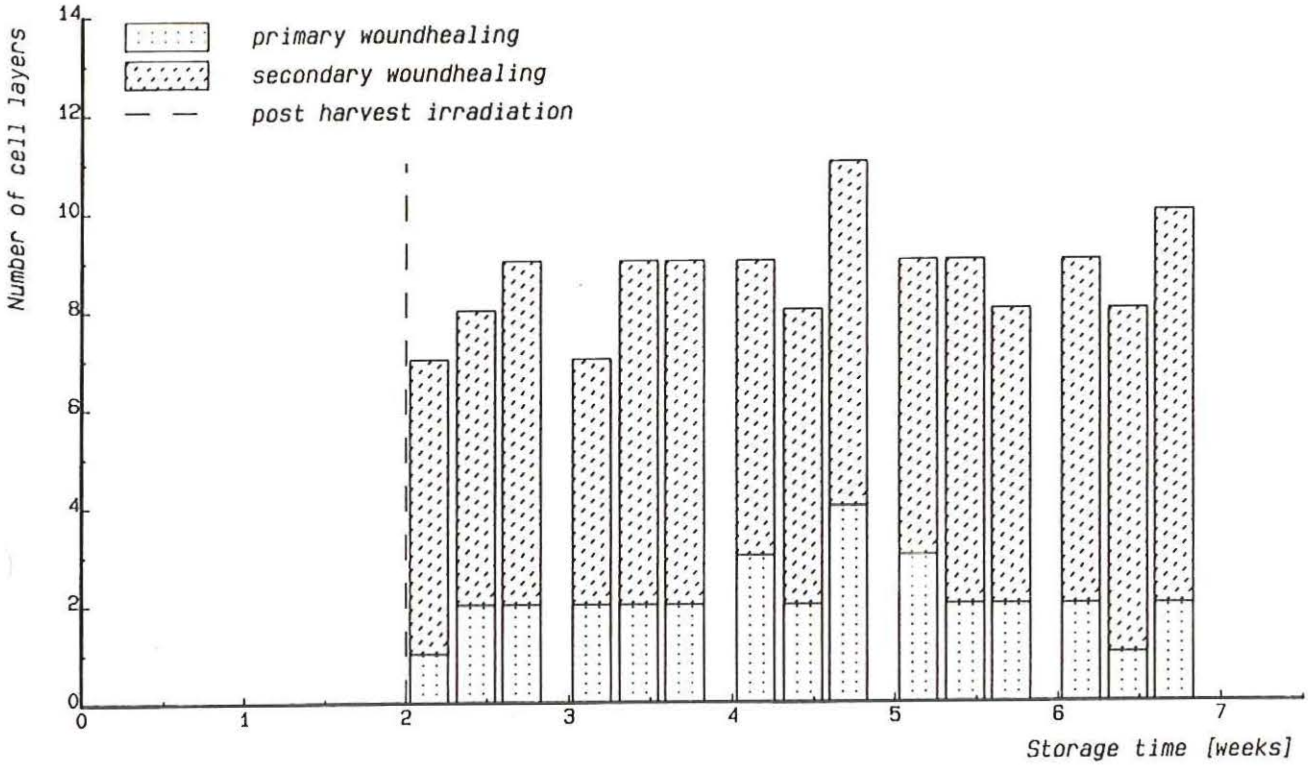

Figure 36: Number of cell layers in artificially injured potatoes, post-harvest irradiated with 50 Gy after 2 weeks storage at 15 °C and subsequently stored at 10 °C up to a total of 7 weeks.

4 CONCLUSIONS

From the results the following conclusions can be drawn:

- During storage at 10 and 20 °C the dormancy period was 5 and 2 weeks respectively;
- A dose of 75 and 100 Gy reduced the loss of weight and gave a complete sprout inhibition to the end of the storage period;
- A dose of 50 Gy stimulated the sprouting of adventive eyes, resulting in a larger number of sprouts per potato. The length of sprouts, however, was limited;
- An irradiation treatment applied immediately after harvest gave the best results concerning sprout inhibition, but for a complete wound healing (primary and secundary suberization) a wound healing period of at least 2 weeks at 15 to 20 °C was necessary;
- In this experiment the percentage of rot did not increase by a irradiation treatment;
- An irradiation treatment reduced the vitamin C content, but did not affect the dehydro ascorbic acid content;

- No relation was stated between the start of sprouting and an increase of dehydro ascorbic acid;
- An irradiation treatment increased the reducing sugar content in deep fat fried potatoes, resulting in a darker colour, especially at potatoes prior frying stored at 10 ^{o}C;
- The increased sugar content did not affect the taste.

REFERENCES

American Society for Testing and Materials (ASTM).
Basic principles of sensory evaluation.
Special Technical Publication 433, 1969.

Atomic Energy of Canada.
An application to the food and drug directorate for approval of the use of gamma radiation from Co-60 for the prevention of sprouting in potatoes.
Department of National Health and Welfare, Otowa, 1962

Boehringer Mannheim GmbH.
Methods of biochemical analysis and food analysis.
Boehringer Mannheim GmbH, Sandhoferstrasse 116, 6800 Mannheim 31, W-Germany, 1986.

Brownell L.E.; F.G. Gustafson; J.V. Nehemias; D.R. Isleib; W.J. Hooker.
Storage properties of gamma irradiated potatoes.
Food Technology 11, 1957, p306.

Burton W.G.; R.S. Hannan.
Use of gamma-radiation for preventing the sprouting of potatoes.
J. Sci. Food Agric, 8, 1957, p707.

Burton W.G.; W.H. de Jong.
The irradiation of ware potatoes.
Int. J. Appl. Radiat. Isot. 6, 1959, p167.

Burton,W.G.
The immediate effect of gamma irradiation upon the sugar content of potatoes previously stored at 2, 4, 5, 6, 10 and 15 °C.
Potato Res. 18, 1975, p109.

Cloutier J.A.R.; C.E. Cox; J.N. Manxon; M.G. Clay; I.E. Johnson.
Effect of storage on the carbohydrate content of two varieties of potatoes grown in Canada and treated with gamma radiation.
Food res., 24, 1959, p659.

Langerak D.Is.; A.B. Cramwinckel; P.C. Hollman; W.J.H.J. de Jong; J.F. Labrijn; H.J. Slangen; H. Stegeman; N.G. van der Veen; Th.C. Wolters; H. Oortwijn.
Application of food irradiation processes to developing countries.
RIKILT report 86.95, P.O. Box 230, 6700 AE, Wageningen, the Netherlands, 1986.

Levis N.F.; P.B. Mathur.
Extension of storage life of potatoes and onions by Cobalt-60 rays.
Int. J. Appl. Radiat. Isotop., 14, 1963, p443.

Matsuyama A.; K. Umeda.
Sprout inhibition in tuber and bulbs.
Preservation of Food by Ionizing Radiation, Ch6, 3, 1983, p159.

Metlitsky,L.V.; Rodader,V.N.; Krushchev,V.G.
Radiation processing of food products, 1968.

Meijers C.P.
Storage of potatoes; Edited by A. Rastovski & A. van Es, Ch 10.
Centre for Agricultural Publishing and Documentation (PUDOC), Wageningen, The Netherlands, 1981, p340.

Moor M.D.; L.D. van Blaricum; T.L. Seen.
The effect of storage temperature of Irish potatoes on resultant chip colour.
Chemson coll. Res. Ser. 43, 1963, p1.

Nair P.M.; P. Thomas,P.; K.K. Ussuf; K.K. Surendranathan; S.P. Limaye; A.N. Srirangararjan; S.R. Padwal-Desai.
Studies of sprout inhibition of onions and potatoes and delayed ripening of bananas and mangoes by gamma irradiation.
Rad. Pres. of Food. proceedings of Symp. Bombay (1972), IAEA SM-166/11, Vienna, 1973, p347.

Quan V.H.; S. Oularbi; D.Is. Langerak; Th.C. Wolters; Y. Tayeb.
Effect of wound healing period and temperature, irradiation and post-irradiation storage temperature on the keeping quality of potatoes.
IFFIT report 68, RIKILT, Wageningen, the Netherlands, 1988.

Radatz W.
Die wurdkorkbildung der kartoffelknolle in abhangigkeit von lagerungs-bedingungen.
Landb. Forsch. Wolkerode 17(2), 1967, p153.

Roushdy H.M.; A.A. Abd Elhugez; M.T. Sharabash; A.A. Mahmoud.
Effect of prestorage chemical and/or radiation treatment on the storageability of potatoes and onions.
Int. Symp. Food Preservation by Irradiation IAEA/FAO/WHO, IAEA-SM-221/7, Wageningen, 1977.

Schwimmer S.; H.K. Burr; W.O. Harrington; W.J. Weston.
Gamma irradiation of potatoes: Effects on sugar content, chip colour, germination, greening and susceptibility to mold.
Am. potato J. 34, 1957, p31.

Schwimmer S.; W.J. Weston; R.U. Markowe.
Biochemical effects of gamma irradiation on potatoes.
Arch. Biochem. Biophys., 75, 1958, p425.

Sparenberg.
Potato and onion irradiation in the Netherlands.
Proceedings of panel, organized by joint FAO/IAEA division of Atomic Energy on Food and Agriculture, IAEA/STI/pub 394, Vienna, March 1974.

Tanako H.; I. Tanaka; K. Umeda; T. Sato.
Sprout inhibition of potatoes by ionizing radiation III. Dose to inhibit sprout and change of sugar content during the low temperature storage.
Rep. Nat. Food Res. Inst. 27, 1972, p64.

Umeda K.
Effect of temperature and humidity on the reducing sugar, polyphenol, organic acid, free amino acid and ascorbic acid content of irradiated potatoes.
Paper presented to FAO/IAEA. res. Coord. Meeting Techn. and Econ. feasibility of Food Irradiation, Accva, Ghana, 1978.

Ussuf K.K.; P.M. Nair.
Metabolic changes induced by sprout inhibition dose of gamma-irradiation in potatoes.
J.Agric. Food Chem., 30, 1972, p282.

van Es A.; K.J. Hartmans.
Storage of potatoes; Edited by A. Rastovski & A. van Es, Ch 2.
Centre for Agricultural Publishing and Documentation (PUDOC), Wageningen, the Netherlands, 1981, p 82.

Wigginton M.F.
Effects of temperature, oxygen tension and relative humidity on the wound-healing process in the potato tuber.
Potato Res., 17, 1974, p200.

Workman M.; M.E. Patterson; N.K. Ellis; F. Heiligman.
The utilization of ionizing radiation to increase the storage life of white potatoes.
Food Technol., 14, 1950, p395.