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Post-harvest characteristics of potato minitubers with different fresh weights and from different harvests. II. Losses during storage

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Summary

Storage losses were studied in minitubers of cvs Agria and Liseta, using five fresh weight classes (< 0.50 g, 0.5–0.99 g, 1.00–1.99 g, 2.00–2.99 g, ≥ 3.00 g), and three successive harvests of the same plantlets. After each harvest, tubers were dried at room temperature (1 day), cured at 18 °C (13 days) and stored at 2 °C (540 days). Two kinds of storage losses were considered: (a) losses of entire tubers because of deterioration, and (b) fresh weight losses of the other tubers. Both kinds of losses were higher in cv. Liseta, in tubers with lower fresh weights and in tubers from the first harvest. Almost all minitubers ≥0.5 g from later harvests and from both cultivars survived storage for 1.5 years. Deterioration occurred mainly from 6 to 12 months of storage. Tubers which deteriorated during cold storage had already shown high weight losses during curing.

Introduction

Minitubers are small potato tubers intended for producing basic and pre-basic seed by direct field planting. They can be produced throughout the year by planting *in vitro* propagated plantlets at high density in a glasshouse, and harvesting tubers from the same plantlets in three successive harvests (Lommen & Struik, 1992a).

Because they are meant for direct field planting and can be produced all year round, many of the tubers must be stored until the next planting season. As minitubers are dormant immediately after harvest (Lommen, 1993), they must be stored at least until dormancy is over. In climates with only one growing season each year, minitubers that are still dormant at the start of a growing season may need to be stored for a further year until the following planting season.

Burton (1973) showed that small, immature 'normal' tubers could suffer extremely high weight losses during the first few hours after harvesting. Furthermore, during storage they may show higher weight losses than larger tubers, because of their higher surface area:volume ratio. Minitubers may therefore prove to be very susceptible to weight losses. Because there is no published information on the storability of minitubers, I studied the behaviour during storage for up to 1.5 years of minitubers of different weight, originating from three harvests of one planting. The performance of these minitubers after different storage periods will be reported upon in a subsequent paper (Lommen & Struik, 1993).

Materials and methods

Minituber production. Minitubers were produced on *in vitro* propagated plantlets in a glasshouse in Wageningen in summer 1988. The tubers were removed from the plantlets in three successive harvests at intervals of 3 weeks. The first two harvests were non-destructive (Lommen & Struik, 1992b). Details of the growing conditions and harvest procedure have been reported (Lommen, 1993).

Minituber storage. After every harvest, the storage period consisted of (1) a drying period of one day at room temperature, (2) a curing period of 13 days at 18 °C in darkness and 80% RH, and (3) a period of cold storage of 540 days at 2 °C in darkness and 80% RH. After drying, soil adhering to the tubers was removed and tubers were sorted according to their weight.

Tuber categories. There were 30 tuber categories planned, representing all combinations of: (a) five fresh weight classes: class 1: < 0.50 g, class 2: 0.50 – 0.99 g, class 3: 1.00 – 1.99 g, class 4: 2.00 – 2.99 g and class 5: ≥ 3.00 g; (b) three harvests: first, second and third; (c) two cultivars: Agria and Liseta. No tubers were available in classes 4 and 5 from the first harvest of cv. Liseta. Table 1 shows the relative contribution of the fresh weight classes and harvests to the total number of tubers produced by each cultivar.

Unless stated otherwise, the values presented were not corrected for relative contributions of every tuber category to the total tuber number. If necessary, missing values were estimated by the statistical programme Genstat, for the two missing tuber categories of cv. Liseta. Means derived from these estimated values were omitted from the time series (tuber losses during storage, Figs 2, 3 and 4) if they were higher than at a later assessment.

Losses during storage. Weight losses were determined by individually weighing 20 tubers from each category. To assess weight losses during curing, the individual

Table 1. Contribution (%) of minitubers from five fresh weight classes and three harvests to the total number of tubers produced by cvs Agria and Liseta.

Cultivar	Harvest	Fresh weight class					
		<0.50 g	0.50 – 0.99 g	1.00 – 1.99 g	2.00 – 2.99 g	≥3.00 g	Sum
Agria	first	4.0	4.1	5.8	4.2	9.2	27.3
	second	5.6	5.9	9.7	6.2	10.4	37.8
	third	12.0	8.0	8.9	3.6	2.5	35.0
	Sum	21.6	18.0	24.4	14.0	22.1	
Liseta	first	16.0	4.7	2.2	0.1	0.0	23.0
	second	6.8	5.5	7.7	5.0	9.9	34.9
	third	14.1	6.9	8.4	5.2	7.3	41.9
	Sum	26.9	17.1	18.3	10.3	17.2	

tuber weights were determined 2 and 15 days after harvest, i.e. 1 day after the start of the curing period and 1 day after its end. The weight loss (%) during this period was related to the weight of the tubers 2 days after harvest. To assess weight losses during cold storage, the individual weights of all tubers were determined every week from 15 until 50 days after harvest, every 2 weeks from 50 until 106 days after harvest, every 3 weeks from 106 until 358 days after harvest and finally at 554 days after harvest. The weight loss (%) during cold storage was related to the weight of the tubers 15 days after a harvest, i.e. 1 day after the cold-storage period started. Tuber weights were always determined at room temperature after acclimatization for 1.5 hours. The individual weights of 60 tubers were determined immediately after harvest. Tubers that deteriorated considerably were removed and regarded as tuber losses (by number). These tubers were omitted from the analysis of weight losses.

Results

Weight losses during curing. From 2 to 15 days after a harvest, weight losses were lower in cv. Agria than in cv. Liseta (Table 2). Data refer only to tubers that did not deteriorate later. During curing, minitubers from the lowest weight class lost a higher percentage of their fresh weight (7 – 8 %) than those from the highest weight class (3 – 5 %, Table 2). No clear differences existed between tubers from the second and third harvests. The importance of weight loss during the curing period was only realized after the weight losses of one tuber category from the first harvest were determined. Therefore, weight losses of all but one tuber category from the first harvest are missing in Table 2. An additional weight loss test on 60 tubers (0.5 – 3 g) from the second harvest of cv. Agria, however, revealed that the first 2 days immediately after a harvest were even more important: 1 day after the curing period started, these tubers had already lost on average 5.7 % of the weight recorded immediately after harvest. During curing, the tubers from these categories lost 4.1 % of their weight 1 day after the start of the curing period (calculated from Table 2).

Table 2. Fresh weight loss (%) during curing of minitubers which did not subsequently deteriorate during storage for 554 days. Weight losses were determined from 1 day after the start of the curing period (i.e. 2 days after harvest) until 1 day after the end of the curing period (i.e. 15 days after harvest), on minitubers from two cultivars, five fresh weight classes and three harvests. SE = 2.0[a].

Cultivar	Harvest	Fresh weight class				
		<0.50 g	0.50 – 0.99 g	1.00 – 1.99 g	2.00 – 2.99 g	≥3.00 g
Agria	first	–	–	5.6	–	–
	second	7.0	4.4	3.9	4.1	3.0
	third	6.7	4.6	4.0	3.5	3.4
Liseta	first	–	–	–	–	–
	second	7.1	5.2	5.9	5.1	4.7
	third	7.9	5.7	5.1	4.5	4.2

[a] SE of all means. The number of surviving tubers can be calculated from Table 4.

Weight losses during cold storage. During storage at 2 °C from 15 to 554 days after harvest, the minitubers that did not deteriorate lost only 15 % of their fresh weight recorded at 15 days after harvest. Weight losses were again consistently lower in cv. Agria than in cv. Liseta, and considerably higher in minitubers from the lowest weight class (19 – 40 %) than from the highest weight class (7 – 13 %) (Table 3). In addition, weight losses were higher in tubers from the first harvest than in those from later harvests (Table 3).

Because evaporative weight losses are generally higher in smaller than larger tubers, due to their higher surface area:volume ratio (Burton, 1973), curves were fitted in which the weight losses of minitubers during the cold-storage period were related to their weight at the start of this period. These curves had to allow comparisons between minitubers from different cultivars and different harvests, irrespective of their initial fresh weight. Because it was uncertain how weight would be lost with time, different curves were fitted for different dates. The relation $y = b \times x^{2/3}$ proved to be most suitable (both accurate and simple), in which y = fresh weight loss from 15 to a certain number of days of storage (22 – 358 days, intervals of 6 weeks),

Table 3. Fresh weight loss (%) during cold storage of minitubers which did not deteriorate during storage for 554 days. Weight losses were determined from 1 day after the start of the coldstorage period (i.e. 15 days after harvest) until 554 days after harvest, on minitubers from two cultivars, five fresh weight classes and three harvests. SE = 6.3 [a].

Cultivar	Harvest	Fresh weight class				
		<0.50 g	0.50 – 0.99 g	1.00 – 1.99 g	2.00 – 2.99 g	≥3.00 g
Agria	first	20.5	16.8	14.9	11.2	9.7
	second	18.5	11.2	10.4	10.5	7.0
	third	19.3	14.8	10.7	9.1	8.5
Liseta	first	40.0	29.4	23.3	–	–
	second	29.2	17.9	15.5	12.8	10.9
	third	33.3	20.7	16.8	13.7	12.5

[a] SE of all means. The number of surviving tubers can be calculated from Table 4.

Table 4. Percentage of minitubers from three successive harvests, two cultivars and five fresh weight classes which had not deteriorated 554 days after a harvest. Sample size = 20 tubers.

Cultivar	Harvest	Fresh weight class				
		<0.50 g	0.50 – 0.99 g	1.00 – 1.99 g	2.00 – 2.99 g	≥3.00 g
Agria	first	70	95	95	95	100
	second	80	95	100	100	100
	third	95	100	100	95	100
Liseta	first	20	75	85	–	–
	second	55	90	100	100	100
	third	65	100	100	100	100

and x = the tuber weight 15 days after a harvest. The $x^{2/3}$ is a measure of the tuber surface, regarding the tuber as being globular and having a specific gravity independent of the fresh weight. Estimates of the regression coefficient b, all significant at $P < 0.001$, showed that after storage periods of 148 days or more, weight losses per tuber in cv. Agria were lower than in cv. Liseta, and that weight losses of tubers from the first harvest were higher than from later harvests (Fig. 1). The estimated value of the coefficient b is also the predicted weight loss (g) of a tuber with an initial weight of 1.00 g. If the weight losses were fitted to x instead of to $x^{2/3}$, the curves explained a smaller part of the variance on all but one occasion (51 out of 52 curves). Tubers of cv. Liseta were more elongated than those of cv. Agria, and therefore the surface area:volume ratio may have been higher in cv. Liseta. There were no obvious differences in tuber shape between tubers from different harvests.

Tuber losses (by number). Fewer tubers of cv. Agria deteriorated during storage than of cv. Liseta (Fig. 2). Tubers which were regarded as being lost initially lost turgor and later shrivelled excessively. These changes were accompanied by a brownish discolouration of the surface. There were no indications that the losses were caused by pathogens, but if tubers were not removed from storage some of them became infected by fungi. No tubers were regarded as lost at the end of the curing period, for most losses occurred between 232 and 358 days of storage in cv. Agria and between 169 and 358 days in cv. Liseta. Thereafter, losses were small. The periods during which most losses occurred coincided with the period during which the first sprouts became visible (Fig. 2).

In both cultivars, most tubers were lost from the lowest weight class (Fig. 3). In cv. Agria, hardly any tubers ≥ 0.5 g (classes 2 – 5) were lost, and differences between these fresh weight classes were negligible (Fig. 3A). In cv. Liseta, losses of tubers of 0.5 – 1 g were still higher than losses of tubers with higher fresh weights (Fig. 3B).

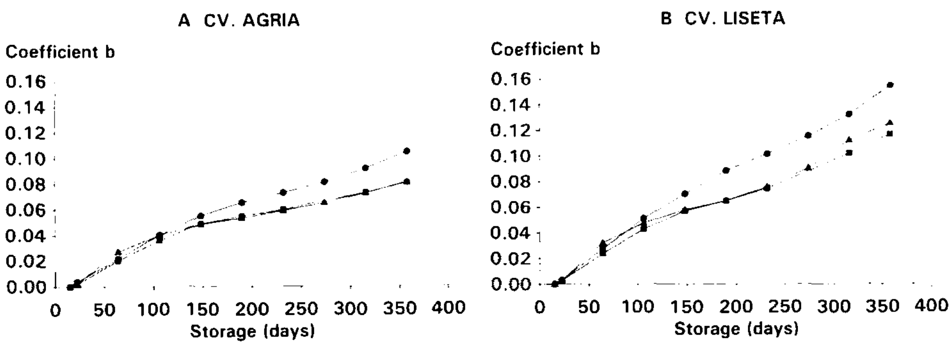

Fig. 1. Progressive fresh weight loss during cold storage of minitubers from the first (●), second (■) and third (▲) harvests, as characterized by the regression coefficient b from the relation $y = b \times x^{2/3}$ in which y = fresh weight loss from 15 days of storage onwards, and $x^{2/3}$ is a measure of the tuber surface of a tuber with a weight x, 15 days after a harvest, regarding the tuber as being globular and having a specific gravity that is independent of the fresh weight. Different curves were fitted for each date. The estimated value of the coefficient b is also the predicted weight loss of a tuber with an initial fresh weight of 1.00 g. A: cv. Agria, B: cv. Liseta.

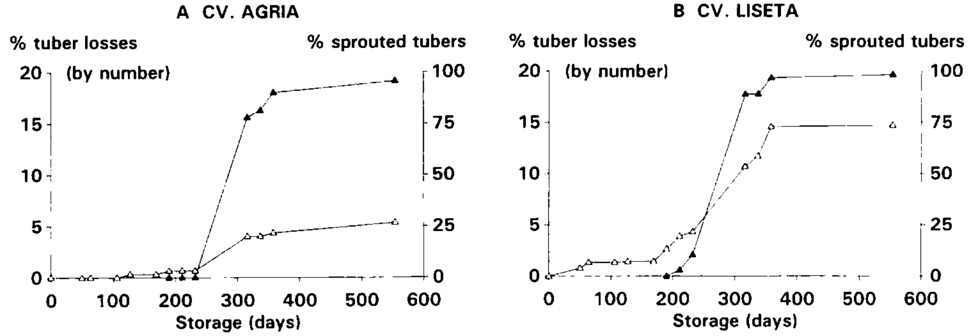

Fig. 2. Percentage (by number) of minitubers deteriorating during storage (△) and percentage of non-deteriorating tubers showing visible sprouting (▲). A: cv. Agria, B: cv. Liseta. Mean values of five fresh weight classes and three harvests.

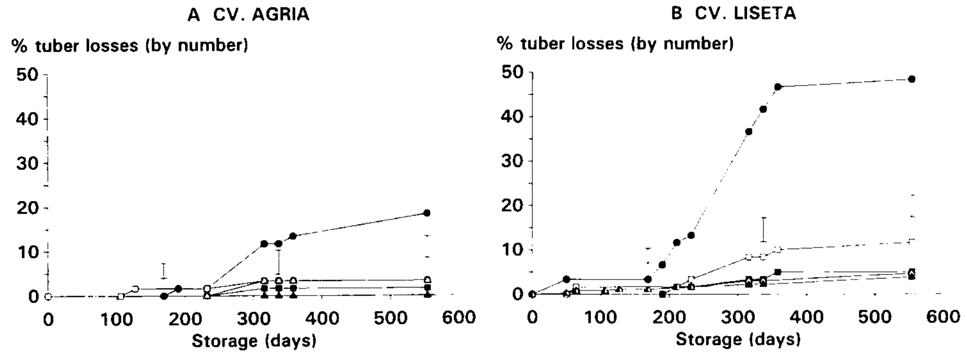

Fig. 3. Percentage (by number) of minitubers deteriorating during storage, originating from fresh weight classes < 0.50 g (●), 0.50 – 0.99 g (□), 1.00 – 1.99 g (■), 2.00 – 2.99 (△) and ≥ 3.00 g (▲). A: cv. Agria, B: cv. Liseta. Mean values of three harvests. Bar: LSD 5%.

From later harvests, fewer tubers deteriorated during storage than from earlier harvests (Fig. 4). The magnitude of the differences depended on the cultivar. In cv. Agria, differences between harvests were small: the percentage of deteriorating tubers from the second harvest did not differ significantly from that at the other harvests (Fig. 4A). In cv. Liseta, the percentage of deteriorating tubers from the first harvest was considerably higher than that from the second harvest (Fig. 4B).

Table 4 shows the percentage of tubers surviving storage up to 554 days for every tuber category. Only 20% of the tubers of < 0.5 g from the first harvest of cv. Liseta survived storage during this period, while only about 60% of the tubers of < 0.5 g from the other harvests of this cultivar could be stored for this period. The storability of both cultivars was good in tubers ≥ 0.5 g (classes 2 to 5), especially if produced in the second or third harvest. From Table 4 it appears that the minimum fresh weight of tubers showing good storability was lower the later the harvest took place.

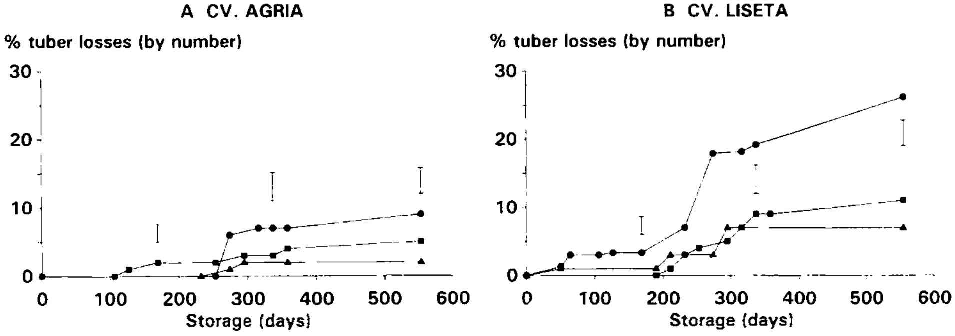

Fig. 4. Percentage (by number) of minitubers deteriorating during storage, originating from the first (●), second (■) and third (▲) harvests. A: cv. Agria, B: cv. Liseta. Mean values of five fresh weight classes. Bar: LSD 5 %.

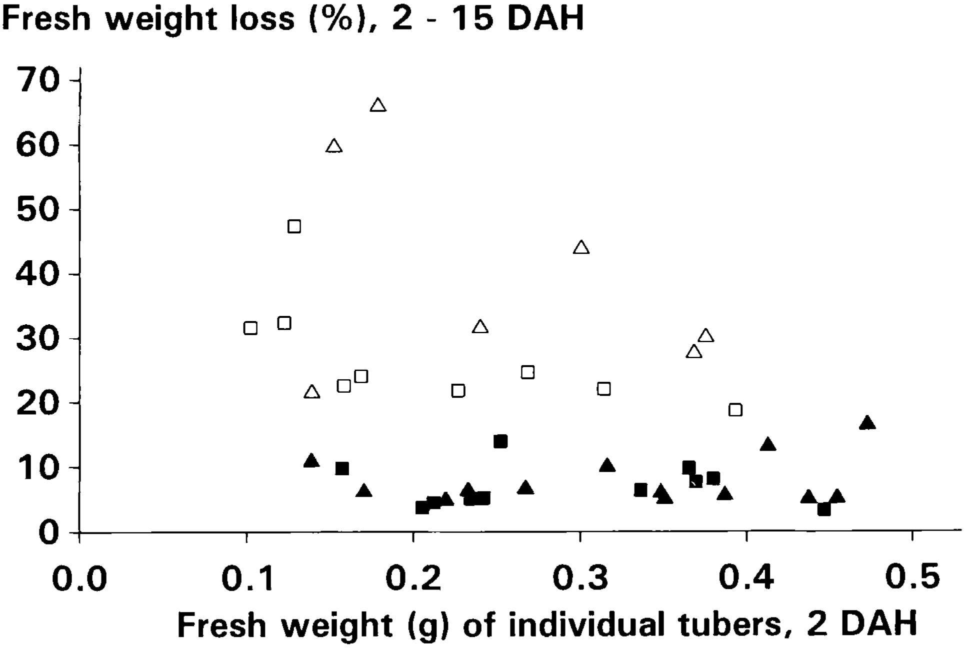

Fig. 5. Relation between the initial fresh weight and the fresh weight loss (%) during curing, of minitubers that survived storage for 554 days (closed symbols) or deteriorated during this period (open symbols). Weight losses were determined from 1 day after the start of the curing period (i.e. 2 days after harvest) until 1 day after the end of the curing period (i.e. 15 days after harvest), on individual tubers (cv. Liseta) from the second (△ , ▲) and third (□ , ■) harvests. DAH: days after harvest.

Tubers were regarded as being lost on the basis of visual inspection. Their individual weights, however, had been recorded up until rejection. It appeared that the tubers which deteriorated during cold storage showed much higher weight losses during curing than the tubers which survived storage for 554 days (Fig. 5). At the time that they were regarded as being lost, tubers appeared to have lost 9 – 85 %, but in general 40 %, of the weight they had 15 days after harvest.

Discussion

Storage losses. Fresh weight losses may have occurred through evaporation (water loss) and respiration (dry-matter loss). No data were collected on the relative contribution of each, but evaporative weight losses can be assumed to have been more important than respiratory weight losses (cf. Appleman et al., 1928; Wilcockson et al., 1985). Evaporation of unsprouted tubers is proportional to their surface area, and is inversely related to the resistance of the tuber periderm (including lenticels). Higher relative weight losses therefore may be expected in smaller tubers, which have a higher surface area:volume ratio. The better fit of the calculated regression lines with $x^{2/3}$ than with x itself supports the view that the surface area was an important characteristic in determining weight losses.

Because evaporation is inversely related to the resistance of the periderm, it will be higher in tubers with an incomplete or less suberized periderm, or in tubers with more or more permeable lenticels. In minitubers, a lower periderm resistance may explain the higher proportional weight losses in tubers from the first harvest (Tables 2, 3; Fig. 1), part of the differences between cultivars (Tables 2, 3; Fig. 1), part of the differences between individual tubers of similar weight (Fig. 5), and probably also part of the higher proportional weight losses of smaller tubers, which are likely to have a higher proportion of their surface area wounded at harvest. No data concerning periderm thickness, periderm suberization, wounding or lenticels were collected, but observation of the tubers at harvest revealed that skin set of tubers from the first harvest was not complete, especially at the bud end of the tuber, and that its skin could be easily removed during handling.

Because the highest losses by weight and number occurred in the same tuber categories, the deteriorating tubers may have been those individuals which – due to normal variability – showed the highest weight losses within each category (cf. Fig. 5). However, depletion of substrate available for respiration may also have been important, because (a) the losses occurred especially in immature and small tubers, which are likely to have both the highest respiration rates immediately after harvest (Burton, 1964) and the lowest carbohydrate reserves; (b) most losses occurred in the period after the onset of sprouting (cf. Fig. 2), when respiration normally increases (Burton, 1974), and (c) the deteriorating tubers initially seemed to resemble tubers which were being resorbed (e.g. loss of turgor and shrivelling).

Improvement of storability. Because tubers which deteriorated during the cold-storage period showed high weight losses during the curing period (Fig. 5), the treatment of the minitubers immediately after harvest appears extremely important. The air drying for 1 day, used to remove soil from the minitubers was probably harmful, especially to the smallest and immature tubers. Burton (1973) showed that immediately after harvesting the weight losses of small, immature tubers could be more than 1 % per hour. The dry conditions may have inhibited periderm formation and suberization (cf. Wigginton, 1974). In later experiments, minitubers were cleaned after harvest by washing them with tap water.

A curing period is extremely important to reduce weight losses during storage (cf. Wilcockson et al., 1985). Conditions during curing were chosen to be suitable for wound healing (cf. Wigginton, 1974). However, weight losses during the first 15 days after harvest were only slightly lower than weight losses during the next 540 days of cold storage. Curing should be carried out at a higher RH or with reduced air movement from ventilation in order to reduce weight losses. In later experiments, the trays in which minitubers were cured were covered loosely with a sheet of plastic, still allowing abundant exchange of air. If respiration also contributes to the observed losses in tuber number, curing should be carried out at a lower temperature or for a shorter period.

The storability of tubers from the first harvest might be improved simply by delaying this harvest for a few days, thus enabling the smallest tubers to grow to a larger and therefore more storable size.

From a practical point of view, losses in tuber number are more important than weight losses. Even without optimizing the storage conditions, minitubers $\geq$ 0.5 g from the second and third harvests can be stored without large losses for a period of 1.5 years. Fortunately, most of the minitubers produced in three harvests are produced in the last two harvests (Table 1; Lommen & Struik, 1992a). By multiplying the relative contribution of each tuber category (Table 1) by the proportion of tubers surviving storage for 554 days (Table 4), it can be calculated that 96 % of all minitubers of cv. Agria and 77 % of those of cv. Liseta survived storage for 1.5 years.

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