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Chill Storage of Mushrooms

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Degree of whiteness is one of the most important aspects of quality in fresh mushrooms. Tests on the effects of chill storage (1 °C) on whiteness of mushrooms showed that both time of putting mushrooms into refrigeration after harvest, and time of removal, had an effect on whiteness both at point of removal and during subsequent storage at ambient temperature. In general, the longer the refrigeration time in a given period of days the whiter the mushrooms. The rate of loss of whiteness at ambient temperature was about the same irrespective of whether mushrooms were stored (1 °C) for 0 or 11 days. Mushrooms were placed in six whiteness categories with the aid of a Hunter Colour Difference meter (from excellent $L > 93$, to very poor $L < 69$). Mushrooms with L values <80 or <69 were considered as unacceptable from a whiteness point of view at wholesale or consumer levels respectively. These categories confer a degree of objectivity to the results in the chill storage tests.

1. Introduction

The production of mushrooms in Ireland has increased rapidly during the last five years and a large proportion of the crop is sold in Britain. Degree of whiteness is one of the most important quality factors associated with mushrooms and generally the whitest mushrooms command the highest price. Loss of weight due to desiccation is a problem and can result in shrivelling of the mushrooms in addition to loss of money for the retailer if the mushrooms are sold on a weight basis.

Much research has been carried out over the last few years on keeping fresh mushrooms white.[1] When mushrooms are subjected to vibrations or rough handling polyphenol oxidase acts on the substrate tyrosine causing browning.[2] This also occurs as the mushroom ages. Bacterial infection is another cause of loss of whiteness.[3–5]

Antioxidants,[6,7] prepackaging,[8,9] and irradiation[10] have been used to maintain mushroom whiteness but all of these techniques have only been moderately successful.

Temperature has a marked effect on the rate of deterioration of mushrooms. Cameron and Chappell[11] have shown that buttons can be stored successfully for periods up to 7 days at 1 °C with a subsequent shelf life of 2–3 days. Tomkins[3] has studied the storage life of batches of mushrooms held at 0, 4, 7, 12 and 19 °C and found that storage life ranged from 17–20 days at 0 °C to 2–3 days at 19 °C.

In the experiments described in this paper the effects of delays in getting mushrooms into refrigeration (1 °C) on the subsequent shelf life and water loss—both in chill storage (1 °C) and afterwards—were studied. Special attention was given to the rate

of deterioration on removal from chill storage. Mushrooms were placed in six whiteness categories with the aid of a Hunter Colour Difference Meter and this confers a degree of objectivity to the results presented.

2. Experimental

2.1. Whiteness measurements

Whiteness of mushrooms from the different tests was measured with a Hunter D25A Colour Difference Meter fitted with a 1 in specimen port and standardised with a white tile ($L = 91.7$, $a = -0.7$, $b = -0.8$). Ten mushrooms from each tray or chip were measured and the mean whiteness value calculated.

2.2. Whiteness grades

Mushrooms were placed in six whiteness categories with the aid of a Hunter meter. Five people experienced in the marketing of mushrooms were asked to describe the whiteness of mushrooms in each category. In this way six meaningful whiteness categories were obtained.

2.3. Experiments 1 and 2

Cultivated mushrooms (*Agaricus bisporus*) grown at Kinsealy Research Centre were used in these experiments. The basic unit tested was 10 mushrooms in a fibreboard tray ($5\frac{1}{2} \times 5\frac{1}{2} \times \frac{3}{4}$ in) covered with an inverted tray to reduce air movement and desiccation. Whiteness and loss of weight of mushrooms were measured daily except when mushrooms were under refrigeration. There were two replicates in each experiment.

2.3.1. Experiment 1

The effects on whiteness and moisture loss of (a) delays in putting mushrooms into refrigeration after harvesting, (b) a breakdown in the refrigeration plant during storage and (c) time of removal of mushrooms from refrigeration were studied. Treatments to simulate the conditions required were termed "putting-in", "breakdown" and "removal" respectively. There were three putting-in treatments, i.e. mushrooms were refrigerated (1 °C) on day 0 at 0, 4 and 8 h post-harvest. A breakdown in the refrigeration plant was simulated by removing half of the trays of mushrooms from refrigeration for 4 h on day 1. The remaining half were kept in refrigeration thus giving two breakdown treatments, i.e. breakdown versus no breakdown. There were four removal treatments; trays were removed from refrigeration on each of days 1 to 4. After removal from refrigeration the mushrooms were stored at 20 °C until day 6, when the experiment was concluded. Thus, trays of mushrooms, refrigerated immediately after harvest, were held 1 day at 1 °C + 5 days at 20 °C, 2 days at 1 °C + 4 days at 20 °C, 3 days at 1 °C + 3 days at 20 °C or 4 days at 1 °C + 2 days at 20 °C. Figures for delayed refrigeration (4 or 8 h) and/or a break in refrigeration (4 h) would have to be deducted from the holding times given above where appropriate, e.g. in the case of a 4 h break in refrigeration the holding time of 2 days at 1 °C + 4 days at 20 °C would become 2 days at 1 °C (less 4 h at 20 °C) + 4 days at 20 °C.

The number of trays tested in the experiment was 48, i.e. putting-in (3) × breakdown (2) × removal (4) × replicates (2).

Control samples (4 trays) were stored for 6 days at 20 °C.

2.3.2. Experiment 2

This experiment was similar to Experiment 1 in that the effects of (a) delayed refrigeration, (b) breakdown in refrigeration and (c) time of removal from refrigeration on whiteness and moisture loss in mushrooms were studied. Putting-in times (into refrigeration, 1 °C) were 0 and 24 h post-harvest and a breakdown in refrigeration was simulated by removing mushrooms, which had been refrigerated at 0 h post-harvest (day 0), from refrigeration for a 24 h period (all of day 1). There were four removal treatments; trays of mushrooms were removed from refrigeration on each of the days 8–11 and were then stored at 20 °C until day 13. Thus trays of mushrooms refrigerated immediately after harvest were held 8 days at 1 °C + 5 days at 20 °C, 9 days at 1 °C + 4 days at 20 °C, 10 days at 1 °C + 3 days at 20 °C or 11 days at 1 °C + 2 days at 20 °C. In the case of mushrooms refrigerated 24 h post-harvest or those which were removed from chill storage for a 24 h period, the 24 h period must be deducted from the refrigeration time. For example, those held 8 days at 1 °C + 5 days at 20 °C now become 8 days at 1 °C (less 1 day at 20 °C) + 5 days at 20 °C.

The number of trays tested in the experiment was 24, i.e. 3 (2 putting-in + 1 break treatment) × 4 removal treatments × 2 replicates.

Control samples (4 trays) were tested for the first six days of the experiment but deteriorated rapidly after this.

2.4. Experiments 3 and 4

These experiments were carried out using chips of mushrooms (3 lb) and not small trays as was the case in Experiments 1 and 2. The effects of delays in refrigeration post-harvest and time of removal from refrigeration on subsequent whiteness and moisture loss were studied.

Mushrooms (*Agaricus bisporus*) from a commercial grower were used in Experiment 3. Even though the mushrooms were quite white at time of harvest, they bruised easily and appeared slightly moist. For this reason more mushrooms were obtained from another grower at a later date and the test was repeated (Experiment 4).

There were three putting-in treatments—refrigerate (1 °C) 2 h, 24 h or 48 h post-harvest—and 3 removal treatments—remove samples from refrigeration on each of days 3 to 5. After removal from refrigeration the mushrooms were stored at 20 °C until day 7. Thus, samples refrigerated within 2 h of harvesting were held 3 days at 1 °C + 4 days at 20 °C, 4 days at 1 °C + 3 days at 20 °C or 5 days at 1 °C + 2 days at 20 °C. In the case of samples which were held for 1 or 2 days at 20 °C before refrigeration, the 1 or 2 days would have to be deducted from the holding times above. This can be seen clearly in Figures 3 and 4 (see section 3) where dotted lines show storage at 1 °C and solid lines storage at 20 °C.

The total number of chips of mushrooms used in each experiment was 27, i.e. 3 putting-in treatments × 3 removal treatments × 3 replicates. Control samples (6 chips) were stored at 20 °C for 7 days.

Whiteness (10 mushrooms/chip) and weight loss were measured at the start of the experiments and daily from day 3 onwards, except when the mushrooms were in refrigeration.

3. Results

3.1. Whiteness grades

The six categories, agreed by panel discussion, for mushroom whiteness, are given in Table 1. In practical terms wholesalers would probably be reluctant to buy mushrooms with an L value <80. A large proportion of the mushrooms sold across the counter by

Table 1. Whiteness categories for mushrooms

Category	Hunter L values	Panel description of whiteness
1	>93	Excellent
2	90–93	Very good
3	86–89	Good
4	80–85	Reasonable
5	69–79	Poor
6	<69	Very poor

retailers would be in the poor colour category ($L = 69$–79) but these mushrooms would probably still be quite wholesome and well flavoured. Mushrooms with L values <69 would not be acceptable to the normal consumer. Two horizontal lines showing the proposed lowest acceptability values for whiteness at wholesale ($L = 80$) and consumer ($L = 69$) levels are drawn in some of the graphs in which whiteness data are presented. These are referred to as W (wholesale) and C (consumer) acceptability lines respectively.

3.2. Experiments 1 and 2

The results for whiteness in Experiment 1 (Figure 1(a)) show that there was little or no difference between the putting-in or break refrigeration treatments. This indicates that delays in refrigeration of up to 8 h after harvesting and/or a break in refrigeration of 4 h on day 1 had little effect on whiteness of a single layer of mushrooms held in unwrapped trays. The values for putting-in and break treatments are averaged over the four times (days 1 to 4) on which mushrooms were removed from refrigeration. The whiteness values for each treatment, therefore, are averages and for this reason W and C lines are not drawn in Figure 1(a). The putting-in and break refrigeration treatments were better than the control throughout the test but, as already stated, average values were used to draw the lines. If, however, individual values are used, even the worst treatment (refrigerate 8 h after harvesting and remove from refrigeration for 4 h on day 1) was slightly better than the control throughout the test indicating that a small amount of refrigeration is better than none.

The length of time mushrooms were left in refrigeration affected their whiteness (Figure 1(b)). Those left in longest remained whitest. It is important to note that the rate of loss of whiteness after removal from refrigeration was about the same (as indicated by nearly parallel lines) irrespective of whether mushrooms were refrigerated for

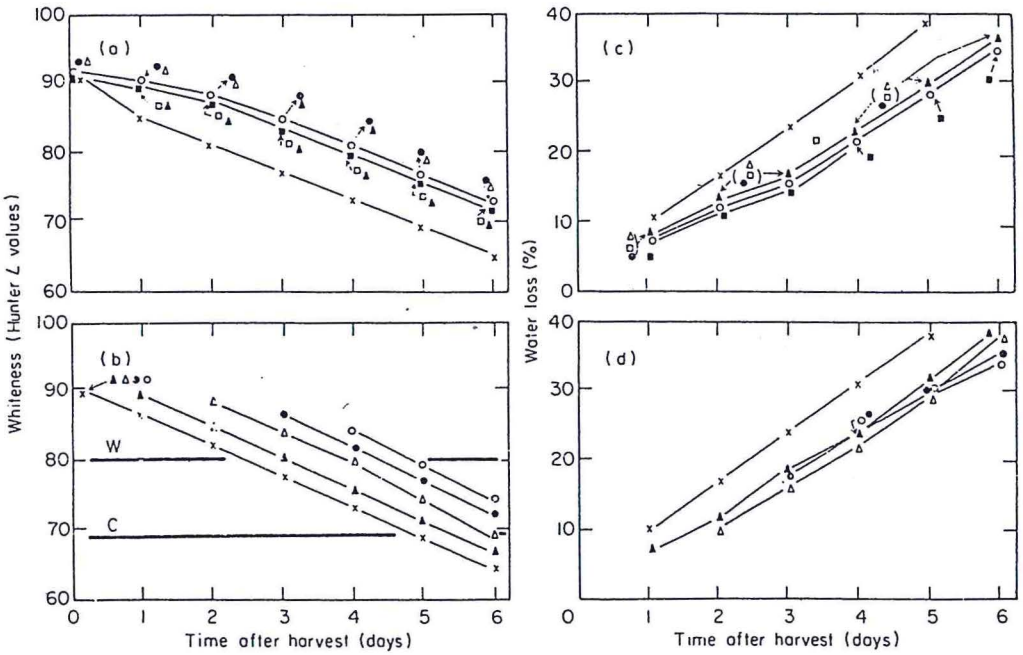

Figure 1. Loss of whiteness (a, b) and water (c, d) for mushrooms held in flat trays (Experiment 1). W = wholesale acceptability line; C = consumer acceptability line; s.e. = average standard error; (a) and (b) s.e. = 0.82; (c) and (d) s.e. = 0.42. Treatments in (a), (c): o—o, refrigerate at once; Δ—Δ, refrigerate after 4 h; □—□, refrigerate after 8 h; ●—●, refrigerate at once, break 4 h day 1; ▲—▲, refrigerate after 4 h, break 4 h day 1; ■—■, refrigerate after 8 h, break 4 h day 1; ×—× control (no refrigeration). Treatments in (b), (d): o—o, refrigerated 4 days; ●—●, refrigerated 3 days; Δ—Δ, refrigerated 2 days; ▲—▲, refrigerated 1 day; ×—×, control (no refrigeration).

1, 2, 3 or 4 days. As in Figure 1(a), lines in Figure 1(b) are drawn from values which were obtained by averaging, this time, over putting-in and break treatments. However, since results for these treatments were so similar, the position of the lines in Figure 1(b) is not affected to a great extent by the averaging process and W and C lines can be drawn. The results (Figure 1(b)) show that no sample was acceptable, from a whiteness point of view, to the wholesaler on day 5 while on day 6 samples which had been refrigerated for 2, 3 or 4 days were acceptable to the consumer. The others were not.

Data on weight loss for mushrooms in Experiment 1 are shown in Figures 1(c) and 1(d). The graphs are constructed by averaging, as in the case of the whiteness measurements. The results are similar to those for whiteness in that delayed refrigeration (up to 8 h) or short breaks in refrigeration on day 1 (4 h) had little effect on weight loss. The times that mushrooms were removed from refrigeration (day 1, 2, 3 or 4) had some effect on loss of weight (Figure 1(d)) but it was only on day 6 that a clear pattern emerged

when mushrooms that were refrigerated longest showed the smallest weight losses and vice versa.

Results for loss of whiteness and weight followed a similar pattern in Experiment 2 to that obtained in Experiment 1. There was little difference between treatments indicating that a delay of 24 h in refrigeration or a break of 24 h in refrigeration (day 1) had no bearing on subsequent whiteness when the mushrooms were removed from refrigeration (day 8 onwards) (Figure 2(a)). W and C acceptability lines are not drawn

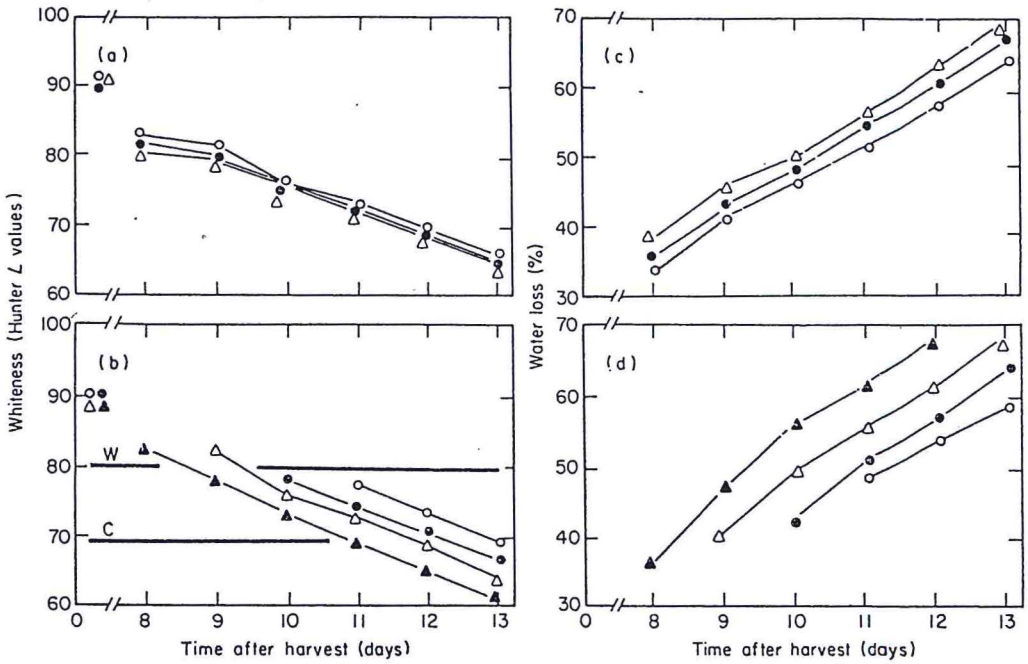

Figure 2. Loss of whiteness (a, b) and water (c, d) for mushrooms held in flat trays) (Experiment 2). W = wholesale acceptability line; C = consumer acceptability line; s.e. = average standard error; (a) and (b) s.e. = 0.76; (c) and (d) s.e. = 0.51. Treatments in (a), (c): o—o, refrigerate immediately; ●—●, refrigerate after 24 h; △—△, break in refrigeration for 24 h (day 1). Treatments in (b), (d): o—o, refrigerated for 11 days; ●—●, refrigerated for 10 days; △—△, refrigerated for 9 days; ▲—▲, refrigerated for 8 days.

for this graph for the same reasons as for Figure 1(a). The effects on subsequent whiteness of removing mushrooms from refrigeration on days 8, 9, 10 and 11 are illustrated in Figure 2(b). Those refrigerated longest remained whitest. Only one sample was still acceptable to the consumer on day 13, three on day 12 and all four on day 11. The rate of loss of whiteness on removal from refrigeration was much the same irrespective of when the mushrooms were removed from refrigeration (Figure 2(b)).

Weight losses for mushrooms in Experiment 2 are shown in Figures 2(c) and 2(d). As in Experiment 1 the graphs are constructed from average figures (averaged over putting-in treatments or over times of removal from refrigeration—days 8–11). As expected, both time of putting mushrooms into refrigeration and time of removal from

refrigeration had an effect on weight loss with the longer refrigeration times giving the least desiccation and vice versa.

3.3. Experiments 3 and 4

The results for whiteness of mushrooms held in 3 lb chips in Experiments 3 and 4 are presented in Figures 3 and 4 respectively. In these experiments delays in refrigeration of 24 and 48 h generally had some adverse effect on subsequent whiteness (Figure 3(a–c), Figure 4(a–c)). In addition, as would be expected, time of removal from refrigeration also had an effect (Figure 3(d–f), Figure 4(d–f)). Since both "putting-in-time" and "taking-out-time" (from refrigeration) influenced whiteness it was decided not to draw the graphs from average figures (as was done in Experiments 1 and 2) but to

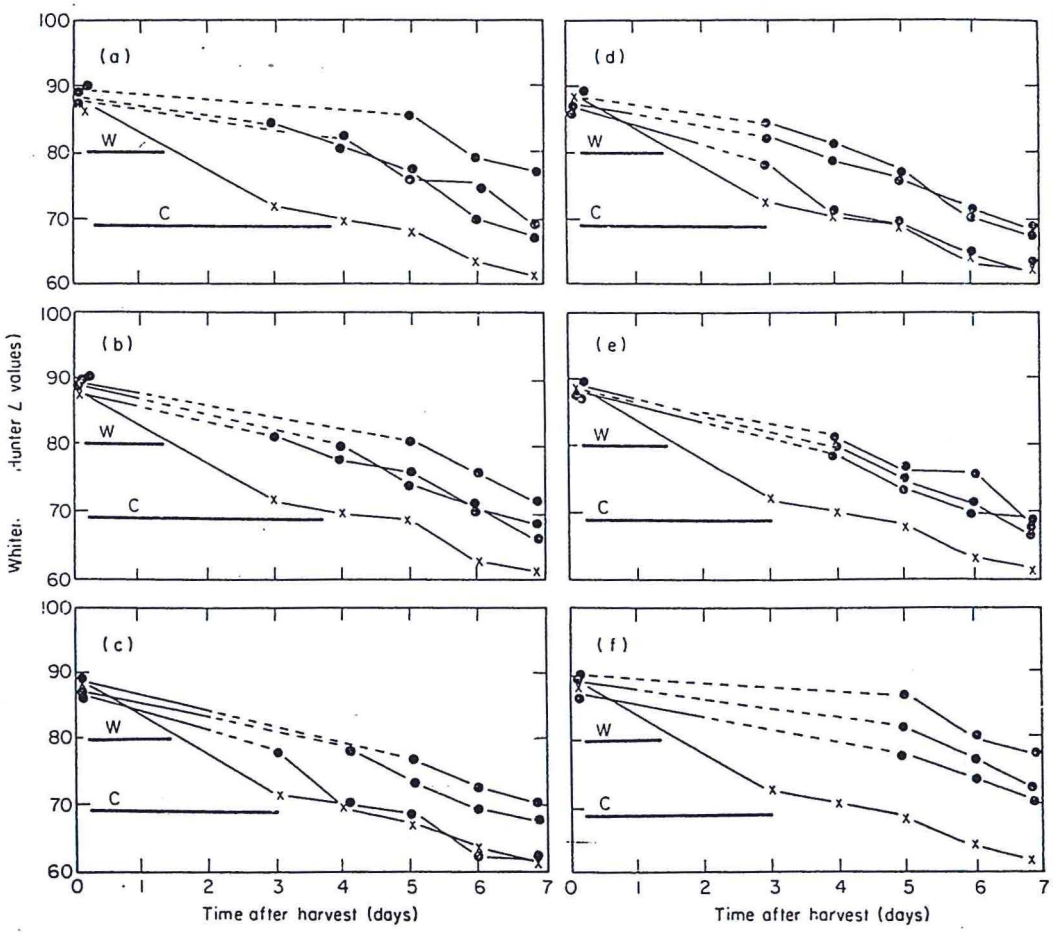

Figure 3. Loss of whiteness for mushrooms in chips (Experiment 3). All combinations of "putting in" and "removal times" to and from refrigeration are shown. W = wholesale acceptability line; C = consumer acceptability line; s.e. = average standard error; (a) s.e. = 0.86; (b) s.e. = 0.85; (c) s.e. = 0.84; (d) s.e. = 0.87; (e) s.e. = 0.83; (f) s.e. = 0.84. ——, Mushrooms at ambient (20 °C); – – – –, mushrooms in refrigeration (1 °C); ×—×, control sample (no refrigeration).

present six individual graphs (instead of two) for whiteness for each experiment. W and C lines were drawn on each graph.

The interrelationship between time of putting mushrooms into refrigeration and time of removal from refrigeration can be seen by inspection of Figure 3(a–f) (Experiment 3) and Figure 4(a–f) (Experiment 4). The data in Figure 3(a–c) shows loss of whiteness of mushrooms which were refrigerated immediately, 24 and 48 h after harvest in all combinations with different times of removal from refrigeration. The data is presented in another form in Figure 3(d–f); here removal from refrigeration on days 3, 4 or 5 is shown in all combinations with time of putting mushrooms into refrigeration. Similarly, for Figure 4(a–c) and Figure 4(d–f) in Experiment 4.

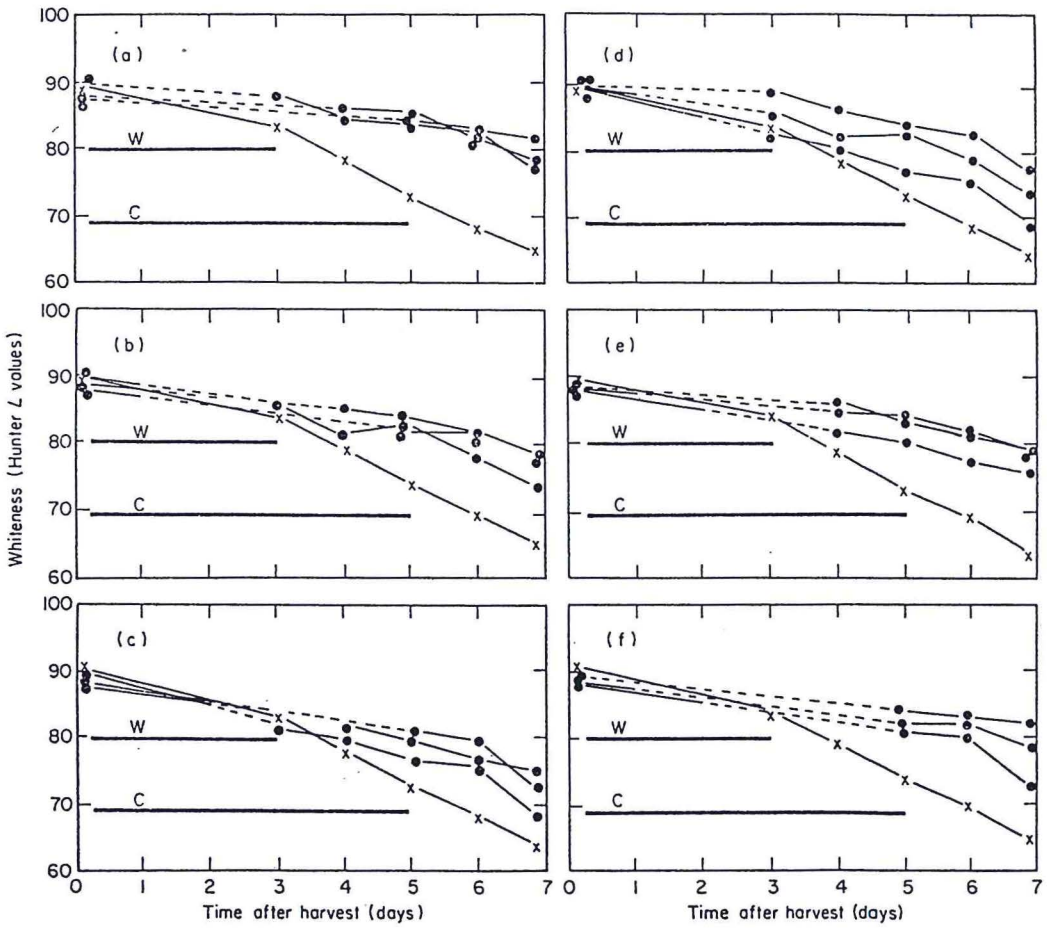

Figure 4. Loss of whiteness for mushrooms in chips (Experiment 4). All combinations of "putting in" and "removal times" to and from refrigeration are shown. W = wholesale acceptability line; C = consumer acceptability line; s.e. = average standard error; (a) s.e. = 0.74; (b) s.e. = 0.71; (c) and (d) s.e. = 0.73; (e) and (f) s.e. = 0.72. ——, mushrooms at ambient (20 °C); – – – –, mushrooms in refrigeration (1 °C); ×—×, control sample (no refrigeration).

In Experiment 3 the whiteness of the control sample had fallen below the W acceptability line by day 2 and below the C line by day 5 (Figure 3(a–f)). In Experiment 4 the control sample remained whiter longer and values fell below the W and C lines on day 4 and 7 respectively (Figures 4(a–f)). This trend was reflected in the other treatments as well and whiteness values were generally higher throughout in Experiment 4 than in Experiment 3.

Inspection of data in Figures 3 and 4 show that, in general, the rate of loss of mushroom whiteness after removal from refrigeration was not affected to any great extent by the various treatments. In Experiment 3 the rate of loss of whiteness was similar to that for the control, while in Experiment 4 the rate of loss was less than that found in the control in some cases.

Loss of weight for mushrooms in Experiments 3 and 4 is presented in Figure 5(a–d). The graphs were prepared by averaging over the various "putting-in" and "removal" refrigeration treatments. The results for both experiments are similar and show, as expected, that refrigeration reduces weight loss.

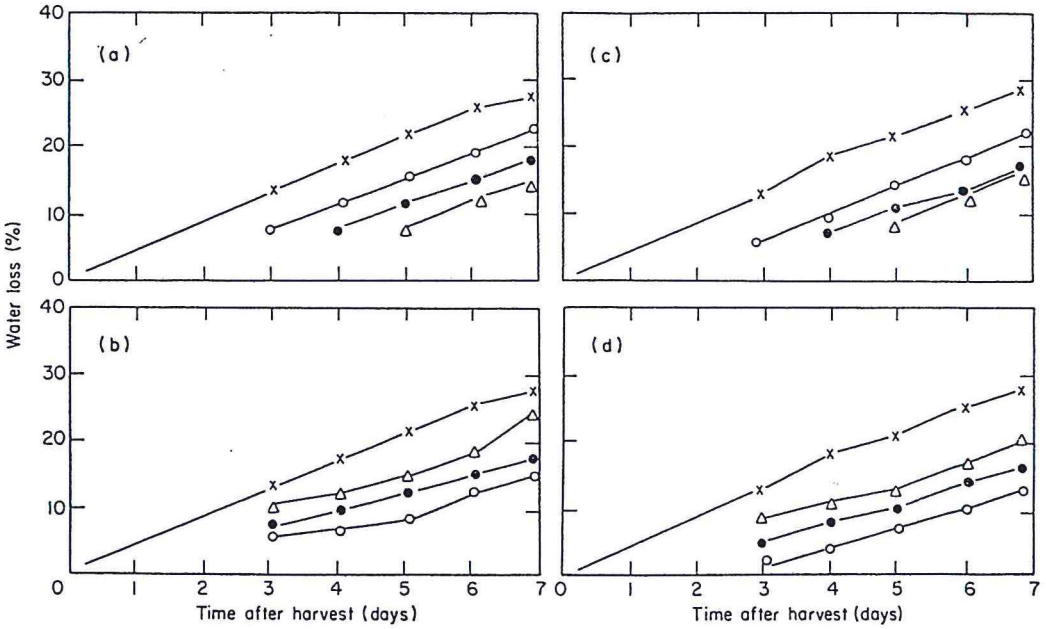

Figure 5. Loss of water for mushrooms held in chips [Experiments 3 (a, b) and 4 (c, d)]. s.e. = average standard error; (a) and (b) s.e. = 0.49; (c) and (d) s.e. = 0.66. Treatments in (a), (c): o—o, refrigerated 3 days; ●—●, refrigerated 4 days; Δ—Δ, refrigerated 5 days; ×—×, control (no refrigeration). Treatments in (b), (d): o—o, refrigerate immediately; ●—●, refrigerate after 24 h; Δ—Δ, refrigerate after 48 h; ×—×, control (no refrigeration).

4. Discussion

Whiteness is used as the main visible quality index in these tests. Other factors such as lengthening of the stipe and opening of the gills normally occur in parallel with loss of whiteness, i.e. assuming that mushrooms used were "tight" buttons in the first place. In a general way, therefore, degree of whiteness is a good index of mushroom acceptability.

In these experiments the shelf life (whiteness) reported tended to be shorter than that reported by other workers. Most attention should be focused on Experiments 3 and 4 (mushrooms in chips) rather than Experiments 1 and 2 (mushrooms in flat trays) since the former can be considered as commercial experiments while 1 and 2 are laboratory tests. In Experiments 3 and 4 there is only one case (Figure 4(a) or (f)) where the whiteness value is above the wholesale acceptability line W on day 7. This occurs where mushrooms were refrigerated immediately and were only out of the refrigerator for 2 days (day 5 to day 7).

The results in general contrast with data presented by Tomkins[3] and Cameron and Chappell[11] who show a storage life of 17–20 days (0 °C) and 9 days (7 days at 1 °C plus 2 days at ambient) respectively. The data (Figure 3(a) or (f), Figure 4(a) or (f)), however, agree more closely with that of Lutz and Hardenburg[12] who showed that mushrooms keep in prime condition for 5 days at 0 °C. It should be stressed that much may depend on the nature of the mushrooms being stored. This can be seen clearly in Experiments 3 and 4. In the former the mushrooms lost whiteness more rapidly than in the latter (Figures 3 and 4), although initial whiteness in both experiments was about the same. Mushrooms in Experiment 3 seemed to be more moist and spongy at time of harvest than those in Experiment 4 and it may be that mushrooms with a high dry matter content have the longest shelf life. Experiments have commenced to investigate this aspect.

In Experiments 1 and 2 mushrooms were held in open trays and delays (from 4–24 h) in getting mushrooms into refrigeration had no adverse effect on subsequent whiteness. This result was unexpected and contrasts with results in Experiments 3 and 4 where mushrooms were held in chips (delays for 24–48 h). A possible explanation may be that the heat of respiration could easily escape from the single layer of mushrooms in the trays. However, in the chips the heat may be partly trapped and this quickens enzyme action and hastens the onset of browning. It is important, therefore, in the case of mushrooms held in chips to refrigerate as soon as possible after harvesting. This above theory is borne out indirectly when the figures for weight loss for mushrooms in trays (Experiment 1) and chips (Experiments 3 and 4) are compared. The control sample in the former had lost 47% after 6 days while the controls in the latter only lost 28% after 6 days indicating greater air movement in the former.

The results for weight loss in Experiment 1 show that the different times of putting mushrooms into refrigeration had little or no effect on weight loss. This may have been due again to the single layer of mushrooms but more likely to the fact that the delays/breaks, before/during refrigeration amounted to a maximum of 12 h in Experiment 1 while maximum delays/breaks in Experiments 2, 3 and 4 were 24, 48 and 48 h respectively.

It is important to note that the rate of loss of whiteness of mushrooms on removal from refrigeration was the same or in some cases less than the rate of loss for the control sample. This is an important result since it further recommends chill temperatures as a method of storing mushrooms. It also discounts a belief held by many consumers that refrigeration preconditions food to rapid deterioration on removal to ambient temperature.

In theoretical terms the dotted lines (indicating mushrooms in refrigeration) in Figure 3(a), (b) or (c) should be superimposable or at least parallel. Similarly, for the dotted lines in Figure 4(a), (b) or (c). This should enable predictions to be made of loss of whiteness at times longer than 5 days in refrigeration by extrapolating the lines. This was not possible in Experiment 3 as the dotted lines were not parallel indicating that this was a poor batch of mushrooms (as already mentioned in the sections 2.4 and 4). In Experiment 4 the dotted lines were more parallel, thereby facilitating extrapolation and thus a reasonable prediction of shelf life at refrigeration times longer than 5 days could be made.

5. Conclusion

Categories of mushroom whiteness are defined in terms of Hunter Colour Meter L values. Minimum acceptability levels for whiteness at wholesale and consumer level are assigned on the basis of these categories. Only one treatment (5 days at 1 °C + 2 days at 20 °C) gave mushrooms with whiteness values above the wholesale acceptability line after 7 days. Extrapolation of the dotted lines in Experiment 4 (Figure 4(a–c)) gives some idea of what the shelf life would be if the period of chill storage had been continued.

Acknowledgements

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