

EFFECT OF WARMING CYCLES DURING STORAGE ON THE BEHAVIOUR OF JONATHAN AND GRANNY SMITH APPLES IN COOL STORAGE

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SUMMARY

The effect of raising fruit temperature for short periods during storage on the incidence of storage disorders has been investigated with both undipped fruit and fruit dipped in an alcohol solution of diphenylamine, a post-harvest treatment for scald control.

Jonathan apples warmed to 70°F for 5 days after 4 weeks' cold storage showed less soggy breakdown than unwarmed fruit.

Warming Granny Smith apples to 45 or 70°F for 2 days after 9 weeks' cool storage gave good control of core flush, and where fruit was dipped in a 2,000 p.p.m. alcoholic solution of diphenylamine prior to storage, warming to 45°F after 6 weeks' storage reduced this disorder.

I. INTRODUCTION

Studies by a number of workers indicate that the incidence of several physiological disorders of cool-stored apples can be reduced by subjecting the fruit to higher temperatures for brief periods during storage.

Smith (1958) reduced low-temperature breakdown in Bramley's seedling apples by warming the fruit to 65°F for 5 days after 6 weeks' storage. In a later experiment (Smith 1959), a reduction in superficial scald was obtained by warming the fruit after 16 and again after 20 weeks' storage. In Australia, Hall, Scott, and Riley (1961) significantly reduced scald in Granny Smith apples by warming the fruit to 68°F after 6, 8½ and 13 weeks' storage.

Padfield (1964) reported that Granny Smith apples subjected to three warming cycles developed substantially less core flush than those held continuously at 31°F. This technique also reduced superficial scald on fruit wrapped in plain paper and eliminated it completely from fruit in oiled paper.

Exploratory trials using the technique of warming cycles were carried out with two Queensland varieties during the 1965 storage season and are reported hereunder. Since Padfield (1959) and Stevenson and Blake (1961) reported that diphenylamine (DPA) wraps tended to reduce internal breakdown in apples stored in normal atmospheres, DPA-dipped fruit was also subjected to the warming treatment and the effect of this compound on a number of disorders was noted.

II. EXPERIMENTS WITH JONATHAN APPLES

Materials and methods.—The experimental fruit was obtained from one Granite Belt orchard on February 17, 1965. This picking date falls in the period recommended by Carroll (unpublished data) for the optimum storage behaviour of this variety.

After transport to the Food Preservation Research Laboratory, the fruit was divided into 16 samples each of four half-bushel cases. Eight samples were dipped in a 2,000 p.p.m. solution of diphenylamine in 30% alcohol. Four of these were then stored at 32°F and the remaining four at 36°F. In addition, four of the untreated samples were also stored at each of these temperatures.

After 2, 4 or 6 weeks' storage, a sample of dipped and undipped fruit from each temperature was removed to a 70°F constant-temperature room for 5 days, after which it was returned to the cool room. A treated and an untreated sample were held continuously at each temperature.

A summary of the treatments is as follows:—

- 1(a) Storage at 32°F continuously.
- 1(b) As for 1(a) but treated with DPA.
- 2(a) Storage at 32°F; warmed for 5 days at 70°F after 2 weeks' storage, then returned to 32°F.
- 2(b) As for 2(a) but treated with DPA.
- 3(a) Storage at 32°F; warmed for 5 days at 70°F after 4 weeks' storage, then returned to 32°F.
- 3(b) As for 2(b) but treated with DPA.
- 4(a) Storage at 32°F; warmed for 5 days at 70°F after 6 weeks' storage, then returned to 32°F.
- 4(b) As for 4(a) but treated with DPA.
- 5(a) Storage at 36°F continuously.
- 5(b) As for 5(a) but treated with DPA.

- 6(a) Storage at 36°F; warmed for 5 days at 70°F after 2 weeks' storage, then returned to 36°F.
- 6(b) As for 6(a) but treated with DPA.
- 7(a) Storage at 36°F; warmed for 5 days at 70°F after 4 weeks' storage, then returned to 36°F.
- 7(b) As for 7(a) but treated with DPA.
- 8(a) Storage at 36°F; warmed for 5 days at 70°F after 6 weeks' storage, then returned to 36°F.
- 8(b) As for 8(a) but treated with DPA.

All fruit was removed from store on July 15, 1965, and after 1 week at 70°F was examined for storage disorders. Firmness was measured on 10 fruit taken at random from each case by means of a Magness penetrometer, using the 7/16 in. plunger. Readings were taken on the opposite sides of each apple and the mean of 20 readings was recorded.

Results.—The results are summarized in Table 1. Separate analyses were carried out for diphenylamine-treated and untreated fruit.

TABLE 1
EQUIVALENT PERCENTAGES* OF DISORDERS IN JONATHAN APPLES
AFTER REMOVAL FROM COOL STORAGE

Treatment	Mould (%)	Superficial Scald (%)	Soggy Breakdown (%)	Bitter Pit (%)	Jonathan Spot (%)	Total Disorders (%)	Firmness (lb)
1 (a)	3.94	3.73	10.14	0.79	3.50	21.08	11.32
1 (b)	0.67	0.32	21.63	8.32	9.42	40.03	12.62
2 (a)	10.73	0.46	5.84	4.24	0.84	19.90	11.44
2 (b)	0.98	0.35	25.39	2.77	1.66	33.36	12.00
3 (a)	9.46	1.97	3.88	7.42	1.16	21.59	11.47
3 (b)	0.79	0.35	14.09	10.14	0.70	26.87	12.20
4 (a)	9.72	3.65	3.71	10.55	2.18	32.07	11.51
4 (b)	0.19	0.00	27.23	10.20	0.00	39.63	12.39
5 (a)	2.05	0.00	2.43	16.47	0.32	23.48	11.86
5 (b)	0.51	0.00	15.84	9.85	1.63	26.07	12.06
6 (a)	14.05	0.93	3.68	18.64	0.00	36.37	11.82
6 (b)	1.93	0.00	18.93	7.49	3.77	31.39	12.12
7 (a)	10.10	0.72	1.36	17.17	0.52	26.85	12.14
7 (b)	0.47	0.00	5.65	13.09	4.59	24.67	12.39
8 (a)	7.55	0.00	2.59	24.02	1.60	38.65	11.97
8 (b)	1.42	0.00	19.77	5.48	3.66	32.78	12.36

* Inverse-sine transformation used for analysis.

No analysis of variance carried out for superficial scald or Jonathan spot.

Mould

No significant differences between storage temperatures

Undipped fruit \gg Dipped fruit

Warmed after 2 weeks \gg Unwarmed fruit

Warmed after 4 weeks > Unwarmed fruit

Warmed after 6 weeks > Unwarmed fruit

Soggy breakdown

Storage at 32°F ≧ Storage at 36°F

DPA dipped fruit ≧ Undipped fruit

Unwarmed fruit > Warming after 4 weeks

Warming after 2 weeks > Warming after 4 weeks

Warming after 6 weeks > Warming after 4 weeks

Bitter pit

Storage at 36°F ≧ Storage at 32°F

No significant differences between dipped and undipped fruit

Warming after 4 weeks > Warming after 2 weeks

Warming after 6 weeks > Warming after 2 weeks

Total disorders

No significant difference between storage temperatures

No significant differences between dipped and undipped fruit

Warming after 6 weeks > Unwarmed fruit

Warming after 6 weeks ≧ Warming after 4 weeks

Firmness

Storage at 36°F > Storage at 32°F

DPA dipped fruit ≧ Undipped fruit

No significant differences between warming treatments

Superficial scald.—Though no analysis of variance was carried out, more scald appeared to occur at 32°F than at 36°F, and the diphenylamine treatment reduced or eliminated scald in all treatments.

Jonathan spot.—The incidence of Jonathan spot was slight, irrespective of treatment, and no analysis of variance was carried out. The results suggest that more spot was present in diphenylamine-treated fruit than in undipped fruit.

Mould.—Storage temperature did not affect the amount of mould development and diphenylamine treatment reduced mould incidence significantly. Warming the fruit after 2, 4 or 6 weeks' storage significantly increased mould incidence.

Soggy breakdown.—Storage at 32°F gave significantly more soggy breakdown than storage at 36°F. Diphenylamine treatment increased the incidence of soggy breakdown. Warming the fruit after 4 weeks' storage gave significantly less soggy breakdown than any of the other treatments.

Bitter pit.—There was more bitter pit development at 36°F than at 32°F but no significant differences were found between dipped and undipped fruit. Warming after 4 or 6 weeks gave more bitter pit than warming after 2 weeks.

Total disorders.—Neither storage temperature nor diphenylamine treatment affected the total percentage of disorders. Warming the fruit after 6 weeks gave more disorders than warming after 4 weeks or not warming at all.

Firmness.—Fruit stored at 36°F was significantly firmer than fruit stored at 32°F, and diphenylamine-treated fruit was firmer than untreated. The different warming treatments did not affect firmness.

III. EXPERIMENTS WITH GRANNY SMITH APPLES

Methods and materials.—The experimental fruit was obtained from one Granite Belt orchard on April 17, 1965, and after transport to Brisbane was divided into 14 samples each of four half-bushel cases. Seven samples were dipped in a 2,000 p.p.m. solution of DPA in 30% alcohol and all fruit was stored at 32°F. After 6, 9 or 13 weeks' storage (intervals used by Padfield 1964), dipped and undipped samples were warmed at 45°F or 70°F for 48 hr and then returned to cool storage at 32°F. A dipped and an undipped sample were held continuously at 32°F.

Individual treatments were as follows:—

- 1(a) Storage at 32°F continuously.
- 1(b) As for 1(a) but treated with DPA.
- 2(a) Storage at 32°F; warmed at 45°F after 6 weeks, then returned to 32°F.
- 2(b) As for 2(a) but treated with DPA.
- 3(a) Storage at 32°F; warmed at 45°F after 9 weeks, then returned to 32°F.
- 3(b) As for 3(a) but treated with DPA.
- 4(a) Storage at 32°F; warmed at 45°F after 13 weeks then returned to 32°F.
- 4(b) As for 4(a) but treated with DPA.
- 5(a) Storage at 32°F; warmed at 70°F after 6 weeks, then returned to 32°F.
- 5(b) As for 5(a) but treated with DPA.
- 6(a) Storage at 32°F; warmed at 70°F after 6 weeks, then returned to 32°F.
- 6(b) As for 6(a) but treated with DPA.
- 7(a) Storage at 32°F; warmed to 70°F after 13 weeks, then returned to 32°F.
- 7(b) As for 7(a) but treated with DPA.

All fruit was removed from store on November 17, 1965, and after 1 week at 70°F examined for storage disorders. Ten fruit taken at random from each case were cut and examined for core flush. Severity of this disorder was graded into absent, slight, medium or severe and 0, 1, 2 or 4 ratings were used. The weighted core flush rating was deduced by expressing the recorded incidence as a percentage of the maximum amount of core flush possible. Superficial scald was similarly expressed on a weighted basis and expressed as a percentage of the total possible in each case of fruit.

Results.—The results are summarized in Table 2. Separate analyses were carried out for diphenylamine-treated and untreated fruit.

TABLE 2
EQUIVALENT PERCENTAGES* OF DISORDERS IN GRANNY SMITH APPLES
AFTER REMOVAL FROM COOL STORAGE

Treatment	Mould (%)	Superficial Scald (%)	Bitter Pit (%)	Weighted Core Flush (%)	Total Disorders (%)	Firmness (lb)
1 (a)	3.18	29.07	0.41	9.43	65.69	13.86
1 (b)	1.89	0.07	0.74	4.76	4.66	13.35
2 (a)	1.21	23.46	0.33	9.92	66.90	13.61
2 (b)	4.56	0.06	2.24	0.63	8.46	13.64
3 (a)	4.67	29.67	0.81	1.18	68.89	13.03
3 (b)	5.21	0.74	0.53	3.65	9.87	13.30
4 (a)	2.16	34.35	1.71	10.85	72.57	13.10
4 (b)	1.33	0.76	1.59	2.20	6.81	13.18
5 (a)	3.53	35.27	0.82	6.13	71.86	13.24
5 (b)	0.90	2.64	2.32	2.31	14.40	13.20
6 (a)	5.45	39.22	0.59	0.92	79.68	12.70
6 (b)	3.76	2.36	1.56	1.41	15.28	13.16
7 (a)	4.58	29.87	0.70	3.15	71.52	13.04
7 (b)	2.42	0.30	1.22	3.65	5.33	12.79

* Arc-sine transformation used for analysis

Mould

(a) No DPA treatment—

- Warming to 45°F after 9 weeks > Warming to 45°F after 6 weeks
- Warming to 70°F after 9 weeks > Warming to 45°F after 6 weeks
- Warming to 70°F after 13 weeks > Warming to 45°F after 6 weeks
- No significant difference between warming temperatures
- Warming after 9 weeks > Warming after 6 weeks

(b) DPA treatment—

- Warming to 45°F after 9 weeks > Warming to 70°F after 6 weeks
- No significant difference between warming temperatures
- No significant difference between warming times.

Superficial scald

- (a) No DPA treatment—
 No significant differences between treatments
 No significant differences between warming temperatures
 No significant differences between warming times
- (b) DPA treatment—
 Warming to 45°F after 9 weeks > No warming treatment
 Warming to 45°F after 13 weeks > No warming treatment
 Warming to 70°F after 6 weeks \geq No warming treatment
 Warming to 70°F after 9 weeks \geq No warming treatment
 Warming to 70°F after 6 weeks \geq Warming to 45°F after 6 weeks
 Warming to 70°F after 9 weeks \geq Warming to 45°F after 6 weeks
 Warming to 70°F after 6 weeks > Warming to 45°F after 9 weeks
 Warming to 70°F after 9 weeks > Warming to 45°F after 9 weeks
 Warming to 70°F after 6 weeks > Warming to 45°F after 13 weeks
 Warming to 70°F after 9 weeks \geq Warming to 70°F after 13 weeks
 Warming to 70°F after 6 weeks \geq Warming to 70°F after 13 weeks
 Warming to 70°F \geq Warming to 45°F
 Warming after 9 weeks > Warming after 13 weeks

Bitter pit

- (a) No DPA treatment—
 No significant differences between treatments
 No significant differences between warming temperatures
 No significant differences between warming times
- (b) DPA treatment—
 No significant differences between treatments
 No significant differences between warming temperatures
 No significant differences between warming times.

Core flush

- (a) No DPA treatment—
 No warming treatment > Warming to 45°F after 9 weeks
 Warming to 45°F after 6 weeks > Warming to 45°F after 9 weeks
 Warming to 45°F after 13 weeks > Warming to 45°F after 9 weeks
 No warming treatment > Warming to 70°F after 9 weeks
 Warming to 45°F after 6 weeks > Warming to 70°F after 9 weeks
 Warming to 45°F after 13 weeks > Warming to 70°F after 9 weeks
 No significant differences between warming temperatures
 Warming after 6 weeks > Warming after 9 weeks
 Warming after 13 weeks > Warming after 9 weeks
- (b) DPA treatment—
 No warming treatment \geq Warming to 45°F after 6 weeks
 No significant differences between warming temperatures
 No significant differences between warming times.

Total disorders

(a) No DPA treatment—

- No significant differences between treatments
- No significant differences between temperatures
- No significant differences between warming times

(b) DPA treatment—

- Warming to 45°F after 9 weeks > No warming treatment
- Warming to 70°F after 6 weeks ≥ No warming treatment
- Warming to 70°F after 9 weeks ≥ No warming treatment
- Warming to 70°F after 6 weeks > Warming to 45°F after 6 weeks
- Warming to 70°F after 9 weeks > Warming to 45°F after 6 weeks
- Warming to 70°F after 6 weeks ≥ Warming to 45°F after 13 weeks
- Warming to 70°F after 9 weeks ≥ Warming to 45°F after 13 weeks
- Warming to 70°F after 6 weeks ≥ Warming to 70°F after 13 weeks
- Warming to 70°F after 9 weeks ≥ Warming to 70°F after 13 weeks
- No significant differences between warming temperatures
- Warming after 6 weeks ≥ Warming after 13 weeks
- Warming after 9 weeks ≥ Warming after 13 weeks

Firmness

(a) No DPA treatment—

- No warming treatment ≥ Warming to 45°F after 9 weeks
- Warming to 45°F after 6 weeks > Warming to 70°F after 9 weeks
- No warming treatment > Warming to 45°F after 13 weeks
- No warming treatment > Warming to 70°F after 6 weeks
- No warming treatment ≥ Warming to 70°F after 9 weeks
- No warming treatment ≥ Warming to 70°F after 13 weeks
- No significant differences between warming temperatures
- Warming after 6 weeks > Warming after 9 weeks

(b) DPA treatment—

- No warming treatment ≥ Warming to 70°F after 13 weeks
- Warming to 45°F after 6 weeks > Warming to 45°F after 13 weeks
- Warming to 45°F after 9 weeks > Warming to 70°F after 13 weeks
- Warming to 70°F after 6 weeks > Warming to 70°F after 13 weeks
- Warming to 45°F after 6 weeks > Warming to 70°F after 6 weeks
- Warming to 45°F after 6 weeks > Warming to 70°F after 9 weeks
- Warming to 45°F after 6 weeks > Warming to 70°F after 13 weeks
- Warming to 45°F ≥ Warming to 70°F
- Warming after 6 weeks ≥ Warming after 13 weeks

Mould.—The temperature of warming had no effect on mould incidence in either dipped or undipped fruit. Warming after 9 weeks gave greater mould incidence than warming after 6 weeks in undipped fruit but time of storage before warming had no effect on dipped fruit.

Superficial scald.—In undipped fruit, there were no significant differences between treatments, and time of storage before warming or warming temperature had no effect on the incidence of superficial scald.

Warming to 70°F produced significantly more superficial scald in dipped fruit than warming to 45°F and warming after 9 weeks' storage gave more superficial scald than warming after 13 weeks. Less superficial scald occurred in unwarmed fruit than in fruit warmed to 45°F after 9 or 13 weeks or that warmed to 70°F after 6 or 9 weeks.

Bitter pit.—No significant differences were found between treatments, warming temperatures or storage time before warming in either dipped or undipped fruit. In all the experimental fruit, the incidence of bitter pit was slight.

Core flush.—In undipped fruit, significantly more core flush occurred when warming took place after 6 or 13 weeks than when warming occurred after 9 weeks. Similarly, core flush incidence was higher in unwarmed fruit than in fruit warmed to 45°F or 70°F after 9 weeks. No significant differences were found between the two warming temperatures.

The results indicate that core flush was generally more pronounced in undipped than in dipped fruit. No significant differences in core flush incidence were found between times of warming or temperatures of warming in the dipped fruit.

Total disorders.—In undipped fruit no significant differences were found between treatments, temperatures of warming or time of storage before warming.

For dipped fruit, warming after 6 or 9 weeks gave significantly more disorders than warming after 13 weeks. Temperature of warming did not affect total disorders. Warming to 70°F after 6 or 9 weeks or warming to 45°F after 9 weeks gave significantly more disorders than in the unwarmed fruit.

Firmness.—In undipped fruit, unwarmed fruit was significantly firmer than fruit warmed to 70°F after 6, 9 or 13 weeks or fruit warmed to 45°F after 9 or 13 weeks. Warming after 6 weeks gave firmer fruit than warming after 9 weeks but no significant difference was found between the two warming temperatures.

In the dipped fruit, warming to 45°F gave firmer fruit than warming to 70°F and warming after 6 weeks gave firmer fruit than warming after 13 weeks. Unwarmed fruit was firmer than that warmed to 70°F after 13 weeks.

IV. DISCUSSION

The results of these experiments indicate that the warming technique may be of only limited value with the varieties Jonathan and Granny Smith. Jonathan apples warmed after 4 weeks showed less soggy breakdown than unwarmed fruit but other disorders were not significantly reduced by warming. The use of diphenylamine in this variety reduced mould and superficial scald but significantly increased soggy breakdown.

Warming untreated fruit at 45°F or 70°F after 9 weeks' cool storage gave very good reduction of core flush in Granny Smith apples. Where the fruit was dipped in diphenylamine, warming to 45°F after 6 weeks reduced this disorder. Since the percentage of total disorders and firmness readings recorded for this treatment did not differ significantly from the control fruit, warming to 45°F after 6 weeks may be a desirable treatment.

While the physiological changes occurring in warmed apples are largely unknown, Padfield (1966) suggests that warming may expel a toxic substance from the interior of the treated apple. He reported that ventilation of either cool or warmed fruit had no effect on core flush development.

It is not certain as yet whether this method of disorder prevention can be applied in commercial practice. Current investigations indicate that fruit in loosely stacked half-bushel cases may need up to 5 days after removal from store at 32°F to reach the ambient temperature of 70°F. The most suitable warming temperature for a variety has not yet been determined.

In future work, the advantages of using more than one warming cycle will be investigated both for normal storage and for controlled atmosphere stored fruit.

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