HIGH-TEMPERATURE CONTINUOUS-FLOW CURING OF SWEET ONIONS

B. W. Maw, C. L. Butts, A. C. Purvis, K. Seebold, B. G. Mullinix

ABSTRACT: A study was undertaken to investigate the feasibility of heat–treating sweet onions under controlled commercial conditions. Three test runs were conducted whereby approximately 4 m$^3$ of onions for each test were passed through a continuous-flow drier. Set-point temperatures of 43°C, 43°C, and 46°C and durations of heat treatment of 17, 24, and 24 h were used, respectively, during the three tests. Samples of heat–treated onions were taken from the dryer at regular intervals and, after prescribed storage intervals, were inspected for the presence of Botrytis allii with the aid of a dye. The increase in disease was calculated. There was a significantly ($P < 0.01$) less increase in disease during storage for those onions having received heat treatment compared with onions conventionally cured. In comparing the least square means, 24 h of heat treatment resulted in a lower incidence of disease than 17 h. Similarly, a set–point temperature of 46°C resulted in a lower incidence of disease than 43°C. Based upon the results of the study, a combination of heat treatment and conventional curing was recommended.

Keywords. Heat treatment, Thin layer drying.

The area of sweet onions (Allium cepa) grown in Georgia has expanded from 161 ha in 1978 (Smittle and Williamson, 1978) to 5050 ha with a production value of $75.05 million in 2003 (Anonymous, 2003).

Following harvest, sweet onions are cured and then, according to the projected market window, are stored under different environments (Maw et al., 1997b). Onions are sold by grade and then by weight within those grades. The USDA, through the Vidalia Onion Marketing Order, establishes the grades (USDA, 1993).

Curing is a continual process taking place whenever environmental conditions are conducive to the removal of moisture from the outer scales of the bulb. Curing may take place in the field, during transit, and even during storage. Onions should receive a minimum amount of curing. As a result, controlled artificial curing is advisable in addition to the natural field curing that may take place. Artificial curing may be accomplished by blowing warm air around the onions. The standard conditions for artificial curing are to pass air, heated to 100°F (37.78°C), around the onions at a static pressure of 0.75 in. (1.91 cm) (Maw et al., 1998a). For a complete cure, as gauged by the scales of the bulb being dry and the neck dry enough to fold over, duration of heat treatment has been shown to be influenced by harvest maturity of the onions (Maw et al., 1997b). For onions of an optimal harvest maturity, 72 h may be sufficient for a complete cure whereas only 48 h may be necessary for onions of a late harvest maturity. However, 96 h may not be sufficient to cure onions of an early harvest maturity.

One of the most prevalent diseases in sweet onions is a neck rot caused by the fungus Botrytis allii (Lacy and Lorbeer, 1995). A detailed account of infestation by Botrytis was given by Overduin (2001) when an entire store of onions was discarded after the disease was discovered in the store. Spores of Botrytis overwinter or are present in soil and are prevalent in fields of the Vidalia onion growing region of Georgia. The stem of an onion plant may become infested at the soil line and spores are known to invade dead or dying onion leaves, growing downwards through the neck into the bulb (Vaughan et al., 1964).

Even though there are other species of Botrytis, which may be confused with Botrytis allii, for example Botrytis byssoides, when infected by Botrytis allii, the onion bulbs develop a semi-watery decay, which may begin in the neck area and move through the entire bulb. White to gray mycelia may appear between the scales of the onion bulb. Sclerotia may form on the outer scales on the shoulders of the bulbs and a grayish mold also form on the outer surface. Preharvest infection may occur from spores present on the external surfaces of the onion bulb. A healthy onion with a well cured neck rarely becomes infested by Botrytis allii. Only seeds that are free of Botrytis allii should be sown (Maude and Presley, 1977).

Because Botrytis allii is known to flourish in the presence of moisture and temperatures of 65°F to 85°F (18.33°C to 29.44°C)
its growth is likely to be hindered when moisture is absent from the path of the fungal growth or when the temperature is increased to above 100°F (37.78°C) (Maw et al., 1998a). Sumner et al. (1999) demonstrated these phenomena in 1997 by placing cultures of Botrytis spp. in incubators for two days at various temperatures and then for a further five weeks at 78°F (25.55°C). All cultures grew and sporulated after heating to 86°F (29.44°C) to 99.5°F (37.5°C), but no cultures grew after heating to 108.5°F (42.5°C).

Walker (1921) emphasized the control of neck rot as early as 1921 when it was reported that a well-cured onion was less likely to encourage growth of the fungus. An air current, heated to as much as 120°F (48.89°C) and circulated over onions, was found to sufficiently dry the neck and thus offer a barrier to the progress of mycelia of the causal fungus. In 1925, Walker acknowledged that the state of maturity of the plant at harvest had a direct bearing on the amount of infection in the bulb at the time of harvest (Walker, 1925). Then again in 1926, in a thorough review of three different neck rot diseases, Walker noted differences in the incidence of neck rot according to onion cultivar (Walker, 1926).

Vaughan et al. (1964) suggested practices for reducing incidences of and losses from neck rot. Such practices included careful handling of the onions and curing in the field along with supplemental artificial curing. Maude et al. (1984) suggested combining an onion seed treatment of benomyl along with curing at 86°F (30.0°C). Without being combined with the seed treatment, curing at this temperature was not effective. Leaving onions in the field after clipping and before artificial curing was discouraged since they could be invaded by the pathogen.

Even though the survival and growth of spores of Botrytis allii in onions may be influenced by a high temperature, the onions must not be damaged by the heat. Onions may withstand high temperatures for a short period after which they are likely to experience damage Purvis (1999). At 115°F (46.11°C), ion leakage was small for onions after only 24 h of heat treatment but increased for 48 h of curing. Heating to a high temperature of 120°F (48.89°C) was advocated by Walker (1921) but no period of exposure was recommended other than that the necks should become fully dry. Hoyle (1948) reported that no bulbs showed heat injury from artificial curing after 16 h in an air blast of 105°F to 18°F (40.56°C to 78.78°C). However, Vaughan et al. (1964) found that artificial drying temperatures in excess of 125°F (51.67°C) for 24 h or 115°F (46.11°C) for 48 h caused serious injury and losses in storage.

Palilov (1971) observed that complete cultivar resistance to neck rot is not a reality, yet some disinfection may be accomplished by heating newly infected bulbs at 45°C for 8 to 12 h. He recognized that resistance to a high temperature is different for onion flesh as compared with the neck rot fungus. Onions may survive 45°C for 5 days and even 48°C for a shorter period but are injured at 49°C, while mycelium and conidia of the neck rot fungus die at 45°C after 5 to 8 h. Palilov (1971) also emphasized the benefits of thoroughly drying onion bulb outer scales to 14% to 16% moisture in order to inhibit secondary infection of neck rot during storage. Diatchenko (1973) even stated that for guaranteed disinfection of onions from neck rot they must be kept at temperatures of 113°F to 118°F (45.00°C to 47.78°C) for no less than 13 to 15 h. Randle (2001, personal communication) suggested that in the event that a limited period of high temperature was insufficient to provide both complete curing and disinfection, then a two stage process may be introduced. Onions could be cured at the recommended temperature of 100°F (37.78°C) until moisture had been appropriately removed and then they could be heat treated at a higher temperature of, for example, 115°F (46.12°C) for 8 h to provide disinfection.

Although Purvis (1999) conducted his laboratory heat treatment study on short day sweet onions, most studies have been conducted on long day, hard onions, including that of commercially heat treating those onions. Thus, a study was conducted to explore heat treating short day sweet onions on a commercial scale for the purpose of suppressing or eradicating the fungal spores of Botrytis allii. A continuous flow drier was available for this study.

**Materials and Methods**

**Materials**

Sweet onions were grown according to recommendations of the Cooperative Extension Service (Boyhan, 2001) on the Vidalia Onion and Vegetable Research Farm in Toombs County, Georgia, within the Vidalia onion growing region of Georgia during the season 2000–2001. At harvest, the onions were undercut using a rotating bar (Maw and Smittle, 1986) and they were hand clipped in the field and placed into mesh sacks. The state of maturity was observed at the time of harvest. The sacks of onions were loaded into pallet bins (Macro bin TM 34, Macro Plastics, Fairfield, Calif.) and transported to the site of the USDA-ARS National Peanut Research Laboratory in Dawson, Georgia.

One pallet bin of onions was conventionally cured at the Vidalia Onion and Vegetable Research Farm as a control for comparison with onions heat treated with the continuous flow dryer. For conventional curing, air, heated to 37.8°C, was forced among the onions by an axial flow fan, being directed from the fan to the pallet bin of onions by a flexible duct attached to both the fan exhaust and the upper edge of the pallet bin, forcing the air to pass downwards through the pallet bin of onions and exiting through the base.

Three test runs were undertaken during the season using sweet onions of three separate harvest dates. The sweet onions were of cultivar according to availability, however, cultivar was not a variable in the study nor were any differences between cultivars sufficient to cause a significant variation in the results of heat–treaing sweet onions.

**Dryer Equipment and Drying**

Heat treatment of the onions was undertaken using a continuous flow dryer (Belt-O-Matic, B.N.W. Industries, Mentone, Ind.) shown in figure 1. This dryer consisted of a moveable stainless steel web stretched between two rollers, one of which was powered by an electrical motor. The speed of the belt could be regulated using a variable sheave belt drive between the electrical motor and roller. The supported web area between rollers was 6.68 m². With the belt at the slowest speed, power cycling was also possible by means of a Dayton solid-state time relay (Dayton Electric Manufacturing Co., Chicago, Ill.) in order to reduce the speed of travel of the belt to that required for the test runs. Heated air was forced upwards through the web by a 0.7–m diameter,
3.72-kW fan with a capacity of 283 m³/min, whose speed was controlled by a 0– to 60–Hz digital speed controller. The air was heated by a 2.11 million–kJ/h propane gas furnace, mounted on the exhaust side of the fan and controlled by a variable flow proportional valve.

Approximately one pallet bin of onions was loaded directly onto the web of the dryer and up to four bins could be held in a hopper shown on the right side of figure 1, from which onions were fed onto the web. A gate on the hopper allowed a steady flow of onions onto the web and was set to the minimum for unobstructed flow, having a opened height of 0.28 m. Thus, the depth of onions on the web was 0.28 m or approximately two onions deep. A vibrator attached to the under side of the sloping base of the bulk hopper assisted in preventing bridging at the gate. There was a delicate balance between air temperature, airflow, and gas pressure in order for the flame to remain lit during all weather conditions. The measured static air pressure in a plenum below the web varied according to the depth of onions through which air was passing, as well as according to the speed of the fan. After passing through the layer of onions, the air, heated and loaded with moisture, was allowed to exhaust into the atmosphere rather than be recycled. Air temperature was monitored by Hobo continuous temperature data loggers (Onset Computer Corp., Mass.): at the plenum where heated air was passing among onions on the web and at an ambient air location. An example of temperature variation during the second test run is given in figure 2. The designated set point along with diurnal variations is shown. Electrical energy and propane gas consumption was measured during each test run. No rain fell during the test runs, which would otherwise have influenced the humidity of the drying air.

After the onions had been heat treated by slowly passing them through the dryer chamber, being supported on the web and heated by forced air, they were discharged from the end of the web into two pallet bins placed side by side outside the dryer (figs. 1 and 3). A sack of cotton was placed in the bottom of each pallet bin to cushion their fall. The sack of cotton was removed when a mound of onions had been established in the bottom of the pallet bin. Samples of heat–treated onions were collected throughout each test run as they were discharged from the dryer. The samples were given a value of curing index on a scale of 0–5 based upon the condition of the neck, scales, and roots (Maw et al., 1997a) and were taken to the Vidalia Onion Research Laboratory where they were graded according to size (Tew Manufacturing Corp., Penfield, N.Y.) into four grades: Jumbo (>89 mm); large (76–89 mm); medium (63–76 mm); and small (<63 mm). Onions from the samples were subsequently analyzed for *Botrytis allii*.

**EXPERIMENTAL TEST RUNS**

**Test Run Number One**

Sweet onions, cultivar ‘Sweet Vidalia,’ were undercut on 4 May and clipped on 7 May. The onions were observed to be of an early harvest maturity when harvested (Maw et al., 1997b). The grade composition was jumbo (55%), large (30%), medium (12%), and small (3%). Five pallet bins of onions were loaded into the dryer, a total net weight of 2554 kg of onions. The dryer was started at 09:30 h on 9 May. Seven samples of onions, each consisting of three replicas of 100 onions, were collected at eight hourly intervals, beginning at 17:30 h on 9 May and ending at 17:30 h on 11 May. The web speed was set to provide a maximum of 17 h of heat treatment for the onions as they traveled on the belt. The first two samples of onions had only 8 and 16 h of...
heat treatment since they were taken in advance of those that had been fed from the hopper. The remaining samples of onions had 17 h of heat treatment as they traveled on the web through the dryer.

The set-point temperature was 46°C for the entire test run. The fan speed was 50% of full speed, producing a linear velocity of 30 to 33 m/min with a measured static pressure of 0.34 to 0.67 kPa. This was less than the recommended back pressure of 2.53 kPa (Maw et al., 1998a) but was characteristic for thin layer drying. The total electrical energy used was 49 kWh and the total propane gas used was 295 L. The curing index of onions before heat treatment was 1 and afterwards was 2 for the first sample, 3 for the second sample, and 4 for successive samples (table 1). The final weight of heat–treated onions was 2288 kg of onions or 89.6% of the original weight. A sample of onions of three replications was taken at harvest representing onions having no curing or heat treatment. The pallet bin of onions cured as a control by conventional means, was given a curing index of 5 from which three replications of a representative sample were kept for analysis.

**Test Run Number Two**

Sweet onions, cultivar ‘Sweet Melody,’ were undercut on 11 May and clipped on 14 May. The onions were observed to be of an optimal harvest maturity when harvested. The grade composition was jumbo (65%), large (30%), medium (4%), and small (1%). Three pallet bins of onions having a total net weight of 1617 kg were loaded into the dryer. The dryer was started at 13:00 h on 15 May. The web speed was set to provide 24 h of heat treatment for the onions. Seven samples, each of three replications of 100 onions, were collected at eight hourly intervals beginning at 16:00 h on 16 May and ending at 16:00 h on 18 May after having had 24 h of heat treatment as they traveled on the web through the dryer.

The set-point temperature was 43°C for the entire test run. The fan speed was 50% of full speed, producing a linear velocity of 30 to 33 m/min with a measured static pressure of 0.0248 to 0.0496 kPa. The total electrical energy used was 60 kWh and the total propane gas used was 341 L (90 gal). The curing index of onions before heat treatment was given as 1.5 and afterwards as 4 for successive samples (table 1). The final weight of heat–treated onions was 1440 kg, or 89.9% of the original weight. A sample of onions of three replications was taken at harvest thus representing onions having no curing or heat treatment. The pallet bin of onions cured as a control by conventional means, was given a curing index of 3.5 from which three replications of a representative sample were kept for analysis.

**Table 1. Curing indices for onions before and after heat treatment or conventional curing.**

<table>
<thead>
<tr>
<th>Test Run</th>
<th>Before Heat Treatment</th>
<th>Heat Treatment (h)</th>
<th>Conventionally Cured</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>3.5</td>
<td>4</td>
</tr>
</tbody>
</table>

**Test Run Number Three**

Sweet onions, cultivar ‘Sweet Vidalia,’ were undercut on 18 May and clipped on 21 May. The onions were observed to be of a late harvest maturity when harvested. The grade composition was jumbo (81%), large (16%), medium (2%), and small (1%). Five pallet bins having a total net weight of 2807 kg of onions were loaded into the dryer. The dryer was started at 13:00 h on 22 May. As in test two, the web speed was set to provide a maximum of 24 h of heat treatment for the onions. Samples were first taken at 16:00 h on 22 May, and at successive eight hourly intervals, the first sample having had only 3 h, the second 11 h, and the third 19 h in comparison with the fourth and successive samples which had 24 h of heat treatment. A total of 10 samples each having three replications of 100 onions were taken, with the last one being taken at 16:00 h on 25 May.

The set-point temperature was 46°C for the entire test run. The fan speed was 40% of full speed, producing a linear velocity of 21 to 24 m/min with a measured static pressure of 0.057 kPa. The total electrical energy used was 45 kWh and the total propane gas used was 386 L. The curing index of onions before heat treatment was given as 1.5 and afterwards as 3.5 for 3 h of heat treatment, 4 after 11 h, 4.5 after 19 h, and 5 for the successive samples of 24 h of heat treatment (table 1). The net weight of heat–treated onions after curing was 2577 kg or 91.8% of the original weight. A sample of onions of three replications was taken at harvest thus representing onions having no curing or heat treatment. The pallet bin of onions cured as a control by conventional means, was given a curing index of 3.5 from which three replications of a representative sample were kept for analysis.

**Identification of Botrytis allii**

Analyses for the presence of Botrytis allii in the onions for each test run were made immediately before and after heat treatment and then on 28 May (assay 1); after 114 days of cold storage on 19 September (assay 2); and after an additional 75 days of cold storage until 3 December (assay 3). From each replication of 100 bulbs within a sample, a sub-sample of 25 bulbs were longitudinally bisected, exposing the neck and basal areas. The halves were placed on a plastic sheet (fig. 4). Though Botrytis neck rot is visible in its later stages of development as a semi–watery decay, eventually turning brown and causing the onion to lose turgidity within the infected region, identification of the disease in its early stages of growth is difficult. For this purpose a solution was sprayed on the onion halves containing 80% ethanol, 0.15% (w/v) methyl red (Tichelaar, 1967) and 0.1% (w/v) bromocresol green as described by Kritzman and Netzer (1978) and Kritzman (1983). After 15 min, the sections of onion bulbs were further examined for the presence of Botrytis allii as indicated by a red stain on the flesh of the onion or an absence of Botrytis allii as indicated by a green stain, the difference in color being caused by the variation in pH of the flesh as influenced by the activity of the Botrytis allii fungus. A rating of absence or presence of Botrytis allii was given to the bulbs as a percentage of the 25 bulbs in a sub-sample.
Figure 4. Onions of a sub-sample prepared for the identification of Botrytis allii.

The percentages of diseased onions were analyzed with four different models, giving emphasis to test run (harvest or harvest maturity), cultivar, duration of heat treatment and to set-point temperature (table 2), since these effects were partially confounded with each other. ProcMIXED (SAS, 2000) was used during the analysis. The least square means and their standard errors were calculated for the unbalanced experimental design. For the various differences among

assay dates, t-tests were made to determine where significant differences occurred.

RESULTS AND DISCUSSION

CURING INDEX

Drying of neck, roots, and scales is time dependent. Since onions used in the first test run were of an early harvest maturity and in the second test run were of an optimal harvest maturity, the curing index did not reach 5 for onions of the first and second heat treatments (table 1). These results imply that the onions were not fully cured by the end of the allotted duration of 17 and 24 h (Maw et al., 1998a). Even though intermediate samples were not taken of the second test run, the gradual change through time is apparent comparing test runs one, two, and three. Even the conventionally cured onions were observed to be insufficiently cured during test runs two and three. In terms of appearance, a lower airflow of 21 to 24 m/min over the onions resulted in a more uniform color distribution over the onion bulb as compared with a higher airflow, which tended to cause a blotchy appearance.

OVERALL TEST RUNS AND HARVEST MATURITIES

Though the least square mean percentages of diseased onions was slightly higher for the sample of heat-treated onions compared with the conventionally cured onions immediately following heat treatment and before storage as indicated on the first assay (1). The increase in notable

Table 2. Least square mean percentages and associated standard errors (SE) of onion bulbs from sub-samples found to be infested with Botrytis allii.

<table>
<thead>
<tr>
<th>Assays</th>
<th>N[a]</th>
<th>Assay Differences</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First (1)</td>
<td>Sec (2)</td>
</tr>
<tr>
<td>Overall test runs/</td>
<td>Heat treated</td>
<td>170</td>
</tr>
<tr>
<td>harvests</td>
<td>Conventional</td>
<td>27</td>
</tr>
<tr>
<td>Between test runs/</td>
<td>Heat treated</td>
<td>45</td>
</tr>
<tr>
<td>harvests[c]</td>
<td>Conventional</td>
<td>9</td>
</tr>
<tr>
<td>1</td>
<td>Heat treated</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Heat treated</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>9</td>
</tr>
<tr>
<td>Between cultivars</td>
<td>Sweet Vidalia</td>
<td>108</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Heat treated</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>9</td>
</tr>
<tr>
<td>Between durations of</td>
<td>Heat treated</td>
<td>45</td>
</tr>
<tr>
<td>heat treatment</td>
<td>Conventional</td>
<td>125</td>
</tr>
<tr>
<td>17 h</td>
<td>Heat treated</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>27</td>
</tr>
<tr>
<td>24 h</td>
<td>Heat treated</td>
<td>107</td>
</tr>
<tr>
<td></td>
<td>Conventional</td>
<td>63</td>
</tr>
<tr>
<td>Between set-point</td>
<td>Heat treated</td>
<td>27</td>
</tr>
<tr>
<td>temperatures</td>
<td>Conventional</td>
<td>27</td>
</tr>
</tbody>
</table>

[a] Number of samples where each consisted of 25 onions.
[b] All differences are between heat-treated and conventional curing treatments, using the unequal N–unequal variance t-test (Steel and Torrie, 1960) except for the two bottom groups (durations of heat treatment and set-point temperature) where three pair-wise comparisons are made among the three means.
[c] Denote significant differences at P < 0.01.
[d] Denote significant differences at P < 0.05.
[e] Cure/harvest 1 = ‘Sweet Vidalia,’ 17−h duration of heat treatment and 110°F (43.33°C) set-point temperature.
 Cure/harvest 2 = ‘Sweet Melody,’ 24−h duration of heat treatment and 110°F (43.33°C) set-point temperature.
 Cure/harvest 3 = ‘Sweet Vidalia,’ 24−h duration of heat treatment and 115°F (46.11°C) set-point temperature.
disease was significantly less for the heat–treated onions than for conventionally cured onions, between the first and second assays (P < 0.01) as well as the first and third (P < 0.05) assays (table 2). As a further calculation, subtracting the percentage found at the first assay from the average of that found at the second and third assays [(2+3)/2 − 1], disease for the heat–treated onions was also significantly (P < 0.05) less than that for onions conventionally cured.

**Between All Test Runs and Harvest Maturities**

Just as for overall test runs and harvests, even though the initial least square mean percentage disease levels may have been greater than for conventionally cured onions, the increase between successive assays was less for the heat–treated onions than for the conventionally cured onions (table 2). In the case of the first test run, these differences were significantly (P < 0.05, P < 0.01, and P < 0.05, respectively) less. Then for the second and third test runs the average increase in disease between assays [(2+3)/2 − 1] was less for heat–treated onions than for conventionally cured onions though the difference was not significant (P < 0.05).

**Between Cultivars**

For ‘Sweet Vidalia,’ the increases in least square mean percentages of disease for heat–treated onions were significantly (P < 0.01, P < 0.05, and P < 0.05, respectively) less than for conventionally cured onions (table 2). For ‘Sweet Melody,’ the average increase in disease between assays [(2+3)/2 − 1] was less for heat–treated onions than for conventionally cured onions though the difference was not significant (P < 0.05).

**Between Durations of Heat Treatment**

There were two treatments of duration for heat–treated onions compared with one for the conventionally treated onions (table 2). Pairs of percentage disease infestations were compared. Neither pair was found to have a significant difference from the conventional, yet examining the least square mean percentages, the increase in disease between first and second along with the first and third assays was less for the heat–treated onions compared with the conventionally cured onions, both for those heat treated for 17 h and those heat treated for 24 h. However, comparing the benefits of one duration of heat treatment over the other, the average increase in disease between assays [(2+3)/2 − 1] was less for the onions heat treated for 24 h (30%) than for those heat treated for only 17 h (33%) though these were not significantly different from one another.

**Between Set–Point Temperatures**

Since two set–point temperatures were used while heat treating onions, the least square mean percentages associated with each of these was compared in turn with the conventional (table 2). Although there were no significant differences, the increase in disease between first and second along with first and third assays was less for the heat–treated onions than for the conventionally cured onions, both for those heat–treated at 43°C and those heat treated at 46°C. However, comparing the benefits of one set–point temperature of heat treatment over another, the average increase in disease between assays [(2+3)/2 − 1] was less for the onions heat treated at 46°C (27%) than for those heat treated at 43°C (33%) though these were not significantly different from one another.

**Summary and Conclusions**

- Heat treatment of sweet onions was undertaken using a continuous flow dryer, in order to explore the effect of heat treating on a commercial scale. Approximately 4 m³ were cured on each of three occasions during the harvest season of 2001. For the three successive test runs, set–point temperatures of 43°C, 43°C, and 46°C and durations of heat treatment of 17, 24, and 24 h were used. During this duration, each test run took up to 72 h with onions continually passing through the dryer.
- Samples of cured onions were taken from the dryer at regular intervals and, at prescribed storage intervals, were inspected for the presence of Botrytis allii with the aid of a dye.
- Over all test runs, the increase in disease between the first and second and again between the first and third assays, was significantly less for those onions that received the heat treatment compared with those onions that were conventionally cured, implying that heat treatment had an effect upon the growth of disease in or on the onion bulbs.
- Between durations of heat treatment, 24 h tended to be better than 17 h and, between set–point temperatures, 46°C tended to be better than 43°C.
- Whereas in a laboratory, control can be exercised over small–scale experiments, in this study experience was gained using commercial equipment. Ambient conditions influenced the temperature of the heated air in the dryer because the unit was large and exposed to the weather. There were diurnal variations as well as variations from storms or cold fronts passing through the area. Constant vigilance of the equipment was required especially in the event of lightning. The speed of the web was checked by painting a stripe across the onions on the web and timing their movement.
- Thin–layer continuous flow drying rather than batch drying was selected for the high heat study because heated air could be directly blown around each onion bulb at the required temperature and for the required duration, thus avoiding a temperature gradient that would take place in the direction of airflow were batch drying to have been used.
- Duration of heat treatment was insufficient to ensure complete curing. It was therefore recommended from the study that in order to ensure that bulbs are properly cured with a curing index of 5, while at the same time limiting the heat treatment to 24 h, a combination of curing and controlled high heat treatment may be considered. Curing would dry the scales, neck and roots to reduce the likelihood of further infestation of disease into the onion bulb and heat treatment would minimize the growth of disease already present in or on the onion bulb.

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