Attempting to Predict Requirements for Scald Control on Delicious Apples: Massachusetts

Final Report

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GENERAL INTRODUCTION

In the fall of 1995 we commenced work on a project to see if we could predict scald susceptibility of Washington-grown Delicious apples. We had developed a prediction system for scald susceptibility of Massachusetts-grown Delicious and proposed to develop a similar system for Washington.

The primary data presented in this paper were collected in Washington by Dr. Eric Curry during the 1995 through 1998 harvest seasons. Fruit came from 6 different central Washington orchards, and were stored either at the Tree Fruit Research Station facilities or at the Stemilt research facility. Some older (1987-91) Washington data had previously been supplied by Dr. Curry. Most of the New England fruit were harvested from four Massachusetts orchards by Dr. Sarah Weis during the 1995 through 1998 harvest seasons. New England fruit were stored at the UMass Horticultural Research Center (HRC), except for one group of fruit which were stored in CA at the Stemilt research facility during the 1997-98 storage season. Equations developed to relate scald susceptibility to preharvest factors were based on data collected by a number of researchers at the HRC between 1986 and 1993.

In New England post-storage superficial scald has been found to decline as fruit are harvested later, as pre-harvest exposure to cool temperature increases, and as fruit maturity at harvest increases. We were able to develop equations which effectively predict scald susceptibility of New England Delicious based on (1) Harvest date (2) Number of pre-harvest days (or hours) in which the temperature goes to 50°F or lower and (3) Harvest starch index. An unexpected benefit has been that the DPA concentration required to control scald is also a function of scald susceptibility, so we can also use our equations to determine how much DPA to apply. The decline in scald susceptibility during the harvest season in New England is rapid enough that it is possible to store some later-harvested fruit without using any DPA. Our goal was to develop a similar set of scald-prediction equations for Washington-grown Delicious.

SOME COMPARISONS OF WASHINGTON AND NEW ENGLAND SITUATIONS

Data presented in Table 1 illustrate characteristics of scald development on Delicious apples in Washington, based on 9 years of results. To the right is shown the mean starch scores for years and sites when fruit were harvested during the designated periods, and they provide an indication of the progress of maturity over time in Washington. This is an important benchmark in evaluating the development of scald, which can be seen by year in the other 9 columns. These scald data make it clear that in most years too much scald develops, in the absence of any scald control procedure, to market fruit successfully. Even when you wait until October to harvest Delicious in Washington, scald susceptibility may be too great to store fruit without any scald control procedure. There is considerable year-to-year variability in scald development, but only one of the years (1995) can be called a true "low scald year". In other years, scald susceptibility sometimes fell to relatively low levels when fruit were harvested in October, but the mean starch score for this period was 2.8. Fruit of this maturity often contain substantial amounts of watercore and have begun to soften significantly, so they possess quality attributes that make them unacceptable for long-term storage, regardless of scald potential. Thus, the data in Table 1 demonstrate that in general scald susceptibility declines too slowly in Washington to produce scald-resistant fruit that are otherwise acceptable for long-term storage. However, this is a generalization and there may be some individual orchard sites that might present more acceptable opportunities. Yet, these will be the exceptions; fruit from most orchards will need scald protective treatments.

Note that the data presented above represent air-stored, rather than CA-stored fruit. Conditions from storage to storage and from year to year are relatively comparable for air storage, but CA conditions among storages and years are more variable. In New England, CA is almost always done in atmospheres containing more than 2% O_2 and this does not control scald. When ultralow oxygen levels are used, however, substantial scald control can result, and this is a variable that needs more examination, as shown later.

The situation seen in Table 1 is substantially different from that in New England. Table 2 compares Washington and New England scald development, fruit ripening, and preharvest temperature conditions. "Percent of fruit with scald" in this table refers only to those fruit which developed serious enough scald to be downgraded commercially. These are fruit which have enough scald that a consumer (or fruit inspector) would be likely to notice it and find it unacceptable. Fruit were stored at 32°F for 25 weeks and kept at room temperature for 1 week prior to rating.

Both regions experienced substantial scald problems on fruit harvested before October, but with the incidence diminishing over time. The "scald score" represents scald severity, and both it and the overall percent of fruit with scald showed a late season drop, indicating that not only is there less scalded fruit with later harvest, but its intensity is less when it occurs. Even though the September-harvested New England fruit developed more scald than the corresponding Washington fruit, that scald was generally less severe, as shown by New England's lower scald scores. New England Delicious also tend to ripen later than Washington Delicious (Starch Index, Table 2), and for this reason, the bulk of the New England crop is harvested later, in the first half of October. Occurrences of scald reducing cool temperatures, defined as 50°F of less, were highly variable from year to year in both Washington and New England, but in general, during August and September neither region consistently experienced the approximately 150 hours of sub50°F that are considered the minimum to create a substantial reduction in scald susceptibility. However, since most of the New England fruit are harvested in October, they are exposed to the cooler weather which nearly always occurs by early October.

Not only does Washington typically not experience 150 or more hours below 50°F during Delicious harvest, but it also experiences more hot (scald enhancing) weather, defined as hours over 85°F, than does New England, and much of that hot weather comes in early September. In New England hot weather generally occurs in August, prior to the onset of cool weather that produces scald resistance. This hot weather in Washington probably negates the benefits of any cool temperatures that preceded it, ensuring that in general, Washington Delicious remain highly scald susceptible through September even when cool temperatures occur.

PREDICTING SCALD DEVELOPMENT USING THE NEW ENGLAND SYSTEM

Our scald prediction system for New England Delicious uses two mathematical equations. The two equations predict which fruit will be 1) especially scald susceptible and 2) especially scald resistant. Equation 1 states: if 8.36 - 0.32(harvest date as days after 8/31) + 0.0546(number of preharvest days at or below 50°F) - 0.055(Cornell generic Starch Index) equals more than 0, then expect over 60% of fruit to scald. (By scald, we mean fruit that show any scald symptoms.) Maximum DPA treatment is required to control scald on these fruit. Only in 1998 do we have data for "any scald symptoms"for Washington-grown fruit. Using this equation, in 20 out of 26 Washington non-DPA treated samples, over 60% of the fruit were predicted to develop scald. In 17 of these 20 cases, over 60% of the fruit actually did develop scald. In the other 6 Washington samples, fewer fruit were predicted to scald, but 5 of those 6 samples exceeded 60% scald. Since the reason for trying to predict which fruit will have lower scald susceptibility is that they will not require the full concentration of DPA, and 5 out of 6 samples placed in the category did not belong there, this system must be considered a failure in 1998. In contrast, for New England, over 60% scald was predicted in 90 of 302 samples during 1995-98, and 69 of the 90 samples actually developed scald in at least 60% of fruit. More importantly, in identifying those which might require less DPA, only 13 of 212 samples (6%) developed more scald than predicted.

The second equation states that if -11.8 + 0.414(harvest date as days after 9/1) - 0.0298(number of preharvest days at or below 50°F) - 0.708(Cornell generic Starch Index) equals more than 0, then expect fewer than 20% of the fruit to scald. Note that 20% was used as a cutoff because when that few fruit have any scald, it is usually not very severe and often avoids detection (i.e., it is in the "1" score category as defined in Table 2). This equation for predicting "good" lots was correct 87% of the time for the 1995-98 New England samples. The 30 samples incorrectly categorized as "good" averaged 34% scald, but the average scald score (0 to 3) for the 14 samples for which the score was available was only 0.6, so most of it would have escaped detection. None of the 26 Washington samples were predicted to be in the "good" category, and all of the samples developed scald on more than 20% of the fruit. This may be perfect prediction, but is hardly good news! These results demonstrate that the mathematical equations developed in New England cannot be directly used in Washington to reliably predict scald.

WHAT MIGHT WE CHANGE TO PREDICT SCALD FOR WASHINGTON?

As seen in Table 1, "low scald years" can occur in Washington, but our system cannot reliably detect them. Can our system be modified to do this? Because various factors included in prediction equations are themselves related to one another, it is impossible to determine from an equation the "true" effect of one variable. For example, if it is hot, fruit tend to ripen sooner. Fruit subjected to high temperature may be made more scald susceptible, but riper fruit may become less scald susceptible, so these two factors must somehow "interact" in opposite directions. Sometimes two different factors move scald susceptibility in the same direction. For example, fruit will be ripest (increasing scald resistance) late in the season when there has been cooler weather (also increasing scald resistance). In order to separate these various effects it is necessary to have data from several different years and/or sites. Table 3 shows (crudely) some of the year-to-year and orchard-to-orchard variation in scald development on Washington Delicious. Tables 4 and 5 show how much scald could have been expected had fruit maturity been consistent over all years and orchards. Note that the means in Tables 4 and 5 assume that the effect of fruit maturity on scald is consistent overall. With enough data, and measurements of most of the important factors in determining scald, one should be able to make a reasonable equation mathematically to describe scald susceptibility, as we have done in New England. If a variable such as high temperature is left out, that will not matter in an area which does not get much hot weather, but the omission will affect an equation's accuracy in predicting scald in an area which does get hot weather at critical times. An equation can allow you to predict susceptibility if the values of the variables fall within the limits of the original data used to make the equations, and if all the really important variables (or factors which correlate to really important variables) are in the equation.

One difference between New England and Washington which stood out was the amount of high temperature occurring during the measurement period. Within the Washington data, in 1995, 1996, and 1997 there was consistently more scald developing on fruit harvested in early September than on those harvested in late August (Table 1). However, it was also hotter in early September than it was in August. Figure 1 demonstrates the concurrent rise and fall of temperature and scald development on fruit as the harvest seasons progressed in 1995, 1996, and 1997. Because the temperature records for 1987-91 are not complete (average temperature is not available), we could not determine the concurrent changes in temperature and scald development as the harvest progressed during those seasons. As intriguing as Figure 1 is, it does not represent enough data to say definitively that the rise in scald between the late August and early September harvests in 1995, 1996, and 1997 is a result of the temperature increase, but it certainly is a possibility. It appears that an effective prediction in Washington should require a factor for high temperature.

Attempts to create Washington equations comparable to the New England equations for scald prediction were not successful. Inclusion of a factor, any factor we could come up with, to account for preharvest high temperature did not improve predictions. Because there were more Washington data for scald score (0 to 3) and "percent of fruit developing a score greater than 1" than for "percent of fruit developing any scald", we concentrated on the former two scald assessments in developing equations. The best single equation we could come up with using the fifty 1995-97 data points was: Predicted Scald Score (0-3)= 0.14 + 0.033*(harvest Date as days after 7/31) - 0.61*Starch Index - 0.0084*(preharvest hours below 50°F) + 0.108*(average daily minimum temperature in °C). The R^2 value of this equation is 0.42, meaning that 42% of the variation in scald score of the 50 samples was explained by the equation. Knowing these four factors, the following is an example of prediction of poststorage scald score: harvest=9/20, so Date=51; Starch Index (SI)=1.5; there have been 75 hours below 50°F; and the average daily minimum temperature between August 1 and harvest (9/20) = 17.0°C (63°F). The equation is: 0.14 + (0.033)*(51) - (0.61)*(1.5) - (0.0084)*(75) + (0.108)*(17.0) = 0.14 + 1.68 - 0.92 - 0.61 + 1.84= 2.13, the predicted Scald Score (severe scald). When the equation was tested on the 26 samples taken in 1998, the following was found:

Predicted score	Number of cases	Actual score		
		Mean ± SD	Minimum	Maximum
Less than 1	1	1.8		
Between 1 and 1.5	2	1.7	1.6	1.8
Between 1.5 and 2	10	1.5 ± 0.5	0.7	2.1
Between 2 and 2.5	13	1.5 ± 0.5	0.6	2.4

Clearly, the equation did not work in 1998.

WHY COULDN'T WE PREDICT SCALD WELL IN WASHINGTON?

As described above, there are a number of differences in the Washington and New England situations. Environmental conditions and time of fruit maturity are different, as well as storage conditions, and marketing goals.

We had set out to examine environmental differences with the idea that scald susceptibility could be studied from that point of view alone. It can not. Washington Delicious do not appear to be more scald susceptible than New England Delicious on any given harvest date (which is not really important), but at a given maturity (as measured by Starch Index), Washington Delicious do appear to be more scald susceptible than New England Delicious, because they mature later in New England when the weather is cooler. Washington Delicious do not respond as well to DPA as New England Delicious do, requiring higher concentrations for still less effective control (Table 6 vs Table 7). Scald susceptibility is greater when fruit are harvested immature, which is done for Washington fruit which will be marketed year-round. In New England fruit are not harvested early because of lack of color, competition with McIntosh harvest, and because the fruit are not marketed over as long a period. We have observed that scald development increases as fruit are stored longer, so year-long marketing of Washington Delicious will require that just about every apple on the market in July will need some form of scald control. Early harvested Delicious just are that scald susceptible.

Exploring the possibility of later harvest, especially for fruit which will not go into long storage, is a possibility if one wants to avoid DPA (or the accompanying fungicides). It is for these fruit that prediction of scald susceptibility would be useful. Of course to do this, more data would need to be collected on later harvested fruit. It is clear that if Delicious are to be harvested before October, there will almost always be enough scald susceptibility that DPA will be needed. Late harvest for short term storage will yield fruit with less scald susceptibility.

SOME REMARKS ON DPA

When we started attempting to predict scald susceptibility of Delicious, there was concern that it might not be feasible to use DPA drenches in the future. It now appears that DPA is acceptable for the immediate future. However, the systems currently used for application of DPA to fruit require the use of fungicides, and there is a lack of safe, effective materials. We have informally experimented with ways to use DPA without fungicides, with some success. For example, when not recycling DPA, it has been applied without increased decay. Another possibility is spraying DPA on the tree, as done decades ago in New England. If trees are sprayed early in the morning, fruit can be harvested as soon as they are dry. In the latter approach, there is no problem of waste disposal, but there is considerable expense in purchasing the DPA. These approaches may be useful in niche situations to meet specific limitations on fungicide uses, because our results show clearly the overwhelming need for DPA on most Washington Delicious. Another change in thinking about DPA is the recognition that it has other positive effects on stored fruit besides scald control, possibly with less than 2000 ppm application.

In any modified use of DPA, a critical financial issue is the concentration necessary to meet the need. Using the lowest possible concentration would make a big difference financially. In our New England studies, fruit from many of the harvests were treated with 0, 500, 1000, or 2000 ppm DPA. If we look at the effect of DPA concentration, whether harvest date is considered or not, it is clear that whether the fruit were grown in New England or in Washington made a huge difference (Table 6 vs Table 7). Analysis of variance showed a linear decrease in scald as DPA concentration increased. There was also a decrease in scald with later harvest. Still, it appears from these data that on Washington fruit, even 2000 ppm DPA may be insufficient to control scald on fruit harvested before September 20, but the reader is cautioned that orchard-to-orchard and year-to-year variations existed that may represent some deviations from this general assessment.

In contrast to the Washington data (Table 6), the New England data (Table 7), the need for DPA varied according to harvest period. Specifically, as the harvest season progressed, less DPA was needed for adequate scald control. This may also be true in Washington, later than September 20, but we do not have enough data for late-harvested fruit to test the question. Late harvested fruit can only be a niche commodity for Washington, but may meet certain needs if little or no DPA is required. New England DPA requirement could be forecast crudely using harvest date alone, as in Table 7, or it could be more effectively forecast using the equations including factors for Starch Index and preharvest days or hours below 50F. We do not know how it might be forecast in Washington, given the small amount of late-season fruit in this study.

WHAT ABOUT CONTROLLED ATMOSPHERE?

In our limited studies of storage conditions, we have seen CA increase, decrease, and have no effect on scald susceptibility. Rapid application of CA gives rapid removal of oxygen, and scald involves oxidation reactions, but this does not necessarily translate into decreased scald development. We have not been able to systematically control time from harvest to DPA treatment and to CA imposition, or CA conditions, and these variables greatly influence scald development in and following storage. (Note: In our studies, when Delicious are stored at least 25 weeks, most scald develops during storage.) Our own experience, using relatively high O_2 concentrations has been that CA can actually increase scald development. The data shown in Table 8, part of the 1998 data supplied to us by Eric Curry, show the same thing for late-harvested Washington fruit. Without knowing the details of how the fruit spent their initial postharvest periods, it is impossible to form any conclusions about the effects of the different atmospheres. However, they emphasize the point that we simply do not understand the complexities of using CA for scald control in the absence of DPA treatment.

CONCLUSIONS:

1. The scald prediction equations developed for New England appear to work well in New England, but are not effective in Washington.
2. Washington Delicious are harvested earlier than New England Delicious, which limits their exposure to scald-reducing low temperatures and increases their exposure to high temperatures shortly before harvest, which we believe increases scald susceptibility.
3. Attempts to construct equations that can predict scald in Washington were not successful, at least partly due to insufficient data late in the harvest period.
4. In general, Washington Delicious require DPA treatment.
5. Despite these generalizations, year-to-year and orchard-to-orchard variations in scald susceptibility leave open the opportunity to identify some low-susceptibility fruit that might present different opportunities.
6. If there are opportunities to market late-harvested fruit, the possibility of scald resistance should be tested.
7. There is a clear need to look more closely at how well CA functions as a scald-reducing technique.

Table 1. Average percentages of Central Washington-grown Delicious which developed commercially significant poststorage scald. Samples were stored in 32°F air for 20-25 weeks prior to 1 week warming at 70°F for scald assessment. Starch Index is an overall average of the samples.

	No. of samples	Percent scald development in:									Starch Index
		1987	1988	1989	1990	1991	1995	1996	1997	1998	
August 21-31	76	93	74	78	71	55	32	66	-	55	1.3
September 1-10	53	97	50	82	55	50	55	73	71	41	1.5
September 11-20	46	89	89	84	38	38	5	59	81	44	1.8
September 21-30	39	88	22	82	27	31	0	57	53	75	2.3
October 1-10	15	-	-	-	5	27	-	19	-	70	2.8
No. of Samples	229	21	20	14	43	55	7	25	18	26	229

Table 2. Comparisons of scald development and associated factors in Washington (WA)and New England (NE)grown Delicious. WA data were collected between 1987 and 1998; NE data are from 1996, 1997, and 1998. Preharvest temperature data relate to exposures of the fruit samples in the table, rather than to overall weather conditions.

Harvest date	Number of samples		Scald Score[z]		% of Fruit with Scald[y]		Starch Index		Preharvest Hours<50F[x]		Preharvest Hours>85F[x]	
	WA	NE	WA	NE	WA	NE	WA	NE	WA	NE	WA	NE
August 21-31	72	-	1.8	-	68	-	1.3	-	6	-	37	-
September 1-10	52	-	1.7	-	60	-	1.5	-	16	-	74	-
September 11-20	44	25	1.7	1.7	59	74	1.9	1.1	44	22	64	14
September 21-30	38	41	1.5	1.0	51	40	2.3	1.3	81	48	87	53
October 1-10	13	63	0.9	0.5	31	22	2.9	1.6	70	141	82	26
October 11-20	-	25	-	0.1	-	3	-	2.2	-	243	-	13

[z] Scald score: 0 = none, 1 = slight, not enough to downgrade fruit, 2 = moderate, fruit would be downgraded, 3 = severe, with rough texture.

[y] Scald includes only fruit with scores of 2 or 3 (above).

[x] Begin counting hours on August 1st.

Table 3. Year-to-year variation in post-storage scald development on air-stored, non-DPA-treated Delicious grown at various sites in Washington.

Orchard		1987	1988	1989	1990	1991	1995	1996	1997	1998	Over all years	
											Scald[z]	SI[y]
1								41	45	36	40	1.7
2							23				23	1.8
3		98	89	92	55	48		72	91	54	73	1.6
4								35			35	2.1
5							22		49	62	48	2.0
6								50	88		67	1.9
7										71	71	2.4
8		100	70		77	84					83	1.6
9		78	51	70	44	26					53	1.5
10					53	52					52	1.7
11					58	58					58	2.0
12					45	20					29	1.6
13					35	29					30	1.5
Over all orchards	Scald[z]	92	70	81	55	46	22	50	66	57	58	
	SI[y]	1.5	1.4	1.3	1.9	1.6	1.8	1.8	1.9	1.9		1.7

[z] Scald is defined as surface browning severe enough to downgrade fruit. This corresponds to "scald score" of 2 or 3.

[Y] SI refers to the Delicious Scald Index as shown in the (WA) Apple Maturity Program Handbook.

Table 4. Least-squares means[z] for scald development in the orchards and years shown in Table 5.

Year	1987	1988	1989	1990	1991	1995	1996	1997	1998				
Scald	82	60	76	57	45	21	56	69	55				
Orchard	1	2	3	4	5	6	7	8	9	10	11	12	13
Scald	38	63	67	44	61	67	87	80	43	60	71	36	37

[z] These are the expected means for the orchards and years, taking into account the large number of empty cells in Table 3. Differences in Starch Index are also accounted for.

Table 5. Least-squares means[z] for scald development in the orchards and years shown in Table 5.

Year	1995	1996	1997	1998			
Scald[z]	22	55	68	54			
Orchard	1	2	3	4	5	6	7
Scald[z]	29	51	59	33	49	57	73

[z] These are the expected means of scald development (percent of fruit with score of 2 or 3) for the orchards and years shown, taking into account the large number of empty cells in Table 3. Possible effects of differences in SI are also accounted for. Only data from 1995-98 are used, because only for those years are there complete temperature records, and therefore only these data could be used for preharvest-weather based scald prediction.

Table 6. Percent of Washington grown fruit (1995, 1996, 1997, and 1998) showing easily discernable scald (score of 2 or 3) following one week at room temperature after 25 weeks in 32°F air.

Harvest[z]	DPA[z] concentration (ppm)				Over all DPA
	0	500	1000	2000	
8/21 to 8/31	49	54	52	41	47
9/1 to 9/10	71	78	73	42	60
9/11 to 9/20	59	58	60	26	51
9/21 to 9/30	42	32	18	6	39
10/1 to 10/10	19	3	5	3	20
Over all harvests	54	55	50	29	47

[z] Effects of both harvest date and DPA concentration statistically significant at odds of 1:1000. Their interaction is not significant at odds of 1:20.

Table 7. Percent of New England grown fruit (1996, 1997, and 1998) showing easily discernable scald (score = 2 or 3) following one week at room temperature after 25 weeks in 32°F air.

Harvested:	DPA concentration (ppm)				Over all DPA
	0	500	1000	2000	
9/11 to 9/20	66	25	12	0	33
9/21 to 9/30	40	18	2	0	21
10/1 to 10/10	21	1	1	1	9
10/10 to 10/20	2	0	0	0	1
Over all harvests	30	10	4	0	16

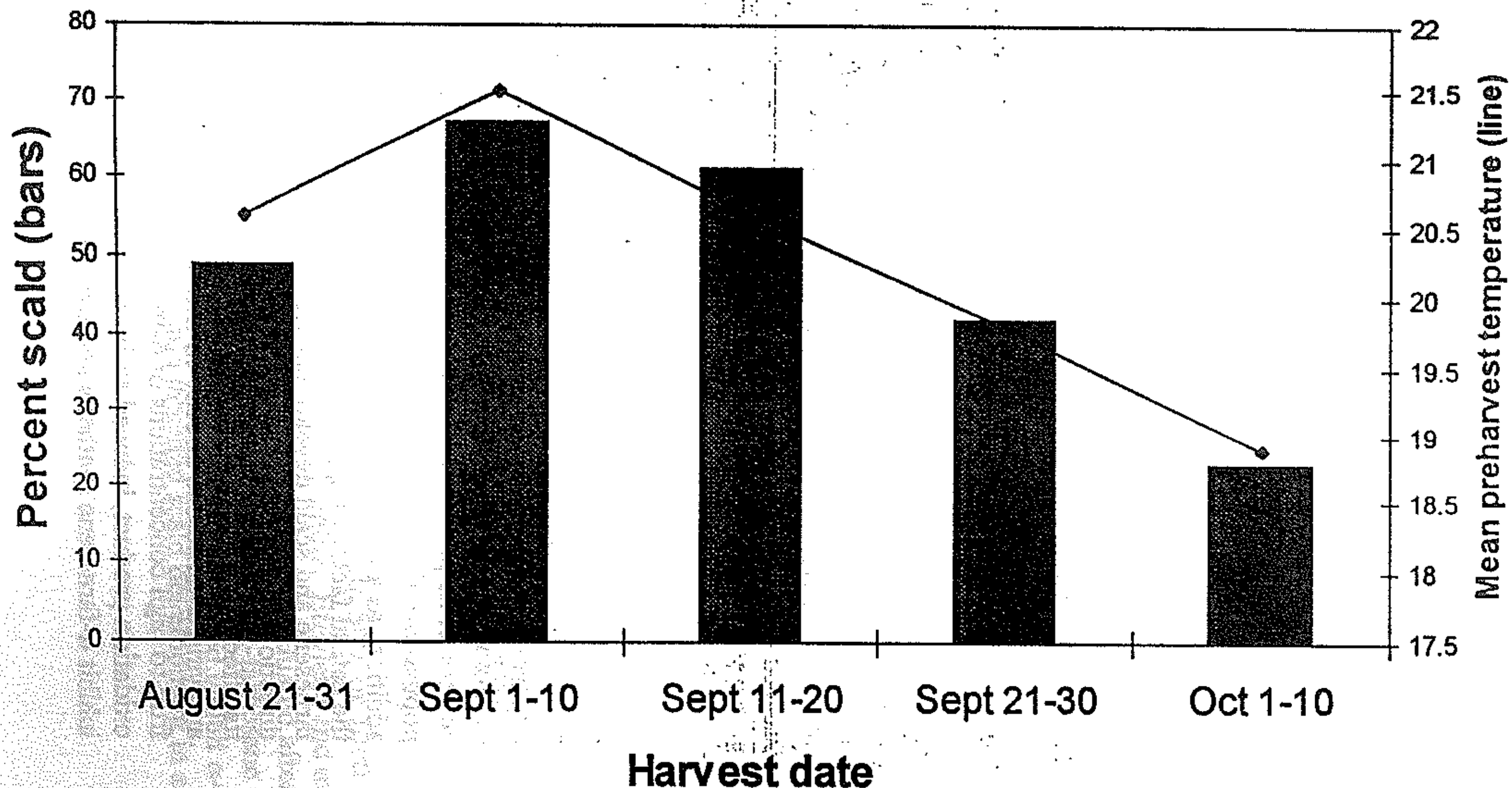
[z] Effects of harvest date, DPA concentration, and the interaction between harvest date and DPA concentration are all statistically significant at odds of 1:1000. (DPA can have less effect statistically at later harvest because there is not much scald to begin with.)

Table 8. Effects of storage atmospheres on scald development on Washington-grown Delicious. Fruit were stored at 32°F in the atmosphere indicated for 25 weeks, then kept at room temperature for 1 week prior to scald assessment.

Harvest Period	Percent of fruit developing scald[z] following storage in:			
	Air	3% O_2 1% CO_2	1.5% O_2 1% CO_2	0.75% O_2 1% CO_2
8/21 to 8/31	52	70	11	9
9/1 to 9/10	61	55	16	8
9/11 to 9/20	55	41	39	18
9/21 to 9/30	55	68	53	40
10/1 to 10/10	32	70	78	70

[z] Scald is defined as browning severe enough to cause fruit to be downgraded (scald score greater than 1).

Figure 1. Relationship between mean preharvest temperature[z] (line) and scald occurrence (bars) on Washington Delicious during 1995-1997



[z] Mean temperature between August 1 and the time of harvest