Literature cited

Beavers, W.B., C.E. Sams, W.S. Conway, and G.A. Brown. 1994. Calcium source affects calcium content, firmness and degree of injury of apples during storage. HortScience 29:1520-1523.

Bernadac, A., I. Jean-Baptiste, G. Bertoni, and P. Monard. 1996. Changes in calcium contents during melon (*Cucumis melo*) fruit development. Scientia Hort. 66:181-189.

Carter, W.W. 1981. Postharvest treatment for control of stem-scar, rind and decay fungi of cantaloupe. Plant Dis. 65:815-816.

Conway, W.S., C.E. Sams, R.G. McGuire, and A. Kelman. 1992. Calcium treatment of apples and potatoes to reduce postharvest decay. Plant Dis. 76:329-334.

Gross, J. 1991. Pigments in vegetables, chlorophylls and carotenoids. AVI Books, Van Nostrand Reinhold, New York.

Hewett, E.W. and C.J. Thompson. 1992. Modification of internal carbon dioxide and oxygen levels in apple fruit by postharvest calcium application and modified atmospheres. Postharvest Biol. Technol. 1:213-219.

Kays, S.J. 1991. Postharvest physiology of perishable plant products. AVI Books, Van Nostrand Reinhold, New York.

Lester, G. 1989. Gamma irradiation, hot water and imazalil treatments on decay organisms and physical quality of stored netted muskmelon fruit. J. Food Safety 10:21-20.

Lester, G. 1996. Calcium alters senescence rate of postharvest muskmelon fruit disks. Postharvest Biol. Technol. 7:91-96.

Lester, G and K.C. Shellie. 1992. Postharvest sensory and physicochemical attributes of honey dew melon fruits. HortScience 27:1012-1014.

Lester, G.E. and M.A. Grusak. 1999. Postharvest application of calcium and magnesium to honeydew and netted muskmelons: Effects on tissue ion concentrations, quality, and senescence. J. Amer. Soc. Hort. Sci. 124:545-552.

Luna-Guzman, I. and D.M. Barrett. 2000. Comparisons of calcium chloride and calcium lactate effectiveness in maintaining shelf stability and quality of fresh-cut cantaloupes. Postharvest Biol. Technol. 19:61-72.

Ryall, A.L. and W. Lipton 1979. Handling, transportation and storage of fruits and vegetables. vol 1. 2nd ed. Vegetables and melons. AVI Publ. Co. Inc., Westport, Ct.

Saftner, R.A., W.S. Conway, and C.E. Sams. 1998. Effects of postharvest calcium and fruit coating treatments on postharvest life, quality maintenance, and fruit-surface injury in 'Golden Delicious' apples. J Amer. Soc. Hort. Sci. 123:294-298.

U.S. Department of Agriculture, 1981. United States standards for grades of honey dew and honey ball type melons. Agr. Mktg. Serv., Wash., D.C. p 6.

The Influence of Paper Wraps on the Quality of 'd'Anjou' Pears after Controlled Atmosphere Storage

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ADDITIONAL INDEX WORDS. physiological disorders, black speck, scald, oil infused paper

SUMMARY. **Pears (*Pyrus communis* 'd'Anjou') were packed in six commercial paper wraps (dry; 3% oil; 3% oil with copper and ethoxyquin; 6% oil; 6% oil with ethoxyquin; 9% oil). After packing, the pears were placed in three different controlled atmosphere (CA) storage conditions in commercial CA rooms: 1) 1.5% oxygen (O_2) and 1% carbon dioxide (CO_2); 2) 1.5% O_2 and 3% CO_2; 3) 1.5% O_2 and 1% CO_2 for 60 days, 4% O_2 for 60 more days and finally 6% O_2 for an additional 90 days. Pears were stored in CA for 120 and 210 days, with or without an additional 30 days in regular atmosphere (RA) storage to simulate shipping and handling. Objective quality evaluations were conducted after each storage period and sensory evaluations after 210 days of storage. Paper type influenced both the peel and flesh color of pears before and after ripening, but did not influence firmness, soluble solids or acid content. Subjective ratings of appearance and disorder incidence were unacceptable for pears stored in a variable atmosphere wrapped in dry or paper containing 3% oil. The disorder black speck was present only in pears wrapped in paper with 6% oil and stored in an atmosphere of 1.5% O_2 and 1% CO_2. Pears stored in an atmosphere of 1.5% O_2 and 3% CO_2 received acceptable subjective scores regardless of paper type.**

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Atmospheres of 2% to 2.5% O_2 and <1% CO_2 are normally used for controlled atmosphere storage of 'd'Anjou' pears (Hansen and Mellenthin, 1979; Hardenburg et al., 1986). Using 2% or less O_2 for long term storage reduced losses of firmness, acidity, greenness and reduced scald severity (Chen et al., 1981; Mellenthin et al., 1980). Elevated levels of CO_2 (up to 3%) have been used for long-term pear storage (Allen and Claypool, 1948; Drake, 1994; Hansen, 1957), but the quality following storage has been inconsistent.

The standard atmosphere for the CA storage of 'd'Anjou' pears in the State of Washington contains 1.5% to 2% O_2 and <1% CO_2 held at –1 °C (30–31 °F) (Meheriuk, 1993). The CA storage law in Washington state requires that winter pears must be stored at <5% O_2 for a minimum of 90 d before they can be certified as CA stored pears (Washington Dept. of Agriculture, 1990).

Speckled skin or black speck is a superficial disorder that occurs in 'd'Anjou' pears following CA storage (Kupferman, 1988). Black speck is not caused by chemicals or pathogens, but is associated with low oxygen (<2%) in storage (Chen and Varga, 1989). Lee et al. (1990) postulated that black speck was associated with preharvest environmental stresses. Regardless of the cause, black speck is a frequently observed problem of late CA-stored 'd'Anjou' pears in Washington State.

For decades, pears have been individually wrapped in paper impregnated with low-viscosity petroleum oils, fungicides and/or antioxidants to help control various disorders and reduce postharvest decay problems. Paper wraps have been used in the Washington State fruit industry since the early 1900s. Initially paper wraps were used to cushion the fruit when in transit and to isolate decay. Use of oil (15%) impregnated paper to reduce scald was suggested by Brooks et al. (1919). Cooley and Crenshaw (1931) later suggested that copper sulfate ($CuSO_4$) be incorporated in the paper wrap to prevent the spread of rot. The oil in paper wraps has been suggested as one possible cause of black speck of ‘d’Anjou’ pears. This research was conducted to determine the interactions, if any, of CA storage environments and different types of commercially used paper wraps on the quality of ‘d’Anjou’ pears stored under commercial CA conditions.

Materials and methods

The six commercial paper wraps [dry (no oil); 3% oil; 3% oil with copper (Cu) and ethoxyquin (E); 6% oil; 6% oil with E; 9% oil] used in this study were furnished by Wrap Pack, Yakima, Wash. The wraps were manufactured 1 week prior to use to ensure freshness of the paper products. Pears were packed commercially at Blue Star Growers, Inc., Cashmere, Wash. Six boxes of pears from each of three growers were wrapped with each paper type, for a total of 108 boxes of packed pears. After packing, the pears from each grower lot were randomly divided into three groups of 36 boxes each. Each group of 36 boxes was then divided into three groups of 12 boxes, and one group of 12 boxes from each grower lot was placed in each of three different controlled atmosphere (CA) storage conditions in commercial CA rooms: 1) CA of 1.5% O_2 and <1% CO_2; 2) CA of 1.5% O_2 and 3% CO_2; 3) CA of 1.5% O_2 and <1% CO_2 for 60 days, then 4% O_2 and <1% CO_2 for 60 d and finally 6% O_2 and <1%CO_2 for 90 d. Pears from all three CA storage conditions were stored for either 120 or 210 d in CA.

The atmosphere in each room was established and maintained using a purge-type computer-controlled CA system. A Servomex analyzer, model 1400B4, (Norwood, Mass.) was used to determine atmosphere concentration on a daily basis. Each room had the capacity for 40 bins of fruit; CA-quality ‘d’Anjou’ fruit was used to fill the remaining space in each room to normal capacity. Two boxes of pears from each paper type and grower were removed from each CA storage room after 120 d and again after 210 d of storage. One box of pears was evaluated immediately after removal from storage and the second box was evaluated after an additional 30 d in RA storage to simulate handling time. Fruit quality of the pears was evaluated using 20 pears immediately after removal from storage (same day) and on 20 pears after an additional 7 d of poststorage ripening at 20 ºC (68 ºF) (estimate of shelf life). The remaining pears were evaluated for rot and physiological disorders. Pears held in RA storage [1 ºC (34 ºF)] for an additional 30 d to simulate shipping and handling time were evaluated upon removal from RA after 0 and 7 d ripening as described. Quality factors evaluated were firmness, external and internal color, soluble solids concentration (SSC), titratable acidity (TA), general appearance, finish and visually detectable disorders (scald, shrivel, black speck, and pithy brown-core).

Firmness was determined using the TA-XT2 Texture Analyzer (Texture Technologies, Scarsdale, N.Y.) equipped with a 7.7-mm (0.3-inch) probe. External and internal color was determined with The Color Machine (Pacific Scientific, Silver Springs, Md.) using the Hunter L*, a*, b* system and calculated hue values (Hunter and Harold, 1987). SSC and TA were determined from a composite of juice expressed from longitudinal slices from each of 10 fruit. An Abbè type refractometer with a sucrose scale calibrated at 20 ºC was used to determine SSC. TA was measured with a Radiometer titrator, model TTT85 (Radiometer, Copenhagen, Denmark). Acids were titrated to pH 8.2 with 0.1 N NaOH and expressed as percent malic acid. After 210 d of CA and 30 d of RA, one tray of 20 pears from each paper type and CA condition was evaluated for general appearance, finish, scald, shrivel, black speck and stem condition by 15 individuals skilled in quality control from five warehouses located in the Wenatchee, Wash., area, using a scale of 1 = none/excellent, 2 = slight/good, 3 = moderate/fair, and 4 = poor/extreme. Pears receiving scores between 2.5 and 3.0 were considered marginal in acceptability and those receiving scores 3.0 or greater were considered unacceptable. Pithy brown-core was evaluated by two laboratory personnel familiar with the disorder. All data were analyzed as a completely randomized design with MSTAT-C (Michigan State Univ., 1988) using growers as

Table 1. Quality attributes of ‘d’Anjou’ pears as influenced by paper wrap after 210 d of controlled atmosphere storage before and after 7 d of ripening.

Paper	Peel color[y]				Flesh color[x]				Scald	Firmness
type[z]	L*	a*	b*	hue	L*	a*	b*	hue	(%)	(N)
0 ripening time (immediately after removal from storage)										
Dry, no oil	63.8b	–6.7a	25.2a	105.1a	79.9c	0.35a	18.0a	88.9c	0	56.6a
3% oil	63.9b	–6.7a	24.9ab	105.3a	81.1bc	0.25ab	17.6ab	89.1c	0	58.0a
3% oil + Cu and E[x]	64.4ab	–6.3a	24.5abc	104.5a	81.5ab	0.18b	17.5ab	89.4bc	0	57.5a
6% oil	65.3ab	–6.5a	24.4abc	105.1a	81.9ab	–0.01bc	17.2b	90.0ab	0	57.9a
6% Oil + E[w]	65.3ab	–6.7a	23.8c	105.8a	82.5a	–0.01bc	17.0b	90.1ab	0	57.8a
9% oil	65.9a	–6.4a	23.7c	105.2a	82.0ab	–0.90c	17.1b	90.3a	0	57.7a
7 d of ripening [20 °C (68 °F)]										
Dry, no oil	66.1c	–3.3a	28.6a	96.6a	81.4a	1.0a	17.0a	86.8b	9.6a	13.1a
3% oil	67.3bc	–3.2a	28.7a	96.6a	82.4a	0.7a	16.8a	87.6a	<1.0b	13.7a
3% oil + Cu and E[x]	67.9bc	–3.2a	28.1ab	96.7a	82.7a	0.7a	16.9a	87.5a	<1.0b	14.0a
6% oil	68.8ab	–3.8a	27.5abc	97.9a	82.9a	0.6a	17.0a	87.9a	<1.0b	14.5a
6% Oil + E[w]	69.6a	–3.5a	26.7bc	97.6a	81.5a	0.6a	17.1a	88.0a	<1.0b	13.9a
9% oil	69.9a	–3.4a	26.4c	97.5a	81.7a	0.6a	16.8a	87.6a	<1.0b	14.5a

[z]Means in a column, within ripening time, not followed by a common letter are significantly different by Tukey’s honestly significant difference test ($P \leq 0.05$).
[y]Hunter L*, a*, b* system and calculated hue values (Hunter and Harold, 1987).
[x]Paper contains 3% oil with copper (Cu) and ethoxyquin (E).
[w]Paper contains 6% oil with ethoxyquin.
[w]4.45 N = 1.0 lb.

replications. Treatments were analyzed in a factorial arrangement using paper type as the main plot, with CA storage condition, storage time and ripening as the subplots. Means showing a significant F test were separated using Tukey's HSD test.

Results and discussion

After 120 d of storage little or no quality differences were evident for pears from the different paper wraps (data not shown). Fruit quality differences among pears from the different paper wraps were present after 210 d of storage (Table 1). As the amount of oil was increased in the paper wraps, peel L* values increased and b* values decreased, but no difference was evident for a*, or hue values for 'd'Anjou' pears after 210 d CA storage but before ripening. After pears were ripened for 7 d, the same color pattern was evident, but differences were larger (3+ units for L* and 2+ units for b*). Despite these color factor differences after storage and ripening, it is doubtful that differences of this magnitude would be noted by the consumer due to the lack of difference in hue values, which mathematically approximate the response of the human eye to color (Hunter and Harold, 1987).

Flesh color immediately out of storage was lighter and more yellow in pears wrapped in dry paper or in 3% oil compared to wraps with higher oil content (Table 1). After ripening, no differences in L*, a*, or b* values were detected in pear flesh and only marginal differences were found in hue (<1 unit); it is doubtful that this difference would be visible to the consumer. After an additional 30 d in RA storage, peel and flesh color patterns were similar to pears taken directly from CA storage (data not shown).

Scald was not evident in 'd'Anjou' pears immediately following CA storage regardless of the type of paper wrap (Table 1). After ripening, only pears wrapped in dry paper showed evidence of scald (9.6% vs. <1.0%); any oil concentration in paper eliminated scald. Firmness values were similar in pears from the different type of paper wrap both before and after CA storage and after an additional 30 d of RA storage regardless of ripening time (data not shown). Soluble solids, titratable acidity and pithy browncore were not influenced by type of paper wrap (data not shown).

Pear quality ratings (general appearance, finish, black speck, scald and stem condition) were strongly dependent upon the storage atmosphere and paper wrap (Table 2). General appearance and finish scores were marginal (>2.5) for pears stored either in 1.5% O_2 and <1.0% CO_2 or in the variable atmosphere. Pears stored in 1.5% O_2 and <1.0% CO_2 in dry paper (no oil), 3% oil + Cu and E, and 9% oil had the best scores for general appearance, but these general appearance ratings were marginal (>2.5) at best, while the other papers (6% oil and 6% oil + E) produced very unacceptable appearance ratings. Scores for finish were similar, with scores for pears in dry paper or paper with 9% oil superior to the scores for the pears in the other papers. Finish was scored as very poor (3.0) for pears in the most commonly used paper (6% oil + E). Shrivel was not a problem with pears stored in 1.5% O_2 and <1.0% CO_2 (data not shown). Black speck was present only in pears stored in 1.5% O_2 and <1.0% CO_2 and only when wrapped in paper containing oil, particularly 6% oil. Regardless of the type of paper wrap used, black speck was not a problem in either 1.5% O_2 and 3.0% CO_2 or the variable atmosphere. Scald was evident only in pears from the variable atmosphere and then only in dry paper or 3% oil paper.

Quality attributes of 'd'Anjou' pears

Table 2. Subjective evaluation of 'd'Anjou' pear quality after 210 d of controlled atmosphere storage (O_2 = oxygen, CO_2 = carbon dioxide) as influenced by the interaction of atmosphere and paper type.

Atmosphere × paper type	General appearance[z]	Finish[z]	Black speck[z]	Scald[z]
1.5% O_2 and <1.0% CO_2				
Dry	2.7 b	2.2 c	1.5 c	1.5 a
3.0% oil	3.2 ab	2.9 ab	2.6 b	1.2 a
3.0% oil + Cu and E[y]	2.8 b	2.8 abc	2.7 b	1.2 a
6.0% oil	3.6 a	2.9 ab	3.6 a	1.2 a
6.0% oil + E[x]	3.3 ab	3.0 a	3.2 ab	1.2 a
9.0% oil	2.6 b	2.3 bc	2.5 b	1.2 a
Variable (1.5% O_2 and <1% CO_2 for 60 d, then 4% O_2 for 60 d and finally 6% O_2 for 90 d)				
Dry	3.7 a	3.4 a	1.6 a	3.3
3.0% oil	3.6 a	3.4 a	1.4 a	3.0 a
3.0% oil + Cu and E[y]	1.7 c	1.7 c	1.2 a	1.1 b
6.0% oil	2.2 bc	2.2 bc	1.2 a	1.3 b
6.0% oil + E[x]	2.7 b	2.7 b	1.2 a	1.2 b
9.0% oil	2.6 b	2.6 b	1.5 a	1.5b
1.5% O_2 and 3.0% CO_2				
Dry	2.5 a	2.4 a	1.0 a	1.4 a
3.0% oil	1.6 b	1.5 b	1.3 a	1.0 a
3.0% oil + Cu and E[y]	2.1 ab	2.0 ab	1.3 a	1.1 a
6.0% oil	1.5 b	1.5 b	1.2 a	1.0 a
6.0% oil + E[x]	2.1 ab	2.2 a	1.4 a	1.1 a
9.0% oil	2.0 ab	2.3 a	1.4 a	1.3 a

[z]Evaluated on a scale of 1 to 4 (1 = excellent/none, 2 = good/slight, 3 = fair/moderate, 4 = poor/severe) N = 15.
Means in a column, within atmospheres, not followed by a common letter are significantly different by Tukey's honestly significant difference test ($P \le 0.05$).
[y]Paper contains 3% oil with copper (Cu) and ethoxyquin (E).
[x]Paper contains 6% oil with ethoxyquin.

Table 3. **Quality attributes of 'd'Anjou' pears as influenced by the interaction of controlled atmosphere regime and storage time followed by 30 d of regular atmosphere storage (SSC = soluble solids; TA = titratable acidity, O_2 = oxygen, CO_2 = carbon dioxide).**

Atmosphere[z]	Storage time (d)	Peel color[y] L*	Peel color[y] hue	SSC (%)	TA (% malic)	SSC/TA ratio	Scald (%)	Firmness (N)[w]
0 ripening time (immediately after removal from storage)								
1.5% O_2 and <1.0% CO_2	120	64.2 cd	105 ab	13.7 a	0.25 a	55 d	<1.0 a	58.7 a
	210	65.1 c	99 d	13.7 a	0.23 b	61 c	<1.0 a	46.9 c
Variable[x]	120	65.2 d	104 b	13.7 a	0.26 a	53 d	<1.0 a	53.1 b
	210	68.8 a	95 e	13.5 a	0.19 d	73 a	<1.0 a	34.2 d
1.5% O_2 and 3.0% CO_2	120	66.4 b	106 a	13.8 a	0.25 a	55 d	<1.0 a	59.6 a
	210	64.6 cd	101 c	13.6 a	0.20 c	68 b	<1.0 a	50.9 b
7 d of ripening [20 °C (68 °F)]								
1.5% O_2 and <1.0% CO_2	120	73.6 a	100 a	14.0 a	0.24 a	60 d	<1.0 b	11.9 bc
	210	68.5 c	91 c	13.8 a	0.20 b	70 c	1.0 b	10.5 c
Variable[x]	120	70.4 b	98 b	13.7 a	0.24 a	59 d	<1.0 b	10.7 c
	210	70.3 b	89 d	13.7 a	0.17 c	81 b	3.30 a	9.3 d
1.5% O_2 and 3.0% CO_2	120	68.5 c	98 b	13.8 a	0.23 a	61d	<1.0 b	11.4 bc
	210	68.4 c	91 c	13.9 a	0.16 c	90 a	<1.0 b	12.8 ab

[z]Means in a column, within atmosphere and ripening, time not followed by a common are significantly different by Tukey's honestly significant difference test ($P \leq 0.05$).
[y]Hunter L*, a*, b* system and calculated hue values (Hunter and Harold, 1987).
[x]CA of 1.5% O_2 and <1% CO_2 for 60 d, then 4% O_2 for 60 d and finally 6% O_2 60 d.
[w]4.45 N = 1.0 lb.

were influenced by the interaction between CA storage atmosphere and time in CA storage after 30 d of additional air storage (Table 3). This interaction between storage atmosphere and time in storage was present and similar immediately after CA storage and after an additional 30 d in RA storage, for peel color, TA, SSC/TA ratio, scald and firmness. Regardless of the atmosphere in question there was a distinct change in color between 120 and 210 days of storage. This color change was evident immediately after storage and after ripening for 7 d. This change in peel color as storage time progressed was more evident and dramatic in pears stored in the variable atmosphere, which were more yellow after 210 d of storage than pears from either of the other storage atmospheres (1.5% O_2 and <1.0% CO_2 or 1.5% O_2 and 3.0% CO_2). Changes in color were present in pears between storage atmospheres immediately after storage, but no scald differences were evident regardless of time in CA storage. Only those pears from the variable atmosphere displayed any scald and then only after 7 d of ripening following storage.

No difference in SSC was evident regardless storage atmosphere or time in storage either before or after ripening (Table 3). TA decreased between 120 and 210 d of storage regardless of atmosphere, but this decline was more evident in pears from either the variable atmosphere or 1.5% O_2 and 3.0% CO_2 when compared to pears from the standard atmosphere (1.5% O_2 and <1.0% CO_2) immediately after storage and after ripening. After 120 d of CA storage, the SSC/TA ratio was equivalent among pears from the different atmospheres both after storage and ripening. After 210 d of storage, there were well-defined differences in the SSC/TA ratio of pears from the different storage atmospheres. Pears from the variable and 1.5% O_2 and 3.0% CO_2 atmosphere exhibited higher SSC/TA ratios than pears from the standard (1.5% O_2 and <1.0% CO_2) storage atmospheres immediately after storage as well as after ripening. There is some indication (Boylston et al, 1994) that higher SSC/TA ratios are associated with greater consumer preference.

Firmness differences in pears from the different atmospheres were not evident after 120 d of storage; after 210 d there were well-defined differences depending on the storage atmosphere. Pears from the 1.5% O_2 and 3.0% CO_2 had the highest firmness values, whereas pears from the variable atmosphere had the lowest firmness values. After ripening, firmness values were comparable between the pears from either the 1.5% O_2 and 1.0% CO_2 or the 1.5% O_2 and 3.0% CO_2 atmosphere and these firmness values were superior to the values determined for pears from the variable atmosphere.

Conclusions

Type of paper wrap had a strong influence on pear quality, but this influence was not present until after extended CA storage. Peel and flesh color, and particularly the amount of scald present, changed during storage depending on paper type. Pears wrapped in dry paper displayed high amounts of scald. There was less dramatic change in both peel and flesh color of pears wrapped in paper containing oil. Subjective scores for general appearance, finish and scald were unacceptable for pears in dry paper or paper with 3% oil stored in a variable atmosphere (CA of 1.5% O_2 and <1% CO_2 for 60 d, then 4% O_2 and <1% CO_2 for 60 d and finally 6% O_2 and <1%CO_2 for 90 d). Black speck was present only in pears stored in an atmosphere of 1.5% O_2 and <1.0% CO_2 wrapped in a paper containing 6% oil. Pears stored in an atmosphere of 1.5% O_2 and 3.0% CO_2 received acceptable quality scores regardless of paper type. For the successful long-term storage of 'd'Anjou' pears, the best poststorage fruit quality is obtained using the standard CA atmosphere (1.5% O_2 and 1.0% CO_2) combined with paper wraps containing no more than 3% oil, or 1.5% O_2 and 3.0% CO_2 regardless of the amount of oil in the paper.

Literature cited

Allen, F.W. and L.L. Claypool. 1948. Modified atmosphere in relation to the storage life of Bartlett pears. Proc. Amer. Soc. Hort. Sci. 59:192–204.

Boylston, T.D., E.M. Kupferman, J.D. Foss, and C. Buering. 1994. Sensory quality of Gala apples as influenced by controlled and regular atmosphere storage. J. Food Qual. 17:477–494.

Brooks, C., J.S. Cooley, and D.F. Fisher. 1919. Nature and control of apple scald. J. Agr. Res. 18:211–240.

Chen, P.M., R.A. Spotts, and W.M. Mellenthin. 1981. Stem-end decay and quality of low oxygen stored 'd'Anjou' pears. J. Amer. Soc. Hort. Sci. 106:522–527.

Chen, P.M. and D.M. Varga. 1989. 'Black speck', a superfical disorder of 'd'Anjou' pears after prolonged CA storage, p.145–156. In: J.K. Fellman (ed.). Controlled atmospheres for storage and transport of perishable agricultural commodities. 5th Intl. Controlled Atmosphere Research Conf.

Cooley, J.S. and J.H. Crenshaw. 1931. Control of botrytis rot of pears with chemically treated wrappers. USDA. Circ. 177.

Drake, S.R. 1994. Elevated carbon dioxide storage of 'Anjou' pears using purge-controlled atmosphere. HortScience 29:299–301.

Hansen, E. 1957. Reactions of Anjou pears to carbon dioxide and oxygen content of the storage atmosphere. Proc. Amer. Soc. Hort. Sci. 69:110–115.

Hansen, E. and W.M. Mellenthin. 1979. Commercial handling and storage practices for winter pears. Ore. State Univ. Agr. Expt. Sta. Rpt. 550.

Hardenburg, R.E., A.E. Watada, and C.Y. Wang. 1986. The commercial storage of fruits, vegetables and florist and nursery stocks. U.S. Dept. Agr. Hdbk. 66.

Hunter, R.S. and R.W. Harold. 1987. The measurement of appearance. 2nd ed. Wiley, New York.

Kupferman, E.M. 1988. Research on skin speckling and pithy brown core of 'd'Anjou' pears reported. Good Fruit Grower 39:17–18.

Lee, S.P., P.M. Chen, T.H.H. Chen, D.M. Varga, and E.A. Mielke. 1990. Differences of biochemical components between the skin tissues of normal and black-speckled 'd'Anjou' pears after prolonged low-oxygen storage. J. Amer. Soc. Hort. Sci. 115:784–788.

Meheriuk, M. 1993. CA storage conditions for apples, pears and nashi, p. 819–858. vol 2. In: Proc. 6th. Intl. Controlled Atmosphere Res. Conf., June 1993, Ithaca, N.Y.

Mellenthin, W.M., P.M. Chen, and S.B. Kelly. 1980. Low oxygen effects on dessert quality, scald prevention and nitrogen metabolism of 'd'Anjou' pear fruit during long term storage. J. Amer. Soc. Hort. Sci. 105:695–698.

Michigan State University. 1988. MSTAT-C,Version 1.0. East Lansing, Mich.

Washington Department of Agriculture. 1990. Washington controlled atmosphere storage requirements for winter pears. WAC 16-449-010. 20 Sept. 1973. Wash. Dept. Agr., Olympia.

Influence of Temperature Gradients on Triploid and Diploid Watermelon Seed Germination

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SUMMARY. Ten triploid and 25 diploid watermelon (*Citrullus lanatus*) selections were evaluated to determine the temperature range and length of test for which germination index (rate of germination over time) and germination percentages were maximum for expediting vigor and seed testing practices. Temperature interacted with watermelon selection indicating that certain selections germinated faster within specific, but differing temperature ranges. Within 2 days after starting the germination process, 90% of triploid selections and 96% of diploid selections germinated to their greatest level and prolonging germination data collection for one week did not change this relationship. Although optimal temperature ranges may differ among the selections, the one temperature within the range common for all selections evaluated that maximized germination was 85 to 90 °F (29.4 to 32.2 °C) for diploids and 85 °F for triploids.

Watermelons are native to South Africa (Simmonds, 1976) and were introduced into Europe in the 16th century and the United States in 1629 (Thompson and Kelly, 1957). Diploid watermelons require warm temperatures of >79 °F (26 °C) for seed germination and proper growth and development (Whitaker and Davis, 1962). In the early 1950s, optimal soil temperatures for diploid seed germination were established that range from 70 to 95 °F (21 to 35 °C) with 95 °F as optimal and 59 °F (15 °C) and 104 °F (40 °C) considered the minimum and maximum temperatures, respectively (Harrington and Minges, 1954). Since then, new hybrid diploid cultivars have replaced the older open-pollinated cultivars and these new cultivars may respond to temperatures differently.

Triploid (seedless) watermelons were first developed in the early 1950s at Kyoto University in Japan (Kihara, 1951). Since their development, inferior seed germination has been a serious problem with triploids. The triploid seeds (3×), originating from tetraploid ovaries (4×), have hard, thick seed coats that interfere with germination (Kihara, 1951; Sachs, 1977). Triploid watermelon seed production is a complicated, expensive process (Marr et al., 1991), compared with diploid seed production. Because of high seed cost and reduced viability with triploid versus diploid watermelon seeds, growers use transplants from seeds that are germinated in temperature-controlled rooms to facilitate uniform germination and improved plant production. Even if triploid plants are produced in controlled environments, seedling emergence and growth may still be reduced with uneven germination and seedling emergence and poor seedling vigor and growth rate.

Presently, the temperature of germination rooms for triploid watermelons may range from 75 to 100 °F (24 to 38 °C) for 24 to 72 h depending on a transplant company's protocol. Vavrina and Maynard (1998) concluded that triploids germinate optimally between 84 to 90 °F (29 to 32 °C) for a 24 to 48 h period or until the radicles emerge from the seed coat. Given the fact that seedless watermelons are currently very popular with consumers, the major seed suppliers have released many new watermelon cultivars to meet those demands (Maynard and Elmstrom, 1992). It is unknown, however, if the general temperature range proposed by Vavrina and Maynard (1998) is appropriate for new triploid watermelons. Still, even

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