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Variation in the Respiration of Harvested Pecans due to Genotype and Kernel Moisture Level

Randy M. Beaudry
Department of Horticulture, University of Georgia, Athens, GA 30602

Jerry A. Payne
ARS/USDA, Science and Education Administration, Southeastern Fruit and Tree Nut Research Laboratory, Byron, GA 31008

Stanley J. Kays
Department of Horticulture, University of Georgia, Athens, GA 30602

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Abstract. **The respiratory rates of nuts of 19 pecan [*Carya illinoensis* (Wang) K. Koch] genotypes were determined with and without shells; at harvest moisture and at 3% kernel moisture. Shell respiration also was determined. Respiratory rates of kernels and intact nuts varied logarithmically with moisture content of the kernel. Respiratory rates of kernels at harvest ranged from 26.9 to 0.3 mg $CO_2 kg^{-1} hr^{-1}$; after drying to 3% moisture, values declined, ranging from 0.21 to 0.06 mg $CO_2 kg^{-1} hr^{-1}$. Respiration also was genotype dependent and was influenced by shell presence. The respiration rate of unshelled nuts was greater than shelled kernels when the moisture level was high, but lower when the kernel moisture level was low. Shell material was found to respire to a limited extent.**

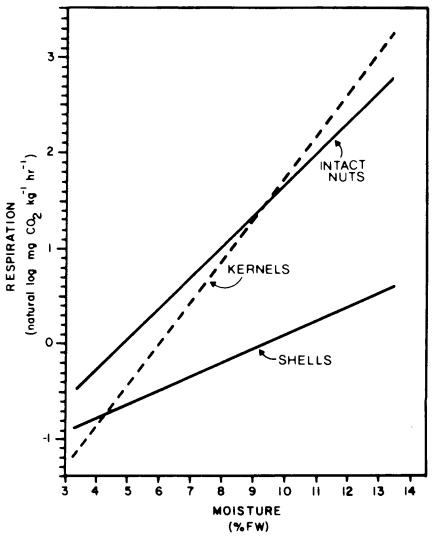

Fig. 1. The relationship between moisture content and respiration of intact nuts, kernels, and shells of pecan genotypes as described by the following equations: intact nuts, Ln mg CO_2 kg^{-1} hr^{-1} = −1.571 + 0.321 (% moisture); kernels, Ln mg CO_2 kg^{-1} hr^{-1} = −2.37 + 0.415 (% moisture); and shells, Ln mg CO_2 kg^{-1} hr^{-1} = −1.45 + 0.157 (% moisture). Regression equations had R^2 values of 0.85, 0.84, and 0.40, respectively, and were statistically significant at the 0.01 level.

During postharvest handling and storage, pecan kernels decline in quality, the rate of which is largely a function of the environmental conditions in which they are held. Kernel moisture content, storage temperature, and storage gas atmosphere have been shown to be critical environmental factors (1). Quality losses during this period are due primarily to breakage, discoloration of the kernels, and oxidation of component lipids.

Initial color and subsequent loss of color quality varies widely between the various cultivars of pecan (2). However, with the exception of lipid concentration (5, 6, 7, 8), little is known about compositional and metabolic factors which vary between cultivars and may be important in the maintenance of quality. In most seed crops, the length of potential storage and the rate at which quality is lost are closely related to product moisture content and the subsequent rate of metabolic activity. Typically, product respiratory rate is used as an index of general metabolic activity.

There is considerable interest in packaging pecans for retail sales in low oxygen environments (1). As with fleshy fruit (4), exposure of pecans to extremely low oxygen concentrations results in decreased organoleptic quality (unpublished data). As a consequence, by utilizing a packaging material in which the oxygen permeability rate is balanced against the respiratory utilization of oxygen, a much more constant internal environment could be maintained during retail sales.

There are many pecan cultivars grown commercially within the United States (3). Because variation in the respiration rate among individual cultivars could effect packaging requirements, determination of this variation would be useful and is needed.

The respiratory rates of 19 genotypes [Alley, Cherokee, Cheyenne, Chickasaw, Delmas, Desirable, Elliott, Mohawk, Moneymaker, Moore, Pabst, Schley, Shawnee, Shoshoni, Stuart, Success, Wichita, 61-6-67 (Mohawk x Starking) and 63-16-125 (Mohawk x Starking)] were measured at harvest and after drying to a constant moisture level (3%). To minimize location variation, samples collected from 4 trees of each cultivar from a 6 ha orchard in south Georgia were pooled. The effect of the pecan shell on the respiration of the nut also was determined by measuring samples with the shell intact and after removal. Samples were dried to a known moisture level by placing them in a forced air dryer (30°C) for varying lengths of time up to 48 hr. Actual moisture levels were determined at the beginning and end of each experiment by drying a representative sample in a forced air oven (60°C) to a constant weight.

Respiration measurements were made on either 10 nuts (unshelled) or 30 kernels (shelled) placed in a 125 ml Erlenmeyer flask sealed with a serum vial stopper. To minimize CO_2 movement through the rubber serum vials, the flasks were inverted, placing the stopper below the surface of a saturated solution of potassium chloride. The flasks were held in the dark at 22°C during the course of the experiments. At 24 hr intervals, a 1 ml gas sample was removed from each flask using a gas-tight syringe and analyzed for CO_2 using a Fisher-Hamilton gas partitioner. The gas sample was separated on a 2.0 m × 4.8 mm column of 42-60 mesh Molecular Sieve 13X and a 1.8 m × 6.4 mm column of DEHS on Columnpak, 60–80 mesh; 70°C,, He carrier at 40 ml/min; thermal conductivity detector. Respiratory data are presented as mg CO_2 kg^{-1} of kernels hr^{-1}.

The contribution by the shell to the amount of CO_2 evolved in unshelled samples was determined by measuring the respiration of the shells alone of several cultivars. Data for each treatment are the mean of 6 replications.

Within a genotype, the highest respiratory rates were found at harvest and were closely correlated with the percentage of moisture level of the kernel (Fig. 1). The rate of CO_2 evolution increased logarithmically with moisture. Below about 4.5% moisture, the respiratory rate no longer declined as a logarithmic function. In this moisture range, which coincides with recommended storage moisture content for pecans, respiration was very low, typically 0.5 mg CO_2 $kg^{-1} hr^{-1}$ or less (Table 1). Distinct differences were found in the respiratory rates of pecan genotypes (Table 1).

Whereas large differences were found between cultivars at harvest, these were, to a large extent, due to differences in kernel moisture levels. When the kernels were dried to 3% moisture, the range between the highest and the lowest declined markedly. Prior to drying, the respiratory rate of shelled kernels ranged from 26.9 to 0.26 mg CO_2 kg^{-1} hr^{-1}. After drying, this range declined to between 0.21 and 0.06 mg CO_2 $kg^{-1} hr^{-1}$.

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Table 1. Respiratory rates of pecan genotypes at field harvest kernel moisture level and at 3% kernel moisture level, with and without shells.

Unshelled		Shelled		
Genotype	Respiratory rate (mg CO_2 $kg^{-1}hr^{-1}$)	Genotype	Respiratory rate (mg CO_2 $kg^{-1}hr^{-1}$)	Kernel moisture (%)
		At harvest		
Delmas	18.08 a	Delmas	26.88 a	12.51
Shoshoni	16.91 a	Shoshoni	20.56 b	12.53
Desirable	13.87 a	Shawnee	16.17 bc	13.46
Stuart	8.22 b	Desirable	15.58 bcd	11.75
Moneymaker	7.64 bc	Moneymaker	11.22 cde	13.23
Shawnee	6.68 bcd	Stuart	10.69 de	9.12
Mohawk	5.24 bcd	Mohawk	8.56 ef	9.95
Cheyenne	5.23 bcd	Cheyenne	7.12 efg	7.00
Chickasaw	3.83 bcd	Chickasaw	4.92 fgh	9.91
Elliott	2.57 bcd	Elliott	3.13 gh	6.93
61-6-67	2.24 bcd	61-6-67	1.66 h	5.60
Cherokee	1.39 cd	Cherokee	1.35 h	7.45
Success	0.97 d	Schley	0.71 h	5.41
Wichita	0.70 d	Success	0.38 h	4.27
Pabst	0.70 d	Moore	0.35 h	3.63
Schley	0.67 d	Pabst	0.32 h	3.25
Alley	0.58 d	Wichita	0.31 h	4.24
63-16-125	0.57 d	63-16-125	0.28 h	4.46
Moore	0.53 d	Alley	0.26 h	3.34
		After drying to 3% moisture		
Delmas	3.01 a	Shawnee	0.212 a	
Stuart	1.18 b	Moore	0.119 b	
Desirable	0.64 b	Chickasaw	0.113 bc	
Shawnee	0.52 b	Shoshoni	0.097 bcd	
Cheyenne	0.52 b	Delmas	0.095 bcde	
Moneymaker	0.50 b	Elliott	0.095 bcde	
Mohawk	0.49 b	Stuart	0.092 cde	
Success	0.42 b	Moneymaker	0.090 cde	
Shoshoni	0.42 b	Cheyenne	0.088 def	
Cherokee	0.41 b	Desirable	0.084 defg	
Pabst	0.36 b	61-6-67	0.081 defgh	
61-6-67	0.32 b	Schley	0.080 defgh	
63-16-125	0.31 b	Mohawk	0.073 defgh	
Chickasaw	0.31 b	Cherokee	0.073 defgh	
Wichita	0.30 b	Success	0.072 defgh	
Alley	0.29 b	Alley	0.069 efgh	
Elliott	0.26 b	Pabst	0.063 fgh	
Moore	0.23 b	Wichita	0.058 gh	
Schley	0.22 b	63-16-125	0.057 h	

Mean separation by Duncan's multiple range test, 5% level.

Genotypes which were ranked high in respiratory rate at harvest also tended to rank high when dried suggesting a distinct genotype effect.

Shell presence significantly depressed the respiratory rate of intact nuts. Pooled data for both 3% and field moisture gave mean respiratory rates of 2.87 and 3.48 mg CO_2 $kg^{-1}hr^{-1}$ for intact and shelled nuts, respectively. However, data indicated a significant interaction between presence of the shell and kernel moisture level with regard to the respiratory rates of the kernels. At high kernel moisture levels (i.e., above ~6%), the presence of the shell decreased the respiratory rate of the nuts (Table 1). Below about 6% kernel moisture, the presence of the shell increased the rate of respiration of the kernels. Differences in regression slopes may, in part, reflect changes in the diffusion rate of gases through the shell with hydration and also the effect of damage sustained by the embryo when shelled and separated into single halves. The depression of the relatively rapid respiratory rate of those pecans over 6% field moisture was not correlated with shell mass (Table 2). Shell mass varied independently from the ratio of intact to shelled respiratory rates (r = 0.292; probability of a greater r value = 0.24). Thus, both thick and thin shells seem to have a similar effect on nut respiration. After drying to 3% kernel moisture, the range in respiratory rate between unshelled genotypes decreased substantially; however, the respiratory rate of the intact nuts remained higher than that of their shelled counterpart.

The shell at harvest contributes to the overall respiration of the nut. Pecan shells respired at rates that varied from 0.11 to 2.88 mg CO_2 $kg^{-1}hr^{-1}$. Shell respiration rate was positively correlated with the moisture level of the removed kernel according to the relation Ln mg CO_2 $kg^{-1}hr^{-1}$ = −1.45 + 0.157 (% kernel moisture) (Fig. 1). Although shell moisture was not determined directly, it was assumed that a relative equilibrium existed between the moisture level in the kernel and the surrounding shell. The rate of increase (slope) of the log of shell respiration with moisture was about one-half that of intact nut respiration, indicating that, as moisture increases, the contribution of respiratory CO_2 from the shell makes up a decreasing portion of the total nut respiration. Although highly lignified, the shell appears to contain a significant number of cells with viable protoplasm. Shell respiration was not significantly correlated with shell mass (Table 2).

The results indicate that the respiratory rate of pecans is highly modulated by the degree of hydration of the kernels. In addition, there is a significant effect of genotype on respiration. Both product moisture, and genotype should be considered when selecting the appropriate packaging material for retail storage at ambient temperature.

Literature Cited

1. Kays, S.J. 1982. Storage of pecan kernels under wholesale and retail conditions, p. 367–382. In: D.G. Richardson and M. Meheriuk (eds.). Controlled atmospheres for storage and transport of perishable agricultural commodities; Timber Press, Beaverton, Ore.
2. Kays, S.J. and D.M. Wilson. 1978. Genotype variation in pecan kernel color and color stability during storage. J. Amer. Soc. Hort.

Table 2. Respiratory rate depression by shell presence in pecans at greater than 6% field moisture.

Genotype	Shell wt. (kg) 30 nuts	Intact respiration rate/shelled respiration rate
Delmas	0.250	0.67
Stuart	0.236	0.76
Desirable	0.127	0.89
Mohawk	0.122	0.61
Moneymaker	0.113	0.68
Elliott	0.088	0.81
Chickasaw	0.087	0.78
Cheyenne	0.081	0.73
Shawnee	0.067	0.41

Sci. 103(1): 137–141.

3. Madden, G. 1979. Pecans, p. 13–34. In: R.A. Jaynes (ed.). Nut tree culture in North America. Northern Nut Growers Assoc., Hamden, Conn.
4. Miyazaki, T. 1983. Effects of seal-packaging and ethylene removal from sealed bags on the shelf life of mature-green Japanese apricot (*Prunus mume* Sieb. & Zucc.) fruits. J. Jap. Soc. Hort. Sci. 52:85–92.
5. Odell, G.V., H.A. Hinricks, P.S. Wang, C.J. Rudolph, P. Koehler, P.S. Jurreja, D. Hopfer, and L. Chu. 1971. Chemical and biochemical study of factors responsible for rancidity and off-flavor in pecans. Rpt. to USDA Crops Res. Div., Project 553185.
6. Rudolph, C.J., Jr. 1971. Factors responsible for flavor and off-flavor development in pecans. PhD Thesis, Dept. of Biochem., Okla. State Univ.
7. Senter, S.D. and R.J. Horvat. 1976. Lipids of pecan nutmeats. J. Food Sci. 41:1202–1203.
8. Senter, S.D. and R.J. Horvat. 1978. Minor fatty acids from pecan kernel lipids. J. Food Sci. 43:1614–1615.

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Influence of Mycorrhizae and Drought Stress on Growth of *Poncirus* x *Citrus* Seedlings

C.R. Johnson and R.L. Hummel

Department of Ornamental Horticulture, University of Florida, Gainesville, FL 32611

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Abstract. **Roots of Carrizo citrange seedlings were inoculated with the vesicular-arbuscular mycorrhizal (VAM) fungus *Glomus intraradices* or provided an inoculum filtrate (non-VAM plants). Plants were exposed to drought stress after transplanting into large containers filled with a phosphorus amended medium (30 mg g^{-1}). Drought stress caused reduction of phosphorus in leaf tissues and dry matter accumulation in VAM plants. However, phosphorus levels, dry weights, and transpiration of VAM seedlings were greater than non-VAM plants. Mychorrhizal infection appears to improve establishment of citrus into transplant situations by improving phosphorus uptake and reducing plant stress.**

Establishment of nursery grown plants into landscape soils is often poor because of drought and nutrient stress. Nurserymen commonly apply luxuriant levels of water and nutrients to container plants to achieve rapid growth, but the root systems of such plants often are underdeveloped resulting in poor establishment in landscape sites (7).

Vesicular-arbuscular mycorrhizal (VAM) fungi enhance growth and development of many plant species (5, 11), and their role in plant nutrition (11, 16) and water relations (8, 12, 13, 15) has been well documented. Researchers have demonstrated improved adaptation of VAM colonized plants in field soils and attributed this response to reduced water stress (8, 10). Mycorrhizae may improve water uptake by increasing exploration of soil volume (15), improving plant nutrition (12, 6), and/or regulating stomates through hormone synthesis (1, 2, 9).

Objectives were to determine the role of VAM on growth, phosphorus nutrition and water relations of citrus seedlings after transplanting into a water stressed medium.

Carrizo citrange [*Poncirus trifoliata* (L.) Raf. x C. *sinensis* (L.) Osbeck] were transplanted at the 3 leaf stage into 100 ml containers filled with a 1 Canadian peat:1 fired montmorillonite clay (v/v) medium having 7 mg kg^{-1} available phosphorus (bicarbonate solution analysis). The medium was amended with superphosphate (8.7% phosphorus) and STEM (Soluble Trace Element Mix manufactured by W.R. Grace and Co., Cambridge, Mass., USA) at 0.50 and 0.25 kgM^{-3}, respectively. Half the plants were inoculated with the mycorrhizal fungus, *Glomus intraradices* Schenck and Smith, using a mixture of chlamydospores (100 spores g^{-1} soil), hyphae, and colonized roots. An inoculum filtrate was applied to the roots of non-VAM plants. VAM plants were fertilized weekly with 40 mg N per ml container from 25-0-25 (17.8% NH_4^+, 7.2% NO_3^-; 21.0% potassium) and non-VAM plants at the same rate of nitrogen from 20-20-20 (14.7% NH_4^+, 5.3%NO_3^-; 8.8% phosophorus; 16.6% potassium) solution. Plants were grown in a glasshouse with maximum daylight irradiance of 970 μmol $s^{-1}m^{-2}$ at 400-700 nm, and temperature was maintained at 30°C day and 21° night. These seedlings were transplanted after 6 weeks into 2.7 liter containers filled with amended medium described previously. Root colonization by *G. intraradices* was determined at transplanting using clearing and staining procedures described by Phillips and Hayman (14).

Plants were subjected to 2 irrigation regimes during the remainder of the experiment. Irrigation regimes were designated as nonstressed (10% weight loss of container capacity) and stressed (20% weight loss of container capacity). Container weights were established after 16 hr of drainage following each irrigation and weighed daily until 10% or 20% weight loss before reirrigation. Plants were fertilized with surface applied Osmocote (18.0% N–6.2% P–15.6%K) at a rate of 10 g per 2.7 l container every 3 months after transplanting. A randomized block design was used with 10 replicates and 1 plant per experimental unit.

Transpiration was determined after 6

Table 1. Influence of vesicular-arbuscular mycorrhizae (VAM) and soil moisture stress on percentage root colonization and P levels in leaves of Carrizo citrange seedlings.

Treatment		P (% dry wt)		Root colonization (%)	
VAM	Soil moisture[z]	At transplant	At termination	At transplant	At termination
−		0.096 a[y]		0	
+		0.105 a		36	
−	Stress		0.108 a		0
−	Nonstress		0.128 b		0
+	Stress		0.157 c		65
+	Nonstress		0.178 d		72

[z]Nonstress (10% weight loss of container capacity) and stressed (20% weight loss of container capacity).
[y]Mean separation within columns by Duncan's multiple range test, 1% level.

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