J. AMER. SOC. HORT. SCI. 116(2):261-264. 1991.

Quality and Storage of ‘Granny Smith’ and ‘Greenspur’ Apples on Seedling, M.26, and MM.111 Rootstock

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Additional index words. Malus domestica, postharvest

Abstract. **Influences of rootstock on the quality of ‘Granny Smith’ and ‘Greenspur’ apples *(Malus domestica* Borkh.) were evaluated over an extended harvest period and after cold storage. Apples from trees on M.26 rootstock had the higher firmness, soluble solids concentration (SSC), and Ca content, but poorer external color (red blush) and a higher percentage of solar injury than fruit from trees on seedling or MM.111 rootstock. External greenness was best on apples from MM.111 rootstock. ‘Granny Smith’ apples had higher firmness, soluble solids, acids, and carbohydrate contents, and less scald but poorer external greenness than ‘Green spur’ apples. ‘Granny Smith’ or ‘Greenspur’ apples from M.26 rootstock appeared to mature earlier than those on MM.111.**

Information on the influence of rootstock on the precocity, growth habit, size, and performance of apple trees is widely available (Abdalla et al., 1982; Brown et al., 1985; Denby, 1982; Larsen and Fritts, 1982). The influence of rootstock on fruit quality and storage, particularly for ‘Delicious’ and ‘Golden Delicious’, has been reported (Autio, 1987; Drake et al., 1988; Fallahi et al., 1985a, 1985b; Larsen et al., 1982). These studies on fruit quality have indicated that rootstock can influence size, firmness, color, soluble solids content (SSC), carbohydrate concentration, ripening and maturity, storage quality, and respiration rate of the scion. fruit before and during storage. Nothing has been reported on the influence of rootstock on fruit quality of ‘Granny Smith’ and ‘Greenspur’ apples. ‘Greenspur’ is a spur type ‘Granny Smith’ with a reported superior skin greenness (Ballard, 1981).

Although ‘Granny Smith’ apples are widely grown (3300 ha, Wash. State Dept. Agr., 1986) in Washington State, the length of the growing season is only marginal and development of proper greenness for good marketing can be a problem. If, as reported, rootstock can influence fruit maturity and quality characteristics, such as color, proper scion/rootstock selection can be used to advance maturity and aid in proper color development. This study was initiated to determine the influence of rootstock on the maturity and fruit quality of ‘Granny Smith’ and ‘Greenspur’ apples.

Materials and Methods

Trees of ‘Granny Smith’ and ‘Greenspur’ on seedling, M.26, or MM.111 rootstock were planted at the Washington State Univ. Royal Slope Research unit, Othello, Wash., in 1982. The design was a randomized complete block with three replications of 10 trees per block for each scion/rootstock combination. Trees were planted in Adkins fine loamy sand in rows spaced 4.9 m apart, and trees were trained to a central leader. Within-row tree spacing varied according to the anticipated final tree size (’Granny Smith’ on seedling at 4.3 m, M.26 at 2.4 m, and MM.111 at 3.0 m; ‘Greenspur’ on seedling at 2.7 m, M.26 at 1.2 m, and MM.111 at 1.8 m). Alfalfa and volunteer grass sods grew between the rows. In 1983 and 1984, each tree was fertilized with 100 g ammonium nitrate. Beginning in May and June 1985, trees were fertilized with foliar applications (13.0 $kg \cdot ha^{-1}$) of 20N-20P-20K containing B (0.02%) and Zn (0.15%).

Three trees per block (nine trees total per cultivar per rootstock combination) were selected for sampling. During 1986, 20 uniform fruit were chosen randomly from each treatment, 10 days before estimated commercial harvest on 27 Sept. (using historical data) and at commercial harvest, 6 Oct. The same procedure was used in 1987 and 1988 except 70 uniformly sized fruit per treatment were harvested at both picking dates (±2 days) each season. Twenty fruit (cultivar per rootstock per harvest per rep) were used for each evaluation, at harvest (0 days), and after 60 and 120 days in storage (1C). At harvest, fruit quality was determined immediately on 10 fruits and 10 fruits were evaluated after 8 days at 20C for shelf life quality. At each harvest, the postharvest ripening rate of 10 additional fruit from each cultivar, rootstock, harvest, and replication were evaluated for evolved ethylene in a flow-through system. Apples from each harvest were monitored daily for 15 days or until detection of ethylene evolution, whichever came first.

Elemental analyses of fruit flesh, firmness, and titratable acidity were measured as described by Drake et al. (1988). External fruit color was determined with The Color Machine (Pacific Scientific, Silver Spring, Md.) using the Hunter L, a, b, YID system (Hunter and Harold, 1987). Carbohydrates were determined by the high performance liquid chromatography method described by Bio-Rad (Bio-Rad, Richmond, Calif.). Scald was determined by visual assessment after 120 days of storage. Analysis of variance (ANOVA) was determined by MSTAT (1988) as a factorial with cultivars (two levels), rootstock (three levels), harvest (two levels), storage (three levels, depending on the year), and replication (three levels). Based on significant F tests, means were separated by Duncan’s multiple range test. Data from 1987 and 1988 were combined for ANOVA.

Results

Ethylene. There were no differences for postharvest ripening rate between cultivars or rootstock, at either harvest date. Neither ‘Granny Smith’ nor ‘Greenspur’ on any rootstock initiated detectable ethylene production during the 15 days immediately

Received for publication 16 Oct. 1989. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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after either harvest. This lack of the ethylene climacteric agrees with the finding of other research (M. E. Patterson, 1990, personal communication).

Fruit quality. 'Granny Smith' were firmer than 'Greenspur' (Table 1). This cultivar difference was present regardless of rootstock, harvest, or storage differences. Apples from trees on M.26 rootstock were firmer than apples from seedling or MM.111 rootstock. Firmness of apples decreased by >5 N between the first and second harvest. As time in cold storage increased from 0 to 60 days a significant drop in firmness (≈10 N) was observed. Between 60 and 120 days of storage there was no further significant change in firmness.

Throughout the harvest and storage period, SSC and titratable acidity were slightly but consistently higher in 'Granny Smith' than 'Greenspur' apples. Apples from trees on M.26 rootstock had ≈0.5% higher SSC than apples from trees on the other two rootstock. Fruit from seedling and M.26 rootstock had similar and significantly higher titratable acidity than fruit from trees on MM.111 rootstock. Neither SSC nor titratable acidity was influenced by harvest date. This lack of difference for SSC and acids could be due to lack of substantial differences in maturity at harvest. However, as storage time advanced, SSC increased and titratable acidity decreased. There were no consistent (present both years) interactions among cultivar, harvest, and storage for firmness, SSC, or titratable acidity.

After 120 days of storage, 'Greenspur' apples displayed significantly more scald development than 'Granny Smith'. Both cultivars showed unacceptable levels of scald without scald control measures. Apples from trees on M.26 rootstock showed less scald than fruit on. seedling rootstock. Scald on apples from trees on MM.111 was intermediate between M.26 and seedling. Apples harvested at commercial harvest (Harvest II) developed more scald than those from the earlier harvest.

There was no difference in solar injury (SI) between 'Granny Smith' and 'Greenspur', but apples from trees grown on M.26 rootstock had about twice the percentage of SI than apples from seeding or MM.111 rootstock, apparently due to the open growth pattern of trees on M.26. More SI was present at Harvest I than II, likely because the more exposed fruit was harvested earlier.

Color. 'Granny Smith' apples were lighter in color than 'Greenspur' apples (Table 2). Regardless of rootstock, this difference in Hunter L values for 'Granny Smith' apples was consistent over both harvest periods (data not shown). As storage time progressed, Hunter L values increased (fruit became lighter in color). 'Granny Smith' apples remained lighter in color during storage than the 'Greenspur' apples. After 120 days of storage, 'Greenspur' apples had Hunter L values about equal to 'Granny Smith' apples at harvest,

Regardless of rootstock, 'Granny Smith' apples had similar negative Hunter 'a' values. Apples from 'Greenspur' trees grown on MM.111 were darker green than apples from 'Granny Smith' trees regardless of rootstock. The degree of greenness of both cultivars decreased as storage time increased. 'Granny Smith' apples lost greenness more rapidly than 'Greenspur'. However, after 120 days of storage, apples from 'Greenspur' trees were about equal in greenness to apples from 'Granny Smith' trees after 60 days of storage.

Hunter 'b' values (yellow) were higher in apples from 'Granny Smith' trees, particularly when 'Granny Smith' and 'Greenspur' apples from the same rootstock are compared. Apples from 'Greenspur' trees did not yellow at the rate of apples from 'Granny Smith' trees as storage time increased. After 120 days of storage, apples from 'Greenspur' trees had Hunter 'b' values similar to apples from 'Granny Smith' trees at harvest (0 days of storage).

'Greenspur' apples mostly had lower YID values, i.e., had darker external color than 'Granny Smith' (Table 2). Apples on seedling rootstock were darker in YID color than eitherMM.111

Table 1. Quality attributes of 'Granny Smith' and 'Greenspur' apples due to rootstock, harvest, and storage.

Variable	Firmness (N)	Soluble solids (%)	Titratable acidity (% malic)	Scald (%)	Solar injury (%)
Cultivar[z]					
G. Smith	80.5 a	13.5 a	0.70 a	36.4 b	12.3[NS]
G' spur	78.5 b	13.2 b	0.68 b	50.6 a	10.7
Rootstock[y]					
Seedling	79.4 b	13.1 b	0.69 a	52.5 a	9.2 b
MM.111	78.4 b	13.2 b	0.66 b	42.8 ab	8.4 b
M. 26	80.7 a	13.7 a	0.71 a	35.2 b	17.1 a
Harvest[z]					
I	82.2 a	13.4[NS]	0.70[NS]	28.7 b	16.4 a
II	76.8 b	13.3	0.68	58.3 a	6.6 b
Storage days[y]					
0	85.9 a	12.4 c	0.80 a	---	---
60	75.5 b	14.0 a	0.69 b	---	---
120	77.0 b	13.7 b	0.59 c	---	---

[z]Mean separation within cultivars by analysis of variance, $P = 0.05$.
[y]Mean separation within rootstock, harvest, or storage by Duncan's multiple range test, $P = 0.05$.
[NS]Nonsignificant.

Table 2. Color of 'Granny Smith' and 'Greenspur' apples as related to cultivar, rootstock, cultivar by rootstock, and cultivar by storage.

Variable	External Hunter color L	a	b	YID
Cultivar[z]				
G. Smith	63.6 a	−7.1 a	30.1 a	71.3 a
G' spur	58.6 b	−7.9 b	27.9 b	70.4 b
Rootstock[y]				
Seedling	61.6[NS]	−7.4 a	29.2 a	64.8 c
MM.111	60.6	−7.8 b	28.6 b	73.3 b
M.26	61.1	−7.1 a	29.3 a	74.3 a
Cultivar and rootstock[x]				
G. Smith				
Seedling	64.0 a	−7.1 a	30.0 a	71.2 abc
MM.111	63.1 a	−7.2 a	29.9 a	70.0 bc
M.26	63.8 a	−6.9 a	30.7 a	72.6 a
G' spur				
Seedling	59.3 b	−7.8 ab	28.5 b	71.6 ab
MM.111	58.2 b	−8.4 b	27.4 b	68.8 c
M.26	58.5 b	−7.4 ab	27.8 b	70.7 abc
Cultivar and storage[x]				
G. Smith				
0	62.1 b	−8.2 c	28.0 b	65.0 b
60	62.6 b	−7.2 bc	30.7 a	73.5 a
120	66.1 a	−5.7 a	31.8 a	75.2 a
G' spur				
0	57.2 d	−9.4 d	25.6 c	64.6 b
60	58.6 cd	−7.3 bc	28.9 b	73.1 a
120	60.2 bc	−6.8 b	29.3 b	73.3 a
	HSD = 2.7	HSD = 1.1	HSD = 1.3	HSD = 2.5

[z]Mean separation within cultivars by analysis of variance, $P = 0.05$.
[y]Mean separation within rootstocks by Duncan's multiple range test, $P = 0.05$.
[x]Mean separation within cultivars by rootstock, or cultivar by storage, using Tukey's HSD.
[NS]Nonsignificant.

or M.26. Apples from 'Greenspur' trees on MM.111 were significantly less yellow (lower YID) than apples from 'Granny Smith' trees on M.26 rootstock. There was no difference in YID color between cultivars when storage was considered.

Carbohydrates. Apples from 'Granny Smith' trees contained significantly more sucrose than apples from 'Greenspur' trees (Table 3). There was no difference between the two cultivars in fructose, glucose, or sorbitol contents. Apples from MM.111 and M.26 rootstock contained more sucrose than apples from seedling rootstock. Apples from M.26 rootstock contained more sorbitol than apples from the other rootstock. There was no difference among rootstock for fructose or glucose content. Differences in carbohydrates., among cultivars and rootstock agreed with SSC; 'Granny Smith' apples were higher in SSC than 'Greenspur' apples (Table 1), and apples from M.26 rootstock had a higher SSC than those from the other rootstock.

Minerals. Fruit, flesh Ca concentration of 'Granny Smith' apples was higher than of 'Greenspur' (Table 4). Potassium and phosphorus were slightly lower and B was much lower in 'Granny Smith' apples than in 'Greenspur'. There was no significant difference in Mg or N content between the two cultivars. 'Granny Smith' apples had a much lower N : Ca ratio because of a higher Ca level in the 'Granny Smith' apples.

There was no difference between fruit from the different rootstock for Ca, K, P, or N. Apples from trees on M.26 rootstock had a high Mg and a low B content. Apples from trees on seedling rootstock had an intermediate magnesium content with a high B content. The N : Ca ratio was lowest for apples from M.26 rootstock, but not significantly lower than for apples from trees on MM.111. The ratio for the latter was similar to that for apples on seedling rootstock, which had the highest N : Ca ratio.

Table 3. Fruit carbohydrate content of 'Granny Smith' and 'Greenspur' as influenced by cultivar and rootstock.

	Carbohydrates (g/100 ml)			
	Sucrose	Fructose	Glucose	Sorbitol
Cultivar[z]				
G. Smith	3.93 a	6.24[NS]	2.62[NS]	0.86[NS]
G' spur	3.82 b	6.20	2.60	0.83
Rootstock[y]				
Seedling	3.64 b	6.14[NS]	2.57[NS]	0.76 b
MM.111	3.99 a	6.20	2.66	0.84 b
M.26	3.90 a	6.43	2.61	0.92 a

[z]Mean separation within cultivars by analysis of variance, $P = 0.05$.
[y]Mean separation within rootstocks by Duncan's multiple range test, $P = 0.05$.
[NS]Nonsignificant.

Discussion

Neither 'Granny Smith' nor ' Greenspur' apples, regardless of harvest date or rootstock, produced detectable ethylene in the 15 days following harvest. There is no single apple maturity indicator, but the onset of detectable ethylene production can be used in other cultivars, along with an increase in SSC and a decrease in firmness and acids (Washington Apple Maturity Handbook, 1986). The two cultivars we used, with little differences in average firmness (only 2.0 N) and very little difference in SSC, confirmed that both can be harvested at the same time.

Apples from trees on M.26 rootstock were firmer and had higher soluble solids and acid content than other rootstock, which agrees with earlier work (Drake et al., 1988). In this earlier work, we determined that fruit from trees on M.26 rootstock were actually more mature than apples from trees on seedling or MM. 111 rootstock, which agrees with previous work by Fallahi et al. (1985c, 1985d). Differences in soluble carbohydrates were evident between cultivars. These carbohydrate differences plus higher acid content of 'Granny' Smith' apples or apples from trees on M.26 would produce a more desirable tasting product.

Increased Ca and a low N : Ca ratio have been shown to increase the firmness of apples and reduce physiological and storage problems (Fallahi et al., 1988; Raese et al., 1989; Raese and Staiff, 1990). Firmness retention seen in 'Granny Smith' apples might have been due to the relatively high Ca content and low N : Ca ratio found for this apple. However, apples from M.26 rootstock were firmer than apples from the other rootstock, but there was no significant difference in Ca levels. Differences in Ca and firmness between apples from different rootstock have been reported for other cultivars (Larsen et al,, 1985). There is some work that suggests that low B content is associated with increased fruit firmness (Bramlage and Thompson, 1963), which could explain the firmer fruit produced on M.26 rootstock.

High N levels enhance greenness of apples (Meheriuk, 1989; Williams and Billingsley, 1974). Even though no differences were found in the N levels between apples from 'Granny Smith' and 'Greenspur' trees nor among apples from the different rootstock, there were significant differences in greenness between 'Granny Smith' and 'Greenspur' apples. 'Greenspur' apples were much greener than 'Granny Smith'. Apples from trees on MM.111 rootstock were less yellow than apples from M.26 or seedling rootstock. The lighter color plus its tendency to sunburn might be due to the more open growth habit of the trees on M.26 rootstock. Since a green surface is preferred for 'Granny Smith'

Table 4. Concentration of selected minerals of apple flesh as influenced by cultivar and rootstock.

Variable	Ca (ppm)	Mg (ppm)	K (%)	P (%)	B (ppm)	N (%)	N : Ca (ratio)
Cultivar[z]							
G. Smith	194 a	231[NS]	0.60 b	0.060 b	16.7 b	0.25[NS]	13.5 a
G' spur	157 b	229	0.67 a	0.065 a	20.1 a	0.26	15.6 b
Rootstock[y]							
Seedling	178[NS]	230 b	0.67[NS]	0.059[NS]	22.6 a	0.27[NS]	16.5 a
MM.111	165	220 b	0.61	0.059	18.6 b	0.27	15.2 ab
M.26	183	239 a	0.63	0.063	14.0 c	0.27	12.1 b

[z]Mean separation with cultivars by analysis of variance, $P = 0.05$.
[y]Mean separation within rootstocks by Duncan's multiple range test, $P = 0.05$.
[NS]Nonsignificant.

type apples, 'Greenspur' apples would best meet the color grade requirements of Washington State. Apples from 'Granny Smith' trees would have better color grade if grown on seedling or MM.111 rootstock than if grown on M.26. Fruit from either cultivar would have trouble meeting color grade if grown on M.26 rootstock under the conditions of this experiment.

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