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Dietary Fiber Composition of 'Starkspur Supreme Delicious' Apple Fruit as Influenced by Rootstock and Growing Region

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Abstract

Fruit from nine year old 'Starkspur Supreme Delicious' apples grown on seven different rootstocks: B.9, M.26 EMLA, M.7 EMLA, CG.10, P.1, MAC.39, and seedling were analyzed to study the effects of rootstock on dietary fiber composition of fruit. Effects of growing region on fiber composition were studied using apples from nine-year old 'Starkspur Supreme Delicious' trees on M.26 EMLA grown in uniform trials in Washington, Minnesota, Kansas, Arkansas, Ohio, North Carolina, and Maine. There were significant rootstock effects on both nonstarch polysaccharide (NSP) content and nonstarch cell wall material (NSCWM) of apple. NSCWM content was not affected by growing region. However, there was significant effect of growing region on NSP content of apple. NSP content ranged from 1.48 g/100g flesh in fruit from trees on B.9 to 1.98 g/100 g flesh in fruit from trees on a P.1 rootstock. It ranged from 1.41 g/100 g flesh in apples grown in Minnesota to 1.77 g/100 g flesh in Arkansas apples. There were also significant rootstock and regional effects on relative composition of monosaccharides.

Introduction

Apples are an important source of dietary fiber. Many nutritional charts list the level of dietary fiber present in apple fruit, however they only occasionally mention the name of the cultivar analyzed. Information on rootstock and growing region are usually never mentioned. However, rootstock and growing region have been known to affect various nutritional and quality aspects of apple fruit. Barden and Marini (1) studied the effect of rootstock on the maturity and quality of apples. They analyzed fruit grown on M.27 EMLA, M.7 EMLA, MAC.24, M.9 EMLA. and OAR 1 rootstocks and reported a significant effect of rootstock on starch content and soluble solid concentration. Effect of stem-piece and rootstock combinations on quality of 'Empire' apples have also been reported (6). Plant growth, yield and fruit quality have been found to be directly influenced by factors related to environmental conditions (2). However, no extensive data regarding the effects of rootstock and growing region on fiber content and composition of apple are available in the literature.

The objective of this research was to study how fiber content and composition of apple fruit were affected by rootstock and growing region.

Materials and Methods

The NC-140 Rootstock Trial (planted 1984) provided the fruit used in this work.

Rootstock Study: Nine year old 'Starkspur Supreme Delicious' apples grown on seven different rootstocks: M.26 EMLA, M.7 EMLA, CG.10, P.1, B.9, MAC.39, and seedling were collected from the rootstock trial at Fletcher, North Carolina.

Growing region study: Apples from nine-year-old 'Starkspur Supreme Delicious' trees on M.26 EMLA rootstocks

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grown in Maine, Kansas, Ohio, Minnesota, Washington, Arkansas, and North Carolina were used in this work.

Experimental Design: The experimental designs for all studies were randomized complete block designs. Statistical analyses were done using SAS Anova procedures (SAS Institute, Cary, NC).

Firmness and Soluble Solids Measurements: Ten apples from each treatment constituted a sample. Firmness of each apple was measured using an Effegi penetrometer with a 11 mm tip. Apples were peeled and tested on two opposing sides and the values were then averaged. Percent soluble solids were determined by placing juice squeezed directly from the apple onto a refractometer.

Analytical Procedures: A detailed explanation of methods and calculations can be found in (5). Nonstarch cell wall materials (NSCWM) were extracted from apple pulp with ethanol according to Southgate's method (11). The dried residue resulting from the procedure constituted the cell wall material (CWM) of apple flesh. The starch portion in CWM was removed with the enzyme amyloglucosidase. The resulting dried residue represented nonstarch cell wall material (NSCWM) of apple pulp and contained nonstarch polysaccharides (NSP), lignins, some proteins, and minerals. NSCWM was then put through a hot water treatment to yield soluble and insoluble NSCWM fractions.

Neutral sugars in the total, insoluble, and soluble NSCWM fractions were converted to alditol acetates and measured according to the method of Blakeney (4).

Samples were analyzed by gas chromatography on a Varian 2800 GC equipped with FID using a SP™2330 glass capillary column (length—30 m and I.D.—0.75 mm). Injector, column and detector temperatures were 220°C, 215°C, and 225°C, respectively. Duplicate injections of 0.5 ul each were made.

Uronic acids were determined using the methods of McFeeters and Lovdal (9) with a correction factor as proposed by Scott (10).

Results

There were significant differences in the fiber content of fruit grown on different rootstocks (Tables 1 and 2). Fruit from trees grown on P.1 rootstock had the highest NSCWM (2.41 g/100 g flesh) content whereas those from trees on M.7 EMLA and M.26 EMLA had the lowest (2.01 g/100g flesh). NSCWM fraction includes proteins and minerals in addition to dietary fiber and is considered an overestimation of dietary fiber content. On the other hand, NSP fraction does not include lignin and hence can be considered a conservative estimate of dietary fiber. NSP content ranged from 1.48 g/100 g flesh in fruit from trees on B.9 to 1.98 g/100 g flesh in fruit from trees on P.1. Relative amount of soluble and in-

Table 1. Influence of rootstock on NSCWM, total, insoluble and soluble NSP content of 'Starkspur Supreme Delicious' apples.

Rootstock	NSCWM	Total NSP	Fiber fraction: Insoluble NSP	Fiber fraction: Soluble NSP
	(g/100 g flesh)	(g/100 g flesh)	(g/100 g NSP)	
Seedling	2.12 cd[z]	1.70 bc	79.2 abc	20.8 abc
M.7 EMLA	2.01 d	1.54 cde	79.2 abc	20.8 abc
M.26 EMLA	2.01 d	1.50 de	81.3 ab	18.7 bc
P.1	2.41 a	1.98 a	76.1 bc	23.9 ab
MAC.39	2.33 ab	1.79 b	74.8 c	25.2 a
CG.10	2.29 abc	1.68 bcd	83.6 a	16.4 c
B.9	2.04 cd	1.48 e	79.5 abc	20.5 abc

[z]Mean separation within columns by LSD, 5% level.

Table 2. Influence of rootstock on monosacchride composition of total NSP in 'Starkspur Supreme Delicious' apples.

Rootstock	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g total NSP)							
Seedling	1.53 a[z]	0.47 a	10.69 bc	5.78 abc	2.14 c	4.59 ab	37.28 ab	37.52 ab
M.7 EMLA	1.51 a	0.35 bc	12.12 ab	6.00 ab	2.50 a	4.71 ab	35.56 b	37.42 ab
M.26 EMLA	1.49 a	0.51 a	12.44 ab	6.05 ab	2.46 ab	4.23 b	36.44 b	36.37 ab
P.1	1.38 a	0.32 c	10.91 abc	5.96 ab	2.53 a	4.65 ab	36.76 ab	37.50 ab
MAC.39	1.52 a	0.40 b	10.30 c	5.09 c	2.32 abc	4.17 b	37.14 ab	39.07 a
CG.10	1.51 a	0.40 b	12.67 a	6.41 a	2.16 bc	4.88 a	39.99 a	31.99 c
B.9	1.55 a	0.50 a	12.05 abc	5.67 bc	1.72 d	4.40 ab	38.75 ab	35.36 b

[z]Mean separation within columns by LSD, 5% level.

soluble fiber content also differed significantly among rootstocks (Table 3). Fruit on MAC.39 rootstock had the highest soluble fiber content (25.2%) and those on CG.10 had the lowest (16.4%).

Sugar composition: There were significant differences in the relative amount of monosaccharide residues in apple fiber depending on the rootstock (Table 4). Rhamnose was the only monosaccharide residue found in a statistically similar amount in apples from trees on different rootstocks. On dry weight basis (8 per 100 g NSP), fucose ranged from 0.32% in fruit from trees on P.1 to 0.51% in fruit from trees on M.26 EMLA; arabinose ranged from 10.30% in fruit on MAC.39 to 12.67% in fruit on CG.10. Fruit on CG.10 had the highest xylose content (6.41%) and those on MAC.39 had the lowest (5.09%) xylose content. Mannose content was the highest in fruit on P.1 (2.53%) and the lowest in fruit on B.9 (1.72%). Galactose ranged from 4.17% of monosaccharide residues in fruit on MAC.39 to 4.88% of monosaccharide residues in fruit on CG.10; glucose ranged from 35.56% in fruit on M.7 EMLA to 39.99% in fruit on CG.10 apples. Uronic acid ranged from 31.99% in fruit on CG.10 to 39.07% in fruit on MAC.39. Rootstock differences were more pronounced in soluble fractions. While rhamnose content of total NSP was not affected by rootstock difference, there were significant differences in rhamnose content of soluble and insoluble fiber fractions from different rootstocks (Tables 5 and 6). There was almost a three fold difference in the xylose content of soluble fiber among rootstocks and 2-fold overall difference in glucose content. Rootstock difference in galactose content was also more pronounced in soluble fiber than in insoluble fiber.

Table 3. Influence of rootstock on monosacchride composition of insoluble NSP in 'Starkspur Supreme Delicious' apples.

Rootstock	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g insoluble NSP)							
Seedling	1.73 ab[z]	0.61 a	11.65 c	6.97 a	2.21 c	4.88 ab	45.46 bc	26.49 a
M.7 EMLA	1.61 bcd	0.44 c	14.10 a	7.36 a	2.89 ab	5.30 a	43.92 c	24.40 bcd
M.26 EMLA	1.62 bcd	0.63 a	14.14 a	7.20 a	2.75 ab	4.55 bc	44.10 c	25.01 ab
P.1	1.53 d	0.42 c	12.38 abc	7.60 a	3.08 a	5.15 ab	46.78 ab	23.07 d
MAC.39	1.85 a	0.54 b	11.92 bc	6.13 b	2.61 b	4.51 bc	47.58 ab	24.86 bc
CG.10	1.56 cd	0.47 c	13.62 ab	7.40 a	2.20 c	4.92 abc	46.74 ab	23.10 d
B.9	1.66 bc	0.63 a	13.18 abc	6.92 ab	1.76 d	4.28 c	48.16 a	23.41 cd

[z]Mean separation within columns by LSD, 5% level.

Table 4. Influence of rootstock on monosacchride composition of soluble NSP in 'Starkspur Supreme Delicious' apples.

Rootstock	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g soluble NSP)							
Seedling	0.89 d[z]	n.d.[y]	7.36 ab	1.60 b	1.88 a	3.59 b	6.37 ab	78.32 d
M.7 EMLA	1.59 a	n.d.	6.65 bc	0.92 de	0.85 d	2.78 c	4.09 d	83.11 b
M.26 EMLA	0.92 d	n.d.	5.04 e	1.04 cd	1.23 bc	2.88 c	3.23 e	85.66 a
P.1	1.32 b	n.d.	6.04 cd	0.74 e	1.12 cd	3.10 c	4.84 c	82.85 b
MAC.39	0.75 e	n.d.	5.52 de	2.04 a	1.48 b	3.12 c	6.06 ab	81.04 c
CG.10	1.61 a	n.d.	7.25 ab	1.15 c	1.82 a	4.29 a	5.73 b	78.08 d
B.9	1.07 c	n.d.	7.40 a	0.91 de	1.13 cd	4.06 a	6.64 a	78.78 d

[z]Mean separation within columns by LSD, 5% level.
[y]Not detectable.

Effect of Growing Region

There were no statistical differences in the NCCWM content of apples grown in different regions (data not shown). However, there were significant differences in NSP content of apples from different regions (Table 5). It ranged from 1.41% in apple grown in Minnesota to 1.77% in apples grown in Arkansas. Relative amount of soluble and insoluble fiber content of apples also showed significant overall regional differences. Soluble fiber content ranged from 16.69% in Ohio apples to 24.14% in Washington apples (Table 8).

Sugar composition: There were significant regional differences in the relative amount of monosaccharide residues in apple fiber. On dry weight basis (per 100 g NSP), rhamnose content ranged from 1.02% in Minnesota apples to 1.49% in North Carolina apples (Table 6); fucose ranged from 0.23% in Maine apples to 0.51% in North Carolina apples. Arabinose content was the lowest (10.83%) in Arkansas apples and the highest (14.35%) in Washington apples; highest level (7.42%) of xylose was found in Kansas apples and the lowest level (4.32%) in Minnesota apples. Mannose content ranged from 4.27% of total NSP in Minnesota apples to 7.42% in Kansas apples. Galactose content ranged from 3.71% of total monosaccharide residues in Washington apple fiber to 5.68% in Minnesota apple fiber; glucose content ranged from 33.67% in Ohio apples to 41.09% in Minnesota apples. Uronic acid content of apples from different growing regions were similar except for Minnesota apples which had a significantly lower level of uronic acid content compared to apples from other locations. There were significant location differences in the monosaccharide content of soluble and insoluble fiber fractions also (Tables 7 and 8). As with rootstocks, differences in the xylose content of soluble fiber were very pronounced. Overall, fiber composition seemed to be more affected by regional differences than by rootstock differences.

Correlation coefficients for correlations between fiber content and monthly precipitation, monthly average minimum and maximum temperature, monthly maximum and minimum

Table 5. Influence of growing region on total, insoluble and soluble NSP content of 'Starkspur Supreme Delicious' apples.

Rootstock	Total NSP	Fiber fraction	
		Insoluble NSP	Soluble NSP
	(g/100 g flesh)	(g/100 g NSP)	
Washington	1.71 ab[z]	75.86 c	24.14 a
Minnesota	1.41 c	76.80 bc	23.20 ab
Kansas	1.54 abc	76.60 bc	23.40 ab
Arkansas	1.77 a	82.06 abc	17.94 abc
Ohio	1.76 ab	83.31 a	16.69 c
Maine	1.63 abc	78.97 abc	21.03 abc
North Carolina	1.50 bc	81.24 ab	18.76 bc

[z]Mean separation within columns by LSD, 5% level.

Table 6. Influence of growing season on monosacchride composition of total NSP in 'Starkspur Supreme Delicious' apples.

Region	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g total NSP)							
Washington	1.13 de[z]	0.48 ab	14.35 a	6.69 ab	2.46 c	3.71 e	34.39 bc	36.79 a
Minnesota	1.02 e	0.38 c	13.72 a	4.27 c	3.00 a	5.68 a	41.09 a	30.83 b
Kansas	1.28 bc	0.39 c	11.17 c	7.42 a	2.77 b	4.60 bc	34.51 bc	37.87 a
Arkansas	1.42 ab	0.33 d	10.83 c	6.36 b	2.47 c	3.89 de	38.93 a	35.76 a
Ohio	1.25 cd	0.46 b	14.10 a	6.55 b	2.63 bc	4.04 de	33.67 c	37.31 a
Maine	0.86 e	0.23 e	13.81 a	6.00 b	3.10 a	4.91 b	35.76 bc	35.33 a
North Carolina	1.49 a	0.51 a	12.44 b	6.05 b	2.45 c	4.23 cd	36.44 b	36.39 a

[z]Mean separation within columns by LSD, 5% level.

temperature, and solar radiation were determined. None of these correlations were significant (data not shown).

Discussion

Both rootstock and regional differences were found to affect fiber content and composition. However, fiber composition was more affected by growing region than by rootstocks. This is not surprising given the fact that regional difference involves many factors such as climate, soil, etc. However, climatic factors such as monthly temperature, precipitation, solar radiation did not have any significant correlation with fiber content and composition. Apparently other unstudied factors such as soil, nutrition, etc. may play significant roles. A more complicated model is needed to explain the regional differences.

Total dietary fiber content of apples used in this study were lower than the values reported by Wills (13). For example, Wills (13) reported dietary fiber content per 100 g edible portion to be 2.3 g whereas fiber content of the apples in the present study ranged from 1.41 g/100 g to 1.98 g/100 g flesh. However, values reported by Wills (13) had been obtained by averaging the values for 'Delicious,' 'Golden Delicious,' 'Granny Smith' and 'Jonathan' apples. Also their results were based on unpeeled apples. Values in the present study however, are similar to or slightly higher than those reported by Marlett (7) for unpeeled 'Red Delicious' apples. Pectic substance content of apples in our study were lower than the values reported by Belo and de Lumen (3). Apples in our study had similar rhamnose, and arabinose content, higher glucose, and xylose content in soluble fraction than reported by Theander and Aman (12). Overall glucose level in insoluble fiber fraction in our study was higher, arabinose level was lower, xylose, rhamnose, and man-

Table 7. Influence of growing region on monosacchride composition of insoluble NSP in 'Starkspur Supreme Delicious' apples.

Region	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g total insoluble NSP)							
Washington	1.24 bc[z]	0.64 a	17.56 a	8.61 a	2.93 b	3.82 d	44.17 bc	21.03 d
Minnesota	1.17 c	0.50 b	16.12 b	5.25 c	3.61 a	6.00 a	52.86 a	14.48 e
Kansas	1.56 a	0.50 b	12.86 d	8.81 a	3.18 ab	4.97 b	43.63 c	24.49 bc
Arkansas	1.57 a	0.41 c	11.68 d	7.38 b	2.71 b	4.04 cd	46.47 b	25.75 abc
Ohio	1.34 b	0.55 b	15.65 b	7.63 b	2.91 b	4.23 cd	39.65 d	28.04 a
Maine	0.86 d	0.28 d	15.93 b	7.21 b	3.56 a	5.16 b	43.91 bc	23.09 c
North Carolina	1.62 a	0.62 a	14.13 c	7.20 b	2.74 b	4.55 bc	44.12 bc	25.01 bc

[z]Mean separation within columns by LSD, 5% level.

Table 8. Influence of growing region on monosacchride composition of soluble NSP in 'Starkspur Supreme Delicious' apples.

Region	Monosacchride							
	Rhamnose	Fucose	Arabinose	Xylose	Mannose	Galactose	Glucose	Uronic acid
	(g/100 g soluble NSP)							
Washington	0.63 d[z]	n.d.[y]	4.97 c	0.66 d	1.08 b	3.36 c	3.69 c	85.62 a
Minnesota	0.56 d	n.d.	6.09 ab	1.20 c	1.29 ab	4.42 a	4.19 bc	82.25 c
Kansas	0.36 e	n.d.	5.80 b	2.12 a	1.42 a	3.40 bc	4.68 ab	82.22 c
Arkansas	0.77 c	n.d.	6.39 a	1.59 b	1.38 ab	3.24 c	4.80 ab	81.83 c
Ohio	0.81 bc	n.d.	6.29 ab	1.20 c	1.25 ab	3.07 c	3.89 bc	83.49 b
Maine	0.83 ab	n.d.	5.80 b	1.54 b	1.50 a	3.97 ab	5.53 a	80.82 d
North Carolina	0.91 a	n.d.	5.09 c	1.04 c	1.23 ab	2.87 c	3.23 c	85.62 a

[z]Mean separation within columns by LSD, 5% level.
[y]Not detectable.

nose levels were similar to values reported by Theander and Aman (12). The difference in results could be partially explained by the fact that they used 'Granny Smith' apples and different analytical technique. Relative proportion of neutral sugars and uronic acid in the present study are similar to values reported by Marlett and Navis (8).

More pronounced difference in xylose, mannose, and galactose content in soluble fiber as opposed to insoluble fiber may indicate a sharp difference in soluble pectin structure. Pectin structure is probably more affected by climatic and rootstock differences than other fiber fractions. This conclusion could not be made with certainty because xylose, mannose, etc may be part of hemicellulose also. In a different study (5) we found cultivar differences, in fiber content and composition to be much more pronounced than the rootstock and regional differences in the present study. In our cultivar study, we found galactose content of apple fiber to show 3-fold difference among cultivars. Also, galactose content was observed to fall almost 3-fold during fruit development. However, galactose was only slightly different depending on rootstock and growing region. Other monosaccharides also differed more among cultivars and during the course of development than among rootstocks and regions. It is possible that fiber composition especially galactose content is affected more by genetic make-up and developmental changes than by factors such as rootstock and growing region. Our study focused on quantitative differences in fiber content and composition. It is possible that rootstock and climatic differences also contribute to fiber composition in ways other than quantitative. For example, rootstock and location difference could affect the structure of polysaccharides and not just relative monosaccharide composition. These possibilities need to be explored in future studies.

Literature Cited

1. Barden, J.A. and M. E. Marini, 1992. Maturity and quality of 'Delicious' apples as influenced by rootstock. J. Amer. Soc. Hort. Sci. 117(4):547-550.
2. Basso, C., F.W.W. Wilms, and H. Stuker. 1990. Soil-plant-fruit nutritional relationship in apple orchards in Southern Brazil. Acta-Hortic. Wageningen: International Society for Horticultural Science. May 1990. (274) pp. 33-42.
3 Belo, P.S. and B.O. de Lumen. 1981. Pectic substance content of detergent-extracted dietary fibers. J. Agric. Food Chem. 29:370-379.
4. Blakeney, R.W., P.J. Harris, R.J. Henry, and B.A. Stone. 1983. A simple and rapid preparation of alditol acetates for monosaccharide analysis. Carbohydrate Res. 113:291.
5. Gheyas, Ferdous. 1994. Dietary Fiber in apple fruit as influenced by cultivar, rootstock, growing region, developmental stage, and storage. PhD. Thesis, North Carolina State University, Raleigh, North Carolina, USA.

6. Lord, W.J., D.W. Greene, R.A. Damon, Jr., and J.H. Baker. 1985. Effects of stempiece and rootstock combinations on growth, leaf mineral concentrations, yield and fruit quality of 'Empire' apple trees. J. Amer. Soc. Hort. Sci. 110. 422-425.
7. Marlett, J.A. 1992. Content and composition of dietary fiber in 117 frequently consumed foods. J. Am. Diet. Assoc. 92:175-186.
8. Marlett, A. and D. Navis. 1988. Comparison of gravimetric and chemical analyses of total dietary fiber in human foods. J. Agric. Food Chem. 36:311-315.
9. McFeeters, R. F. and Lovdal, J. A. 1987. Sugar composition of cucumber cell walls during fruit development. J. Food Sci. 52:996-1001.
10. Scott, R.W. 1979. Colorimetric determination of hexuronic acids in plant materials Anal. Chem. 5(7):936-141.
11. Southgate, D.A.T. 1981. Use of the Southgate Method for unavailable carbohydrates in the measurement of dietary fiber, pp. 1-14. In. W.P.T. James and O. Theander (eds). The Analysis of Dietary Fiber in Food. Marcel Dekker, Inc.
12. Theander, O. and P. Aman. 1979. Studies on dietary fibres. Analysis and chemical characterization of water-soluble and water-insoluble dietary fibres. Swedish J. Agric. Res. 9:97-106.
13. Wills, R.B.H., J.S.K. Lim, and H. Greenfield. 1987 Composition of Australian foods. 40. Temperate fruits. Food Technology in Australia. 39(11):521-530.