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Dietary Fibre Content of Thirteen Apple Cultivars

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Abstract: Fibre composition of the following 13 apple cultivars was studied: 'Cortland', 'Empire', 'Fuji', 'Golden Delicious', 'Gala', 'Granny Smith', 'Jonagold', 'Mutsu', 'McIntosh', 'Delicious', 'Rome', 'Stayman' and 'York'. Fruit samples from each of these cultivars were analysed for non-starch cell wall materials (NSCWM) and non-starch polysaccharides (NSP). NSCWM was further fractionated into soluble and insoluble fibre fractions. Both NSCWM and NSP content were found to be significantly influenced by cultivar. NSCWM content ranged from 19·1 g kg^{-1} apple flesh in 'Fuji' to 36·2 g kg^{-1} in 'York'. Mean($\pm$ SD) NSCWM content of all the cultivars was 23·1 $\pm$ 4·5 g kg^{-1}. NSP content of apple flesh ranged from 13·8 g kg^{-1} in 'McIntosh' to 28·7 g kg^{-1} in 'York' with the overall mean for all cultivars being 17·9 $\pm$ 4·2 g kg^{-1}. Relative amount of monosaccharides found in the hydrolysates of apple fibre also varied among cultivars. The greatest difference was observed in galactose content.

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INTRODUCTION

Dietary fibre is the sum of lignin and polysaccharides not hydrolysed by the endogenous secretions of the human digestive tract (Trowell 1976). Fibre is believed to help in the prevention of certain diseases and health problems such as diabetes (Anderson and Bryant 1986), diverticular diseases (Painter and Burkitt 1971) and obesity (Anderson and Bryant 1986). Increased understanding of the role of dietary fibre in human health and nutrition has prompted nutritionists all over the world to emphasise the importance of dietary fibre in the human diet. However, foods with different fibre composition function differently in the human body. For any dietary recommendation of dietary fibre to be truly effective, it is important not only to know the fibre content but also the fibre composition of food materials and how various factors affect fibre content and composition.

Apples (*Malus domestica*) are an important source of dietary fibre. Detailed fibre composition of apple has been reported (Theander and Aman 1979; Ross *et al* 1985; Marlett 1992). These studies involved only one (Theander and Aman 1979) or two (Ross *et al* 1985; Marlett 1992) apple cultivars. However, Gormley (1981) reported significant differences in dietary fibre content of 'Golden Delicious', 'Red Jonathan' and 'Cox's Orange Pippin' apples. Wiley and Thompson (1960) analysed 'Stayman', 'Golden Delicious', 'York Imperial', 'Rome Beauty', 'Jonathan' and 'North West Greening' apples and reported significant cultivar effects on pectin content. Cellulose content has also been reported to differ significantly among apple cultivars (Kertesz *et al* 1959). An effective database on apple fibre content and

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composition should be based on values from a number of apple cultivars because of genetic differences among cultivars. No such extensive database currently exists. The objective of the current research was to describe the fibre content and composition of 13 apple cultivars.

EXPERIMENTAL

Materials

The following 13 cultivars were sampled: 'Delicious', 'Golden Delicious', 'Rome', 'McIntosh', 'Granny Smith', 'Stayman', 'York', 'Fuji', 'Jonagold', 'Cortland', 'Empire', 'Mutsu' and 'Gala'. Fruit were obtained from commercial orchards in Western North Carolina during summer of 1993. Fruit belonging to the same cultivar came from the same orchard and same year's growth. Also, since all the apples came from the same region, they may be assumed to have been grown under similar climatic and soil conditions. All the fruit were harvested at commercial market maturity. Ten apples, randomly chosen from the harvested fruit, constituted a sample for fibre analysis. Three samples of each cultivar were analysed and each sample constituted a true replicate.

Determination of firmness and soluble solid content of apples

Firmness of apples was measured using an Effegi penetrometer with an 11 mm tip mounted on a drill press. Apples were peeled and tested on two opposing sides and the values were averaged. Soluble solid content was determined by placing juice squeezed directly from the apple onto a refractometer. The firmness and soluble solid values of these apples at sampling are listed in Table 1.

TABLE 1
Firmness and soluble solid content of apples[a]

Cultivar	*Flesh firmness* (*N*)	*Soluble solids* ($g\ kg^{-1}$ *flesh*)
Cortland	54·8 ± 5·5	137 ± 7
Empire	61·5 ± 5·8	155 ± 10
Fuji	71·2 ± 5·2	165 ± 7
Gala	90·9 ± 4·6	117 ± 8
Golden Delicious	55·4 ± 5·1	148 ± 10
Granny Smith	74·6 ± 3·8	126 ± 6
Jonagold	53·8 ± 4·3	127 ± 7
McIntosh	54·6 ± 6·2	117 ± 8
Mutsu	70·3 ± 4·7	120 ± 10
Delicious	76·0 ± 4·8	91 ± 5
Rome	83·9 ± 5·3	121 ± 10
Stayman	73·8 ± 7·0	118 ± 8
York	123·8 ± 6·5	141 ± 10

[a] Values are mean ± SD ($n = 3$).

Extraction of non-starch cell wall materials

Non-starch cell wall materials (NSCWM) were extracted from apple pulp according to Southgate's method (Southgate 1981). The fruit were peeled and cored, and 80 g of flesh was homogenised with 95% ethanol. The amount of ethanol added was adjusted so as to make the extraction at 85% (v/v). The mixture was heated on an electric hot plate, brought to a boil and filtered hot through a Buchner funnel using Whatman 541 filter paper. The residue was resuspended in 85% ethanol followed by heating and filtration as before. This process was repeated once and the tissue was then extracted twice in acetone in a similar way. The extracts were discarded and the residue was dried overnight in a vacuum oven at 35°C. The dried residue constituted the cell wall material (CWM) of apple flesh. The starch portion in CWM was removed through enzymatic hydrolysis. Amyloglucosidase (from *Aspergillus niger*, lyophilised, Boehringer Mannheim) stock solution was prepared by dissolving 100 mg amyloglucosidase (6 U mg^{-1} lyophilisate) in 10 ml citrate solution (pH 4·6). The citrate solution consisted of 44 mg citric acid·H_2O and 85 mg trisodium citrate·$2H_2O$ dissolved in 10 ml distilled water. To perform enzymatic hydrolysis of starch molecules in cell wall materials, approximately 300 mg of the dried CWM sample was put in a centrifuge tube with 4 ml of hot water. The tubes were placed in a boiling water bath for 10 min to gelatinise the starch in the sample. After cooling, 0·2 ml 2 M sodium acetate buffer (pH 5·0) was added to the mixture. Amyloglucosidase stock solution was diluted 1 : 5 (v/v) with water and 1 ml of this diluted solution along with a few drops of toluene was added to each tube. The tubes were then kept overnight in an incubator (37°C). The next morning five volumes of 95% ethanol were added to the mixture and the mixture was centrifuged. The supernatant was extracted and the extraction process was repeated using 80% ethanol. The residue was washed with acetone and dried. The dried residue represented NSCWM of apple pulp and contained non-starch polysaccharides (NSP), lignins, some proteins and minerals.

Fractionation of NSCWM into soluble and insoluble fractions

Approximately 150 mg of the dried NSCWM sample was placed in a centrifuge tube with 10 ml hot water. Tubes were placed in a boiling water bath for 20 min. After cooling, the mixture was centrifuged. The residue was resuspended in hot water and the extraction procedure was repeated. The supernatants were then combined and the residue was washed with acetone followed by oven-drying. This dried residue constituted insoluble NSCWM and contained insoluble NSP, lignin, some proteins and minerals. To precipitate soluble NSCWM, five volumes of 95% ethanol were added to the combined supernatant and the mixture was centrifuged. The supernatant was discarded and the extraction was repeated. The residue was washed with acetone and dried. The dried residue constituted soluble NSCWM.

Determination of neutral sugars and uronic acid in cell wall material fractions

Neutral sugars in the total, insoluble and soluble NSCWM fractions were measured according to the method of Blakeney *et al* (1983). Neutral sugars (rhamnose, fucose, arabinose, xylose, mannose, galactose and glucose) were calculated as anhydro sugars using standard curves of L-rhamnose, D-fucose, D-arabinose, D-xylose, D-mannose, D-galactose and D-glucose. The amount of each of these sugars were initially calculated as g kg^{-1} NSCWM fraction. The amount of uronic acid present in the NSCWM fractions was determined using the method suggested by McFeeters and Lovdal (1987).

Statistical analysis

Statistical analyses were carried out using the GLM procedure of SAS (SAS Institute, Cary, NC, USA). Analyses of variance were performed using cultivar, replication, and experimental error as sources of variation. When the analyses showed overall cultivar difference, individual means were compared using the least significant difference (LSD) values.

RESULTS

Non-starch cell wall materials

NSCWM content ranged from 19·1 g kg^{-1} apple flesh in 'Fuji' to 36·2 g kg^{-1} in 'York' (Table 2). There were significant ($P < 0{\cdot}0001$) differences among the cultivars, especially between 'York' and other cultivars. Mean(±SD) NSCWM content in 13 cultivars was 23·1 ± 4·5 g kg^{-1}. Dietary fibre consists of cellulose, hemicelluloses, pectins and lignins. NSCWM of apple flesh was obtained by the removal of reducing sugars and starch by alcohol extraction and enzymatic hydrolysis, respectively. No additional steps were taken to remove proteins. NSCWM values reported in Table 2 include some proteins and minerals in addition to dietary fibre and hence is an overestimation of dietary fibre.

Non-starch polysaccharides

NSP values (Table 2) ranged from 13·8 g kg^{-1} apple flesh in 'McIntosh' to 28·7 g kg^{-1} in 'York', with significant statistical differences among cultivars ($P < 0{\cdot}0007$). However, all cultivars except 'McIntosh' and 'York' had statistically similar NSP content (Table 2). The mean(±SD) NSP content for the 13 cultivars was 17·9 ± 4·2 g kg^{-1}. NSP content was calculated by adding the amount of individual monosaccharides. NSP fractions in this study represent cellulose, hemicellulose

TABLE 2
Effect of apple cultivar on non-starch cell wall material (NSCWM), total non-starch polysaccharides (NSP), and the insoluble and soluble fractions of NSP[a]

Cultivar	*NSCWM content (g kg^{-1} flesh)*	*NSP content (g kg^{-1} flesh)*	*Fibre fraction (g kg^{-1} total NSP)*	
			Insoluble NSP	*Soluble NSP*
Cortland	21·3 ± 1·4cd	15·4 ± 1·7bc	831 ± 26a	169 ± 26c
Empire	25·4 ± 1·5b	19·1 ± 1·8b	709 ± 23c	291 ± 23a
Fuji	19·1 ± 1·6d	15·5 ± 1·5bc	752 ± 26c	248 ± 26a
Gala	21·2 ± 1·7cd	16·1 ± 1·9bc	805 ± 26ab	195 ± 26bc
Golden Delicious	22·0 ± 1·8cd	17·5 ± 2·3bc	740 ± 35c	260 ± 35a
Granny Smith	24·2 ± 2·3bc	19·6 ± 3·3b	732 ± 37c	268 ± 37a
Jonagold	21·6 ± 1·6cd	16·7 ± 1·9bc	759 ± 22bc	241 ± 22ab
McIntosh	19·3 ± 1·5d	13·8 ± 1·8c	735 ± 28c	265 ± 28a
Mutsu	22·1 ± 1·1cd	17·4 ± 2·1bc	756 ± 32bc	244 ± 32ab
Delicious	21·2 ± 2·4cd	16·6 ± 2·2bc	814 ± 36a	186 ± 36c
Rome	24·0 ± 2·2bc	20·0 ± 2·8b	835 ± 25a	165 ± 25c
Stayman	22·0 ± 1·8cd	16·9 ± 1·9bc	752 ± 35c	248 ± 35a
York	36·2 ± 1·6a	28·7 ± 3·4a	821 ± 34a	179 ± 34c

[a] Values are mean ± standard deviation ($n = 3$). Mean separation within columns by LSD, 5% level.

TABLE 3

Effect of apple cultivar on monosaccharide composition (g kg^{-1}) of total non-starch polysaccharides (NSP).

Cultivar	*Monosaccharides*							
	Rhamnose	*Fucose*	*Arabinose*	*Xylose*	*Mannose*	*Galactose*	*Glucose*	*Uronic acid*
Cortland	12·8 ± 1·1cd	5·1 ± 0·7bc	143·2 ± 10·4ab	56·3 ± 9·1bc	26·8 ± 2·4ef	120·0 ± 8·1b	335·1 ± 10·6cde	300·7 ± 13·5ef
Empire	13·5 ± 0·8bc	5·0 ± 0·6bc	122·6 ± 9·0e	61·7 ± 5·4ab	35·7 ± 4·2abc	80·0 ± 6·7e	357·4 ± 13·5ab	324·0 ± 16·5cde
Fuji	14·9 ± 0·7ab	3·6 ± 0·5ef	130·9 ± 7·7bcde	54·5 ± 6·0bc	23·3 ± 3·0f	99·8 ± 7·8cd	325·7 ± 12·2def	347·2 ± 15·8bc
Gala	13·9 ± 1·1abc	6·9 ± 0·5a	105·5 ± 5·0f	64·0 ± 6·4ab	37·4 ± 3·9ab	63·1 ± 6·8f	353·6 ± 11·2abc	355·7 ± 14·0ab
Golden Delicious	13·9 ± 1·6abc	6·5 ± 0·6a	123·5 ± 7·8de	62·5 ± 5·8ab	40·0 ± 4·3a	88·0 ± 8·3de	344·9 ± 10·3bcd	320·6 ± 16·0de
Granny Smith	10·8 ± 0·8ef	6·4 ± 0·4a	126·2 ± 8·2cde	59·7 ± 8·6abc	32·9 ± 3·1bcd	105·1 ± 8·5c	315·0 ± 13·7efg	343·8 ± 17·0bcd
Jonagold	15·6 ± 1·1a	4·8 ± 0·5bcd	117·8 ± 5·8ef	61·4 ± 6·1ab	30·2 ± 2·6cde	84·5 ± 7·2e	335·7 ± 12·2cde	350·0 ± 17·2bc
McIntosh	10·5 ± 0·8f	5·2 ± 0·6b	144·9 ± 10·0a	70·0 ± 7·3a	27·3 ± 2·3def	100·5 ± 7·0cd	304·5 ± 16·2g	337·1 ± 14·9bcd
Mutsu	12·5 ± 1·6cde	4·3 ± 0·5cde	121·7 ± 8·7e	49·6 ± 4·9cd	36·0 ± 3·0abc	80·7 ± 6·5e	314·0 ± 13·1fg	381·2 ± 17·9a
Delicious	12·5 ± 0·8cde	2·9 ± 0·4f	136·6 ± 6·7abcd	63·2 ± 7·5ab	25·8 ± 3·3ef	45·7 ± 6·6g	363·5 ± 10·8ab	349·7 ± 15·8bc
Rome	10·4 ± 0·9f	4·1 ± 0·4de	127·7 ± 7·9cde	56·4 ± 6·8bc	30·2 ± 3·8cde	150·4 ± 8·3a	357·3 ± 11·2ab	263·4 ± 13·3g
Stayman	11·7 ± 0·9def	3·2 ± 0·4f	123·6 ± 8·0de	59·7 ± 7·5abc	30·3 ± 3·8cde	99·9 ± 8·2cd	373·4 ± 12·0a	298·3 ± 16·3ef
York	11·2 ± 1·1def	2·9 ± 0·5f	137·1 ± 6·8abc	42·5 ± 5·6d	31·5 ± 4·3bcde	131·6 ± 6·9b	365·6 ± 12·8ab	277·7 ± 10·5fg

[a] Values are mean ± SD (n = 3). Mean separation within columns by LSD, 5% level.

TABLE 4

Effect of apple cultivar on monosaccharide composition (g kg^{-1}) of insoluble non-starch polysaccharides (NSP)

Cultivar	*Monosaccharides*							
	Rhamnose	*Fucose*	*Arabinose*	*Xylose*	*Mannose*	*Galactose*	*Glucose*	*Uronic acid*
Cortland	14·2 ± 0·7bcde	6·2 ± 1·7bc	159·6 ± 7·1ab	69·4 ± 8·7bcd	30·8 ± 3·6ef	133·1 ± 9·1b	403·6 ± 16·9de	183·0 ± 10·0bc
Empire	15·4 ± 0·9b	6·7 ± 1·4bc	140·9 ± 8·7def	73·5 ± 7·9bcd	45·1 ± 4·5ab	90·3 ± 11·0e	462·0 ± 18·2a	166·1 ± 10·2cd
Fuji	14·3 ± 0·7bcde	4·6 ± 1·2de	157·6 ± 7·7abc	68·0 ± 6·3cd	27·9 ± 3·5f	120·5 ± 8·4bc	423·5 ± 13·0cd	183·5 ± 10·8bc
Gala	14·6 ± 1·5bc	8·4 ± 1·5a	121·8 ± 11·9g	78·1 ± 6·4bcd	39·3 ± 3·4abc	72·9 ± 6·8f	426·1 ± 15·4cd	238·9 ± 12·8a
Golden Delicious	12·9 ± 0·8cdef	9·2 ± 1·6a	134·6 ± 12·2fg	80·2 ± 6·6b	45·5 ± 4·9a	101·9 ± 9·0de	412·7 ± 17·7cd	202·9 ± 13·5b
Granny Smith	12·6 ± 1·2ef	9·2 ± 1·4a	152·0 ± 7·7bcde	79·6 ± 5·5bc	37·6 ± 3·3bcd	123·2 ± 12·0bc	384·7 ± 13·7e	201·1 ± 10·1b
Jonagold	17·3 ± 1·6a	6·1 ± 1·5c	136·7 ± 7·6efg	80·7 ± 11·0b	37·9 ± 4·0abcd	97·7 ± 10·6e	436·4 ± 12·7bc	187·2 ± 11·9bc
McIntosh	12·0 ± 0·8f	7·2 ± 1·8b	171·0 ± 7·6a	93·4 ± 6·0a	33·5 ± 5·3def	119·4 ± 11·6bc	379·9 ± 10·0e	183·5 ± 11·2bc
Mutsu	14·5 ± 0·8bcd	5·9 ± 1·6c	155·9 ± 6·8abcd	67·5 ± 5·7d	44·7 ± 4·6ab	99·2 ± 7·1de	415·6 ± 15·7cd	196·8 ± 12·1b
Delicious	14·0 ± 1·2bcde	3·6 ± 1·0e	159·2 ± 9·2ab	78·5 ± 7·7bcd	28·4 ± 3·4ef	51·3 ± 6·4g	427·8 ± 12·4cd	237·2 ± 15·3a
Rome	11·9 ± 0·8f	4·7 ± 0·6d	136·4 ± 8·3fg	70·7 ± 5·31bcd	34·9 ± 5·2cdef	163·7 ± 10·0a	410·3 ± 13·6d	167·4 ± 14·0cd
Stayman	13·1 ± 0·8cdef	3·9 ± 1·0de	144·1 ± 13·4bcde	76·7 ± 7·5bcd	34·1 ± 5·6cdef	113·6 ± 9·7cd	452·9 ± 15·4ab	161·5 ± 10·7d
York	12·7 ± 0·8def	3·7 ± 1·1de	143·2 ± 7·7cdef	53·7 ± 5·7c	35·5 ± 4·4cde	154·5 ± 12·4a	424·1 ± 17·8cd	172·5 ± 13·7cd

[a] Values are mean ± SD (n = 3). Mean separation within columns by LSD, 5% level.

and pectins. However, lignin is not included in the NSP fraction. Also the recovery of monosaccharides from polysaccharides are usually less than 100% due to loss during hydrolysis. NSP can be considered to be a very conservative estimate of dietary fibre. NSP and dietary fibre are used interchangeably in this article. Insoluble NSP represented an average of 772 ± 49 g kg^{-1} total NSP. It ranged from 709 g kg^{-1} in 'Empire' to 835 g kg^{-1} in 'Rome'. Differences among cultivars ($P < 0{\cdot}0001$) were statistically significant. 'Empire' had the highest (291 g kg^{-1}) and 'Rome' the lowest (165 g kg^{-1}) soluble NSP values, the average for 13 cultivars being 228 ± 49 g kg^{-1}. Soluble NSP content presented in Table 2 was calculated as the difference between total NSP and insoluble NSP. However, the monosaccharide composition of total, insoluble and soluble NSP were determined separately rather than using the data for total and insoluble NSP to estimate the monosaccharide composition of soluble NSP. This was done to reduce the extraneous variations that usually result when a parameter is measured by difference. Distribution of monosaccharides in total, insoluble, and soluble NSP are presented in Tables 3, 4 and 5.

Rhamnose

Rhamnose is considered to be present in the main chain of pectins. It accounted for only a small portion of the monosaccharides in apple NSP, ranging from 10·4 g kg^{-1} in 'Rome' to 15·6 g kg^{-1} in 'Jonagold' (Table 3). There were significant statistical differences in the amount of rhamnose present in different cultivars. Rhamnose accounted for an average of $12{\cdot}6 \pm 1{\cdot}8$ g kg^{-1} total monosaccharides in apple fibre. On a fresh weight basis, rhamnose comprises an average of $0{\cdot}23 \pm 0{\cdot}05$ g kg^{-1} apple flesh. Mean rhamnose content in insoluble NSP of 13 apple cultivars was $13{\cdot}8 \pm 1{\cdot}7$ g kg^{-1}. Soluble NSP had an average of $9{\cdot}9 \pm 2{\cdot}8$ g kg^{-1} rhamnose.

Fucose

Fucose is believed to be present in side chains of pectic substances. It was found in small amount in the hydrolysates of apple NSP. Of all the monosaccharides determined, fucose was present in the least amount. Fucose comprised an average of $4{\cdot}7 \pm 1{\cdot}1$ g kg^{-1} total monosaccharides in dietary fibre, ranging from 2·9 g kg^{-1} in 'York' and 'Delicious' to 6·9 g kg^{-1} in 'Gala'. On a fresh weight basis, fucose accounted for an average of $0{\cdot}08 \pm 0{\cdot}03$ g kg^{-1} apple flesh. Average fucose content of insoluble fibre was $6{\cdot}1 \pm 2{\cdot}0$ g kg^{-1}. No fucose could be detected in soluble NSP.

Arabinose

Arabinose is mostly found in hemicellulose. A small amount of arabinose may also be found in the side chains of pectic substances. Mean arabinose content of 13 apple cultivars was $127{\cdot}8 \pm 12{\cdot}4$ g kg^{-1} NSP. Arabinose values ranged from 105·5 g kg^{-1} in 'Gala' to 144·9 g kg^{-1} in 'McIntosh'. On a fresh weight basis, average arabinose content in the 13 cultivars was $2{\cdot}3 \pm 0{\cdot}6$ g kg^{-1}. Insoluble NSP had an average arabinose content of $147{\cdot}2 \pm 15{\cdot}0$ g kg^{-1} while mean arabinose content in the soluble NSP fraction was $67{\cdot}1 \pm 19{\cdot}5$ g kg^{-1}.

Xylose

Xylose is mainly found in hemicellulose. It may also be found in the side chains of pectins. Average xylose content in 13 cultivars was $58{\cdot}6 \pm 8{\cdot}8$ g kg^{-1} NSP, with 'York' having the lowest (42·5 g kg^{-1}) and 'McIntosh' the highest (70·0 g kg^{-1}). There were significant differences among 13 cultivars. On a fresh weight basis, mean xylose content was $1{\cdot}0 \pm 0{\cdot}2$ g kg^{-1} apple flesh. As expected, a major proportion of xylose was found in insoluble NSP. Insoluble NSP in 13 cultivars of apple had an average xylose content of $74{\cdot}6 \pm 10{\cdot}1$ g kg^{-1} while average xylose content in the soluble NSP fraction was $9{\cdot}1 \pm 4{\cdot}0$ g kg^{-1}.

Mannose

Mannose is mainly present in the hemicellulose portion of dietary fibre. It was found in small quantities in the hydrolysates of apple NSP. Mannose represented an average of $31{\cdot}3 \pm 5{\cdot}6$ g kg^{-1} total monosaccharides in NSP. It ranged from 23·3 g kg^{-1} in 'Fuji' to 40·0 g kg^{-1} in 'Golden Delicious'. On a fresh weight basis, mannose represented an average of $0{\cdot}6 \pm 0{\cdot}2$ g kg^{-1} apple flesh. Insoluble fibre contained an average of $36{\cdot}6 \pm 6{\cdot}8$ g kg^{-1} of mannose while mean mannose content in the soluble fibre fraction was $11{\cdot}7 \pm 3{\cdot}1$ g kg^{-1}.

Galactose

Galactose is found mainly in hemicellulose. It may also be found in the side chains of pectins. Of all the monosaccharides studied, galactose showed the most pronounced cultivar difference. It represented an average of $96{\cdot}1 \pm 27{\cdot}7$ g kg^{-1} total monosaccharides in apple NSP. Galactose ranged from 45·7 g kg^{-1} in 'Delicious' to 150·4 g kg^{-1} in 'Rome' indicating more than 3-fold difference among cultivars. Even on a fresh weight basis, galactose content was highly cultivar dependent. It ranged from 0·8 g kg^{-1} apple flesh in 'Delicious' to 3·8 g kg^{-1} in 'York', with the average being $1{\cdot}8 \pm 0{\cdot}8$ g kg^{-1}. Average galactose content of insoluble NSP was $110{\cdot}9 \pm 31{\cdot}0$ g kg^{-1}. The mean value for galactose content of soluble fibre was $52{\cdot}4 \pm 19{\cdot}4$ g kg^{-1}.

Glucose

Glucose is the monomeric unit of cellulose. It may also be found in main and side chains of hemicellulose and side chains of pectin. Glucose is the most abundant neutral sugar in apple fibre. It represented an average of $342{\cdot}0 \pm 23{\cdot}9$ g kg^{-1} total monosaccharides in NSP

TABLE 5

Effect of apple cultivar on monosaccharide composition (g kg^{-1}) of soluble non-starch polysaccharides (NSP).

Cultivar	*Monosaccharides*							
	Rhamnose	*Fucose*	*Arabinose*	*Xylose*	*Mannose*	*Galactose*	*Glucose*	*Uronic acid*
Cortland	6·3 ± 0·7g	ND[b]	61·7 ± 6·6de	5·8 ± 1·0ef	10·9 ± 1·6bcde	53·8 ± 6·5e	45·9 ± 6·3bcd	815·7 ± 8·0d
Empire	8·2 ± 0·6ef	ND	70·5 ± 5·9bcd	16·3 ± 1·8a	16·3 ± 1·9a	49·0 ± 6·6efg	55·0 ± 5·0ab	784·8 ± 8·8f
Fuji	16·5 ± 0·9a	ND	41·6 ± 5·6f	12·0 ± 1·6c	10·0 ± 1·6de	40·5 ± 5·2g	43·4 ± 4·9cde	835·9 ± 6·7c
Gala	10·4 ± 0·9c	ND	33·7 ± 5·5f	7·6 ± 0·9de	11·6 ± 1·9bcd	29·4 ± 4·0h	35·4 ± 4·8efg	871·9 ± 8·6a
Golden Delicious	13·9 ± 0·9b	ND	95·4 ± 6·9a	13·0 ± 1·9bc	15·8 ± 2·0a	68·6 ± 8·2bc	60·2 ± 6·0a	733·0 ± 12·8h
Granny Smith	8·7 ± 0·8de	ND	63·6 ± 6·9cde	4·7 ± 0·8f	14·0 ± 1·9ab	63·7 ± 6·4cd	27·1 ± 6·4g	818·1 ± 8·4d
Jonagold	9·4 ± 0·9cde	ND	57·0 ± 6·9e	6·6 ± 0·9def	6·6 ± 1·6f	43·2 ± 5·5fg	35·1 ± 5·2efg	842·1 ± 9·8c
McIntosh	6·8 ± 1·3fg	ND	100·4 ± 8·5a	14·6 ± 1·8ab	8·0 ± 1·7ef	74·5 ± 8·2b	50·0 ± 6·6abc	745·7 ± 8·3gh
Mutsu	8·6 ± 0·6de	ND	54·4 ± 7·2e	5·2 ± 0·7f	11·7 ± 1·5bcd	28·3 ± 3·1h	33·6 ± 5·0efg	858·2 ± 6·5b
Delicious	10·5 ± 0·7c	ND	60·7 ± 6·9de	11·2 ± 1·4c	10·7 ± 2·2cde	29·1 ± 3·9h	32·9 ± 5·6fg	844·9 ± 11·8c
Rome	10·0 ± 0·7cd	ND	77·4 ± 7·2b	8·8 ± 1·9d	10·3 ± 2·3cde	94·1 ± 9·6a	43·2 ± 7·4cde	756·3 ± 8·8g
Stayman	10·3 ± 0·9c	ND	80·0 ± 7·5b	7·9 ± 1·2de	13·5 ± 1·9abc	56·0 ± 6·5de	37·7 ± 6·7def	794·6 ± 13·4ef
York	9·5 ± 1·1cde	ND	75·2 ± 9·1bc	4·9 ± 0·9f	12·1 ± 2·0bcd	51·2 ± 7·7ef	47·6 ± 8·0bcd	799·6 ± 9·6e

[a] Values are mean ± SD ($n = 3$). Mean separation within columns by LSD, 5% level.
[b] ND, not detected.

ranging from 304·5 g kg^{-1} in 'McIntosh' to 373·4 g kg^{-1} in 'Stayman'. On a fresh weight basis, glucose in apple fibre comprised an average of 6·2 ± 1·7 g kg^{-1} apple flesh. In insoluble NSP, average glucose content was 420·0 ± 25·6 g kg^{-1} whereas mean glucose content in soluble NSP was 42·1 ± 10·6 g kg^{-1}.

Uronic acid

Uronic acid is the major constituent of pectic substances. It is one of the major monosaccharides in apple fibre. Uronic acid represented an average of 326·9 ± 35·2 g kg^{-1} total monosaccharides in NSP of 13 cultivars ranging from 263·4 g kg^{-1} in 'Rome' to 381·2 g kg^{-1} in 'Mutsu'. Uronic acid accounted for an average of 190·9 ± 26·1 g kg^{-1} insoluble fibre. Uronic acid was by far the most abundant monosaccharide present in soluble NSP, the average for the 13 cultivars being 807·8 ± 43·4 g kg^{-1} soluble NSP, ranging from 733·0 g kg^{-1} in 'Golden Delicious' to 871·9 g kg^{-1} in 'Gala' (Table 5). On a fresh weight basis, uronic acid represented an average of 5·8 ± 1·2 g kg^{-1} apple flesh. More than 50% of the pectin found in apples was soluble in all cultivars except 'Cortland', 'Gala', 'Delicious' and 'Rome'.

Correlation between firmness and fibre constituents

Besides nutritional values, fibre components are believed to contribute to the texture and firmness of fruits. Average flesh firmness of the 13 apple cultivars was 72·7 ± 19·4 N. Correlation of NSP and individual sugars (fresh weight) with firmness was studied. NSP ($r^2 = 0{\cdot}41$; $P < 0{\cdot}0001$), glucose ($r^2 = 0{\cdot}45$; $P < 0{\cdot}0001$), galactose ($r^2 = 0{\cdot}34$; $P < 0{\cdot}0001$), mannose ($r^2 = 0{\cdot}23$; $P < 0{\cdot}0022$), arabinose ($r^2 = 0{\cdot}34$; $P < 0{\cdot}0001$), rhamnose ($r^2 = 0{\cdot}18$; $P < 0{\cdot}0066$) and uronic acid ($r^2 = 0{\cdot}24$; $P < 0{\cdot}0016$) content were significantly positively correlated with firmness. Xylose and fucose content were not correlated with firmness.

DISCUSSION

Average fibre content reported in this study is somewhat lower than values reported by Wills and El-Ghetany (1986). However, unpeeled apples were used in that study. NSP values in the present study are more or less similar to the values reported for peeled 'Delicious' apples (Marlett 1992) and for two unnamed apple cultivars (Ross *et al* 1985).

The importance of fruit fibre has been considered to lie in its high soluble fibre content. Average soluble fibre percentage in the present study was higher than the values reported by Theander and Aman (1979) and Marlett (1992).

Monosaccharide composition in this study differed to a certain extent from the values reported by Theander and Aman (1979). Average arabinose and xylose content of insoluble fibre were lower and galactose content was higher. Mannose and glucose content were similar. The neutral sugar composition of insoluble fibre in the present study was more or less similar to values reported by Marlett (1992).

Soluble NSP was found to have lower arabinose content, and higher glucose and xylose content than reported by Theander and Aman (1979). Galactose content was more or less similar. Neutral sugar composition of soluble NSP in the present study was similar to the values reported by Marlett (1992).

Although there was significant cultivar differences in the abundance of each sugar component, arabinose and xylose were less variable than glucose and uronic acid especially on a fresh weight basis. Of all the monosaccharides, galactose was the most affected by cultivar difference. Cultivar differences seen in the less abundant sugars, ie rhamnose, fucose and mannose may have been accentuated by difficulties faced in measuring sugars found in small quantities.

On a fresh weight basis, 'York' had the highest concentration of almost all the monosaccharides. Unfortunately, 'York' is a processing variety and fiber content is known to diminish during processing.

Most cultivars had more pectin in soluble fibre than in insoluble fibre. However insoluble fibre was found to have more total rhamnose than soluble fibre indicating the possibility that insoluble pectins in apple have more rhamnose in their main chains than soluble pectins. It was not clear from the present study whether cellulose or pectin is the most abundant fibre component in apple fibre. On average, slightly more glucose than uronic acid was found in apple fibre. However, the entire amount of glucose need not necessarily have come from cellulose. A small portion of it may have come from hemicellulose and pectin. At least the glucose molecules in the soluble fibre could not have been part of cellulose.

Flesh firmness is determined to a large extent by cell wall polysaccharides. Significant correlation between firmness and fiber composition was observed in the present study. However, fairly low r^2 values indicate that firmness is affected by variables other than fibre content and composition. Separate studies on the effect of storage and developmental stage showed much stronger correlation of firmness with NSP and monosaccharide content within the same cultivar (Gheyas 1994). It is possible that flesh firmness variation within a cultivar is determined more by relative amount of monosaccharides present while firmness in different cultivars are explained more in terms of structure of polysaccharides in addition to the amount of polysaccharides.

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