

1 **Sugars in Whole Sesame Seed : Effects of Cultivars, Planting Dates, and Row Spacings**

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10 **ABSTRACT**

11 Mean contents of fructose, glucose, raffinose, stachyose, sucrose, and total sugars in whole
12 sesame seed, produced during 2011 and 2012 in mid-Atlantic region of the United States of America,
13 were 0.95, 1.28, 2.22, 0.14, 0.82, and 5.39 g/100 g meal, respectively. Planting time effects were
14 significant for contents of fructose, stachyose, and sucrose. Early planting (Late May to early June)
15 resulted in 5.4 and 34.3% increase in contents of fructose and sucrose, respectively over late planting
16 (Early July). On the other hand, early planting resulted in an increase of 70% in content of
17 stachyose, a non-nutritive sugar. An increase in row spacing from 37.5 cm to 75 cm increased the
18 content of fructose by 24.7% but resulted in 8.1% decrease in content of glucose. Cultivar effects
19 were significant only for sucrose. S26 and S32 cultivars had significantly higher content over that of

20 22K (0.89, 0.89, and 0.69 g/100 g meal, respectively). These results indicate that sugar contents in
21 sesame whole seed could be manipulated by using specific growing conditions and cultivars and
22 could be helpful in determination of sugar intake via consumption of whole seeds.

23 Keywords: *Sesamum indicum* L.; Total sugar content; Fructose content; Glucose content; Sucrose
24 content; Raffinose content; Stachyose content.

25

26 1. INTRODUCTION

27 This study was conducted to determine if sesame (*Sesamum indicum* L., Pedaliaceae) could
28 be produced in a non-traditional area to diversify cropping system and to characterize composition of
29 sesame related to human nutrition. Sesame is one of the oldest crops known to humans.

30 International demand for sesame continues to increase every year. The world's traded sesame seed
31 recently surpassed one million tons per year and was valued at approximately \$850 million. In the
32 last 15 years, world trade in sesame has increased by nearly 80%. The United States imports more
33 sesame than it grows. In 2010, the United States imported sesame seed valued at \$69.9 million
34 which was relatively unchanged from 2009 [1]. This observation indicates that there is potential for
35 enhancing sesame production in the United States. Due to significant reductions in tobacco
36 (*Nicotiana tabacum* L.) and peanut (*Arachis hypogea* L.) acreage in Virginia in recent times, the New
37 Crops Program of Virginia State University has been evaluating several summer crops that can be

38 grown in Virginia to help agricultural diversification and to enhance farm incomes. In this regard,

39 sesame is considered a potentially lucrative crop.

40 It is well established that foods determine human health. Given that all foods originate from

41 plants, it is imperative that composition of plant products to be used as foods be clearly known so that

42 informed decisions could be made regarding human nutrition. Diabetes and obesity are two of the

43 most critical health issues in the United States today, with millions of dollars poured into research

44 every year to further uncover the sources of this epidemic in order to cure/manage the disease.

45 Researchers at the Yale School of Medicine have uncovered a feed-forward mechanism whereby

46 excess sugar consumption may lead to increased fat production in the liver and the ensuing

47 development of diabetes [2]. Although there is a lack of dietary trials linking sugar consumption with

48 human diseases, it is commonly suggested that sugar consumption should be limited [3,4,5,6].

49 Through the ages, sesame seeds have been a source of food and oil. About 65% of the

50 annual sesame crop is processed into oil and 35% is used in food [1]. There is a complete lack of

51 information about sesame production in this region and additionally regarding composition of sesame

52 seed produced in this region. One objective of our research was to determine if sesame could be

53 successfully produced in Virginia. Additionally, we were interested in characterization of sugars in

54 sesame seed produced in the mid-Atlantic region of the United States of America to address issues

55 related to management of diabetes.

56

57 2. MATERIALS AND METHODS

58

59 2.1 Plant material and Production

60 Five proprietary sesame cultivars (22K, S26, S28, S30, and S32) from Sesaco Corporation (San
61 Antonio, Texas, USA) were used in this study. This field study was conducted at Randolph Farm of
62 Virginia State University located in Ettrick, Virginia. These cultivars were planted in four-row plots with
63 row spacings of 37.5 and 75 cm in an Abel Sandy Loam soil. Sesame was planted on May 23 and
64 June 8, respectively (PT1) during 2011 and on July 9 and July 17, respectively (PT2) during 2012
65 using a split-plot experimental design with planting dates as main plots, row spacings as sub-plots
66 and cultivars as sub-sub-plots with four replications of a Randomized Complete Block Design. The
67 soil received a pre-plant incorporated application of approximately 2 liters of trifluralin herbicide per
68 hectare. Seeding rate for this study was approximately 3 kg/ha, the plot length was 3 m and the seed
69 was planted on a flat bed. Seeding was accomplished using a four-row research planter. The
70 experimental area did not receive any irrigation. Upon maturity, the plots were harvested by using a
71 research combine.

72 The experimental area received a fertilizer application of 112 kg per hectare each of N, P, and
73 K. All plots were harvested manually at maturity, generally in November to December of each year.
74 Seeding rate for this study was approximately 3 kg/ha, the plot length was 3 m and the seed was

75 planted on a flat bed. The experimental area did not receive any irrigation. Upon maturity, the plots
76 were harvested by using a research combine.

77

78 2.2 Determination of contents of fructose, glucose, sucrose, total sugars, raffinose, and stachyose
79 contents in whole sesame seeds

80 Fructose, glucose, sucrose, raffinose, stachyose and total sugars in whole sesame seeds
81 were extracted from defatted ground sample and analyzed by high-performance liquid chromatograph
82 (HPLC) following the methods optimized by Johansen et al. [7]. Triplicate of 1.0 g of the defatted
83 sample was placed in 25 mL centrifuge tube and suspended in 2 mL of 99% (v/v) ethanol then heated
84 in a boiling water bath for 5 min. The sample was placed in the fume hood until all ethanol had
85 evaporated. Sugars were then extracted from the defatted sample with 10mL of deionized water
86 containing 5 mg trehalose internal standard at room temperature in a horizontal shaker at 200 rpm for
87 60 minutes. The suspension was then centrifuged at 13000 rpm for 10 minutes, and 500 μ L of the
88 clear supernatant was filtered through a syringe nylon membrane filter (25 mm diameter, 0.2 μ m;
89 Waters Associates, Inc., Milford, MA USA). An aliquot of 20 μ L of the filtered sugars extract were
90 auto-injected into a Waters Alliance 2695-HPLC System equipped with Waters refractive index
91 detector (Waters 2414 RID - Waters Associates, Inc., Milford, MA USA). The separation of fructose,
92 glucose, sucrose, raffinose, and stachyose was achieved using a Prevail carbohydrate column ES
93 5 μ m (250 x 4.6mm), preceded by a Prevail carbohydrate ES guard column 53mm x 7.0mm (Grace,

Deerfield, IL USA). Column, sample and detector temperature were maintained, respectively, at 50, 25, 30 °C. The mobile phase, acetonitrile/water (75 :25 v/v), was run isocratically at a flow rate of 1.0 mL/min, and the elution was monitored by Waters 2414 RID. Sugars in the extracts were identified by comparing their retention times with standard sugars. Quantification of fructose, glucose, sucrose, raffinose, and stachyose in the sample was done by comparing the area of the peaks of the respective sugars in the sample chromatogram with that of the trehalose internal standard using Empower II software (Waters Associates, Inc., Milford, MA USA). The concentrations of fructose, glucose, sucrose, raffinose, and stachyose were expressed as g/ 100 g oil-free meal.

2.3 Statistical analysis

All data were analyzed using the Analysis of Variance procedures in version 9.3 of SAS [8]. The means were compared using Fisher's Protected Least Significant Difference at a 5% level of significance.

3. RESULTS AND DISCUSSION

Analysis of variance (Table 1) indicated that planting dates significantly affected contents of fructose, sucrose, and stachyose; row spacings significantly affected contents of fructose and glucose; and cultivars significantly affected only the content of sucrose in whole sesame seeds.

112 Earlier planting (Late May to early June) resulted in 0.98 g/100 g meal fructose content in
113 whole sesame seed whereas late planting (early July to middle of July) resulted in 0.93 g/100 g meal
114 fructose – an increase of 5.4% due to earlier planting. Similarly, early planting resulted in 34%
115 increase in contents of sucrose over late planting (0.94 and 0.70 g/100 g meal, respectively) in whole
116 sesame seed (Table 2). Early planting increased content of stachyose, a non-nutritive carbohydrate,
117 70% over late planting (0.17 and 0.10 g/100 g meal, respectively). Increasing the spacing between
118 rows from 37.5 cm to 75 cm resulted (Table 3) in an 24.7% increase in fructose content (1.06 and
119 0.85 g/100 g meal, respectively) and caused an 8.1% decrease in glucose content (1.33 and 1.23
120 g/100 g meal, respectively). Differences among five sesame cultivars were generally not significant
121 for most sugars (Table 4). Content of sucrose in S26 and S32 cultivars were significantly higher as
122 compared to 22K cultivar (0.89, 0.89, and 0.69 g/100 g meal, respectively).

123 Use of a limited number of cultivars in this study may have resulted in limited effects on
124 contents of various sugars in whole sesame seed. However, most of the worldwide sesame
125 production is based on use of traditional cultivars that are tall and are shattering types [9]. Shattering
126 of sesame capsules in traditional cultivars is not conducive to mechanical harvesting. Sesaco, a
127 private company based in Texas (USA), has been breeding sesame to develop dwarf and shatter-
128 resistant sesame cultivars for several years and released the first dwarf and shatter-resistant sesame
129 cultivar in 1982 [9]. In 2010, Sesaco had more than 100,000 acres of sesame under contract
130 production with growers in southwest Kansas, Oklahoma and central Texas. All dwarf and shatter-

131 resistant sesame cultivars from Sesaco are proprietary. We expect that inclusion of a wider number

132 of sesame cultivars in studies like this would indicate an expanded range of sugar contents.

133 Our results indicated that early planting resulted in increased contents of fructose, sucrose,

134 and stachyose in whole sesame seed. However, contents of glucose, total sugars and raffinose were

135 not affected by planting date indicating that sesame can be produced in Virginia by using either early

136 or late planting dates. However, early planting is expected to produce sesame seeds that are sweeter

137 over those produced by planting late. Raffinose and Stachyose are considered non-nutritive and are

138 not completely digested by human beings [10]. In recent times, non-nutritive carbohydrates in food

139 grains are receiving increasing attention due to their limited digestibility and potential use in obesity

140 reduction efforts [11].

141 With regards to identifying an optimal row spacing for sesame production in Virginia, relative

142 to sugar content of whole sesame seed, our results indicate that based on contents of all sugars other

143 than fructose and glucose, either a closer row spacing (37.5 cm between rows) or a wider row

144 spacing (75 cm between rows) could be used. Our objectives were to identify optimal row spacing for

145 sesame production in Virginia because farmers, generally, resist purchase of new equipment when

146 initially evaluating production of new, non-traditional crops. Most Virginia farmers own soybean

147 planters either configured for 37.5 cm or 75 cm rows, therefore, sesame in Virginia could be planted

148 with existing planters. Given that amount of seed for planting is small, it might be desirable to use

149 37.5 cm rows because of weed control due to shading. On the other hand, if sesame is to be
150 produced organically via cultivation than 75 cm rows might be desirable.

151

152 **4. CONCLUSIONS**

153 Results of our study indicated that sesame could be easily produced as a commercial crop in
154 Virginia. These results also indicate that sugar contents in sesame whole seed could be manipulated
155 by using specific growing conditions and cultivars.

156

157

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164 **REFERENCES**

- 165 [1] AgMRC. Sesame Profile. Ag Marketing Resource Center. Iowa State University, Ames, IA.
166 2013. Accessed 20 December 2013. Available: <http://www.agmrc.org/search/index.cfm>.
- 167 [2] Yale Scientific. Research links sugar consumption, fat production, and diabetes. 2011.
168 Accessed 7 February 2014. Available: [http://www.yalescientific.org/2011/04/research-links-](http://www.yalescientific.org/2011/04/research-links-sugar-consumption-fat-production-and-diabetes/)
169 [sugar-consumption-fat-production-and-diabetes/](http://www.yalescientific.org/2011/04/research-links-sugar-consumption-fat-production-and-diabetes/).
- 170 [3] Howard BV, Wylie-Rosett J. Sugar and Cardiovascular Disease: A statement for healthcare
171 professionals from the Committee on Nutrition of the Council on Nutrition, Physical Activity,
172 and Metabolism of the American Heart Association. Circulation. 2002;106:523-527.
- 173 [4] Yudkin J. Sugar and ischemic heart disease. Practitioner. 1967;198:680-683.
- 174 [5] Yudkin J. Dietary factors in atherosclerosis: sucrose. Lipids. 1978;13:370-372.
- 175 [6] Jacobs DR Jr., Meyer KA, Kushi LH, Folsom AR. Whole-grain intake may reduce the risk of
176 ischemic heart disease death in postmenopausal women: the Iowa Women's Health Study.
177 1998. Amer. J. Clinical Nutrition. 1998;68:248-257.
- 178 [7] Johansen HN, Glitso V, Knudson KEN. Influence of extraction solvent and temperature on
179 the quantitative determination of oligo-saccharides from plant materials by high-performance
180 liquid chromatography. J. Agric. Food Chem 1996; 1470-74.

- 181 [8] SAS. SAS System for Windows. SAS Institute, Inc., Cary, NC. 2013.
- 182 [9] Langham DR, Wiemers T. Progress in mechanizing sesame in the US through breeding.
183 2002; 157-173. In J. Janick and A. Whipkey (eds.) Trends in New Crops and New Uses.
184 ASHS Press, Alexandria, VA.
- 185 [10] Nakakuki T. Present status and future of functional oligosaccharide development in Japan.
186 Pure and Applied Chemistry 2002; 74 (7): 1245–1251.
- 187 [11] Hoover R, Zhou Y. In vitro and in vivo hydrolysis of legume starches by α -amylase and
188 resistant starch formation in legumes – A review. Carbohydrate Polymers 2003; 54: 401-417.

189 Table 1. Partial analysis of variance (Mean squares) for contents of sugars

190 in seeds of five sesame cultivars grown using two planting dates and

191 two row spacings in Virginia during 2011 and 2012.

192

Variable	Years	Planting dates	Row spacing s	Cultivar s	R ² %	CV %	Mean
Fructose	*	*	**	ns	96.4	36.9	0.95 ^x
Glucose	ns	ns	**	ns	98.2	10.2	1.28 ^x
Sucrose	ns	*	ns	*	91.6	28.7	0.82 ^x
Total sugars	*	ns	ns	ns	95.4	12.7	5.39 ^x
Raffinose	*	ns	ns	ns	96.3	11.1	2.22 ^x
Stachyose	ns	**	ns	ns	94.4	46.3	0.14 ^x

193 *, **: Mean squares significantly different from residual mean squares at 5 and 1%

194 levels, respectively when tested against appropriate error mean squares as per split-plot

195 analysis.

196 x : Sugar contents as g/100 g meal.

197

198 Table 2. Effects of planting dates on contents of sugars in seeds of five sesame
 199 cultivars grown using two row spacings in Virginia during 2011 and 2012.

200

Variable	Early planting (PT1)	Late planting (PT2)
Fructose ^x	0.98 a*	0.93 b
Glucose ^x	1.43 a	1.13 a
Sucrose ^x	0.94 a	0.70 b
Total sugars ^x	5.29 a	5.48 a
Raffinose ^x	2.08 a	2.37 a
Stachyose ^x	0.17 a	0.10 b

201 x : Sugar contents as g/100 g meal.

202 * : Mean within rows followed by similar letters were not different according to LSD at 5% level.

203 Table 3. Row spacing effects on contents of sugars in seeds of five sesame
 204 cultivars produced using two planting dates in Virginia during 2011 and 2012.

205

Variable	37.5 cm	75 cm
Fructose ^x	0.85 b*	1.06 a
Glucose ^x	1.33 a	1.23 b
Sucrose ^x	0.84 a	0.79 a
Total sugars ^x	5.37 a	5.40 a
Raffinose ^x	2.27 a	2.18 a
Stachyose ^x	0.13 a	0.14 a

206 x : Sugar contents as g/100 g meal.

207 * : Mean within rows followed by similar letters were not different according to LSD at 5% level.

208 Table 4 . Cultivar differences for contents of sugars in seeds of sesame

209 produced using two row spacings and two planting dates in Virginia

210 during 2011 and 2012.

211

Variable	22K	S26	S28	S30	S32
Fructose ^x	1.12 a*	0.87 a	0.96 a	0.96 a	0.85 a
Glucose ^x	1.24 a	1.42 a	1.30 a	1.28 a	1.16 a
Sucrose ^x	0.69 b	0.89 a	0.81 ab	0.81 ab	0.89 a
Total sugars ^x	5.39 a	5.58 a	5.54 a	5.28 a	5.14 a
Raffinose ^x	2.21 a	2.28 a	2.36 a	2.13 a	2.14 a
Stachyose ^x	0.13 a	0.12 a	0.11 a	0.16 a	0.17 a

212 x : Sugar contents as g/100 g meal.

213 * : Mean within rows followed by similar letters were not different according to LSD at 5% level.