J. Appl. Glycosci., **66**, 47–50 (2019)
doi: 10.5458/jag.jag.JAG-2018_0007

Note

Sugar Composition in Asparagus Spears and Its Relationship to Soil Chemical Properties

(Received August 31, 2018; Accepted November 30, 2018)
(J-STAGE Advance Published Date: December 7, 2018)

Hideyuki Takahashi,[1,†] Chiharu Yoshida,[1] and Takumi Takeda[1]

[1] *Iwate Biotechnology Research Center*
(*Kitakami, Iwate 024-0003, Japan*)

Sugars are one of the most important factors determining the taste and texture of asparagus (*Asparagus officinalis*). In this study, we quantified soluble and insoluble sugars in asparagus spears grown in four different agricultural fields. We measured soil chemical properties in each of the fields, and further investigated the relationship between sugar contents in the spears and soil chemical properties. We found a possible relationship between the contents of glucose and fructose and values of cation exchange capacity, available phosphoric acid, and exchangeable calcium and magnesium in the soil. These findings will be useful information for improving asparagus quality.

Key words: *Asparagus officinalis*, soil chemical property, monosaccharide, oligosaccharide, polysaccharide

Asparagus (*Asparagus officinalis*) is a long-lived perennial that can be harvested every spring when spears begin to appear. Asparagus is known as a nutritious vegetable that contains high levels of amino acids,[1)] minerals,[2)] and vitamins. [3)] Since asparagus also contains functional compounds such as saponins,[4)] rutin,[5)] and asparaptine,[6)] it is believed to have advantageous effects on human health. Sugar content is one of the most important factors determining the eating quality of asparagus, *e.g.*, glucose, fructose, and sucrose contribute to sweetness, and polysaccharides affect texture.[7)] Previous reports have shown that the major storage carbohydrates of asparagus are sucrose and fructans, which are accumulated in the roots and hydrolyzed to hexose to be used as the energy source for spear development.[8)9)] Since the sugar content of asparagus spears is highly dependent on transport from underground organs, the contents rapidly decrease after harvest.[7)10)] Therefore, high sugar content in preharvest spears is necessary to improve and maintain quality for commercial purposes. Previously, Maeda *et al*.[4)] reported that there was no significant difference in the sugar contents of green and white asparagus spears, whereas protodioscin content was apparently higher in white asparagus spears, implying that sugar content may be affected by other environmental factors such as temperature and soil properties. Although the effect of temperature on sugar content in asparagus has been investigated,[11)12)] to the best of our knowledge, the effect of soil properties has not been estimated.

In this study, we used green asparagus (*A. officinalis* cv. Welcome) grown in Kanegasaki-cho, Iwate Prefecture, Japan. After harvest, samples were cut into apical, middle, and basal sections of 6 cm each in length, and immediately freeze-dried. Asparagus spears were harvested from four different agricultural fields (#1 to #4) to determine whether there is a relationship between sugar content and soil chemical properties. First, soil pH, electrical conductivity (EC), cation exchange capacity (CEC), available phosphoric acid (P_2O_5), exchangeable calcium (Ca), magnesium (Mg), potassium (K), and base saturation (BS) of each agricultural field were measured using standard protocols as described by Loan *et al*.[13)] (Fig. 1A). The pH of the soils was within the weakly acidic range, with the highest pH (6.6) in field #1 and the lowest (5.7) in field #3. EC is the ability of soil to conduct electrical current and is used as an indicator of salinity level. The EC values of fields #2 and #3 were greater than those of fields #1 and #4. CEC is a parameter that represents the total capacity to hold cations; the highest CEC value was observed in field #2 and the lowest was observed in field #1. The contents of P_2O_5, Ca, Mg, and K were lowest in field #1, but the contents of P_2O_5, Ca, and Mg were highest in field #2, whereas the content of K was highest in field #3. BS is the percentage of the CEC that is occupied by three major cations (Ca, Mg, and K). BS of the soils in this study varied from 67.6 to 93.1 %. High BS (over 90 %) was observed in the soil of fields #1 and #2, suggesting that the soil materials were almost saturated with cations. Although apparent differences in soil properties were observed, there were almost no differences in the appearance of spears harvested from the four agricultural fields (Fig. 1B). These results indicate that the effect of soil properties on the growth of asparagus spears is small, at least with respect to the parameters used in this study.

Next, the sugar contents in the apical, middle, and basal sections of the spears were quantified (Fig. 2). Soluble sug-

[†]Corresponding author (Tel. +81–197–682911, Fax. +81–197–683881, E-mail: h-takahashi@ibrc.or.jp).
Abbreviations: EC, electrical conductivity; CEC, cation exchange capacity.

A

	No. 1	No. 2	No. 3	No. 4
pH	6.6	6.1	5.7	6.4
EC (dS/m)	0.08	0.20	0.25	0.06
CEC (meq/100g)	23.0	56.2	40.4	37.2
P_2O_5 (mg/100g)	129.5	267.0	177.0	215.5
Ca (mg/100g)	440.5	761.0	458.5	600.5
Mg (mg/100g)	68.5	104.0	89.0	92.0
K (mg/100g)	105.5	198.5	272.0	119.5
BS (%)	93.1	91.5	67.6	77.0

B

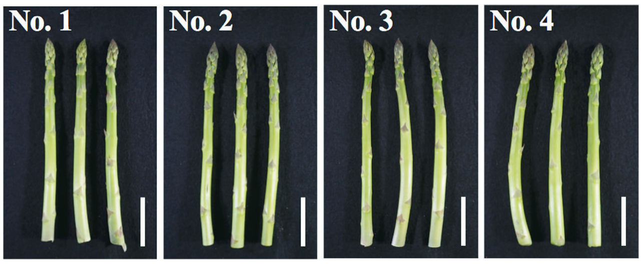

Fig. 1. Soil properties of the four agricultural fields used to grow green asparagus.

(A) Soil properties of each of the four fields. Soil was collected at two points in each field and the average of each parameter is presented. (B) Photographs of green asparagus samples from each of the four fields. Scale bars represent 5 cm.

ars were quantified by liquid chromatography- quadrupole time-of-flight mass spectrometry according to the method of Takahashi *et al.*[14] Among the soluble sugars, glucose and fructose were dominant, followed by sucrose in all of the sections. The abundance of sugars in asparagus spears has also been reported.[15] In the present study, raffinose content was apparently higher in apical sections compared to other sections. The contents of glucose, fructose, and xylose increased from apical to basal sections of all spears, and the contents in basal sections were from 2.3- to 4.1-fold higher than those in apical sections. On the other hand, the contents of sucrose and raffinose decreased from apical to basal sections, except for sucrose content in field #2. We therefore measured invertase activity according to the method of Takahashi *et al.*[16] The activity increased from apical to basal sections (Fig. 3), suggesting that hydrolysis of oligosaccharides; especially sucrose, may be related to the amounts of glucose and fructose. The contents of glucose, fructose, xylose, and sucrose in all sections were highest in field #2. We also measured the contents of starch and cell wall sugars. Extraction of starch and hemicellulose were sequentially carried out by treatment with amylase and 1M NaOH containing 0.1 % (w/v) $NaBH_4$ based on a previous report.[17] The residual insoluble materials were defined as cellulose. The amounts of the extracted sugars were calculated from the absorbance at 640 nm after staining with 0.5 % (w/v) anthrone in H_2SO_4 based on a standard calibration curve for glucose. Starch contents were similar in apical and middle sections, but were higher in basal sections than other sections. On the other hand, hemicellulose contents were highest in middle sections. A previous report showed that asparagus spears contain hemicellulose such as arabinan, xylan, xyloglucan, heteromannan, and arabinogalactan.[18] In this study, we detected a significant amount of xylose, suggesting that xylan or xyloglucan may be the major hemicellulose. Our results also showed that hemicellulose is accumulated in the most expanding region of asparagus spears.[15] This is in agreement with the previous finding that accumulated xyloglucan was observed in the elongation region of pea stems.[19] We also found that

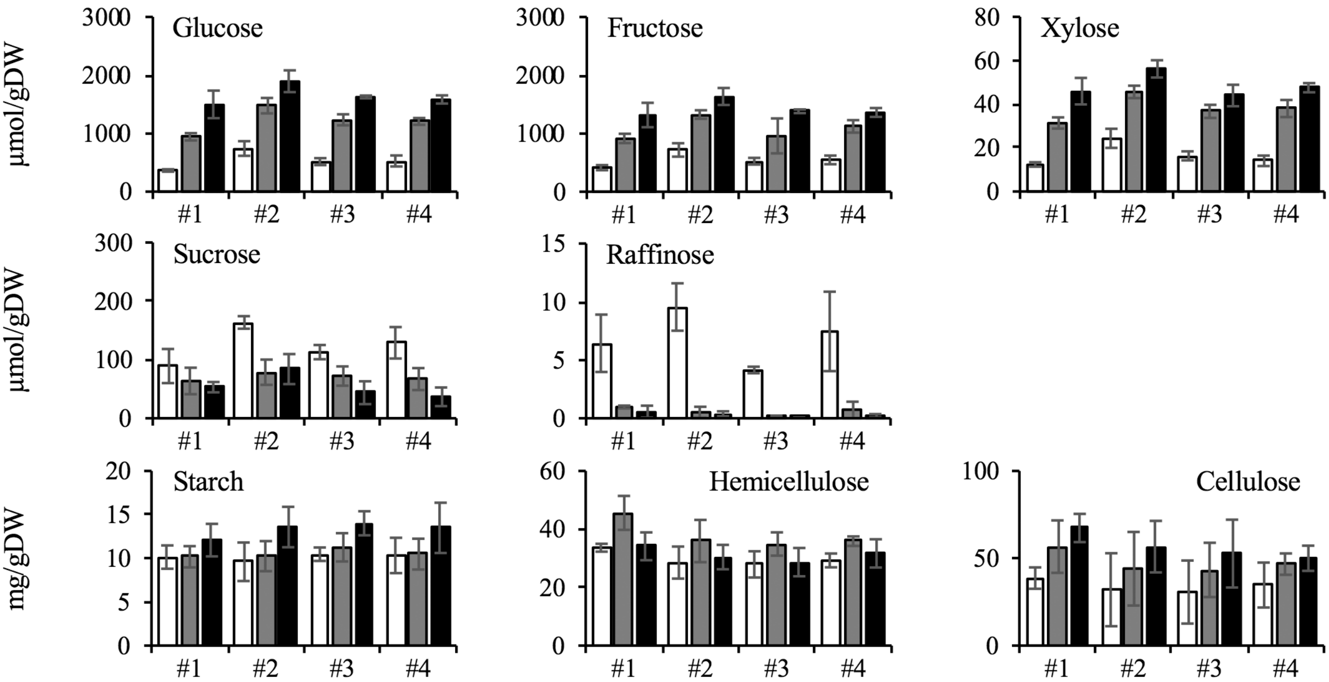

Fig. 2. Effects of soil properties on sugar contents of asparagus spears.

Sugar contents in apical (white bars), middle (gray bars), and basal (black bars) sections of spears harvested from each agricultural field (#1 to #4) were compared. Values represent the mean ± standard deviation calculated from three independent experiments.

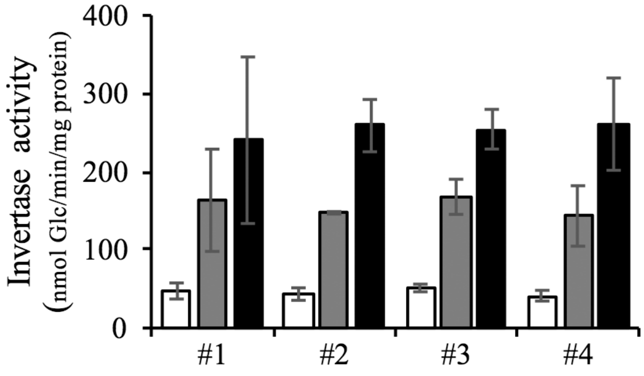

Fig. 3. Comparison of invertase activity in asparagus spears.
Invertase activity in apical (white bars), middle (gray bars), and basal (black bars) sections of spears harvested from each agricultural field (#1 to #4) were measured. Values represent the mean ± standard deviation calculated from three independent experiments.

cellulose contents increased from apical to basal sections. It is reported that the hardness of asparagus spears increases towards the bottom,[20] suggesting that cellulose contents contribute to the hardness of spears. The contents of hemicellulose and cellulose in spears of field #1 were highest among the spears tested, whereas the contents of glucose, fructose, and xylose were lowest.

We also carried out correlation analysis to assess the relationship between sugar contents and soil properties (Table S1; see J. Appl. Glycosci. Web site). Pearson's correlation coefficient (r) and P-value were calculated using Excel 2016 (Microsoft). The pairs possessed a high correlation ($r > 0.85$) in all sections, as shown in Fig. 4. We found a possible correlation between soil properties and the contents of glucose and fructose. A significant positive correlation was observed between glucose content and CEC ($p < 0.05$) and a similar trend was also observed between fructose content and CEC. Furthermore, the contents of glucose and fructose increased with the increase of P_2O_5 content in soil. Glucose content showed a correlation with soil Mg content, whereas fructose content showed a correlation with soil Ca content.

In conclusion, we evaluated the chemical properties of soil from four different agricultural fields and measured the sugar contents of asparagus spears grown in each field. We found a possible relationship between the contents of glucose and fructose in asparagus spears with the values of CEC, P_2O_5, Ca, and Mg in soil. Although the effects of soil on plant metabolism are mainly focused on soil components such as nutrients and organic materials, this study revealed that soil chemical properties also affect metabolite levels in plants.

However, there are still some points we have to consider. For example, sugar contents are known to be affected by soil nitrogen fertility. Since we found that the content of glutamine, one of the parameters of nitrogen assimilation,[21] showed little variation in the spears (Fig. S1; see J. Appl. Glycosci. Web site), nitrogen in the soil might also affect sugar contents in the spears. Furthermore, since rhizomes are a source of sugar, sugar contents in the spears are probably affected by those in the rhizomes. Both of these possibilities should be examined in future research. Because asparagus is a vegetable with a short shelf life, postharvest treatment of asparagus has been vigorously studied. On the other hand, there are few reports about the cultural environment affecting the sugar content of asparagus spears despite sugar being an important determinant of taste and texture. Our results will be useful as an agronomic factor for influencing the quality of preharvest asparagus.

ACKNOWLEDGEMENTS

We thank Mr. Yoshiichi Takahashi, Mr. Eiroh Suzuki, Mr.

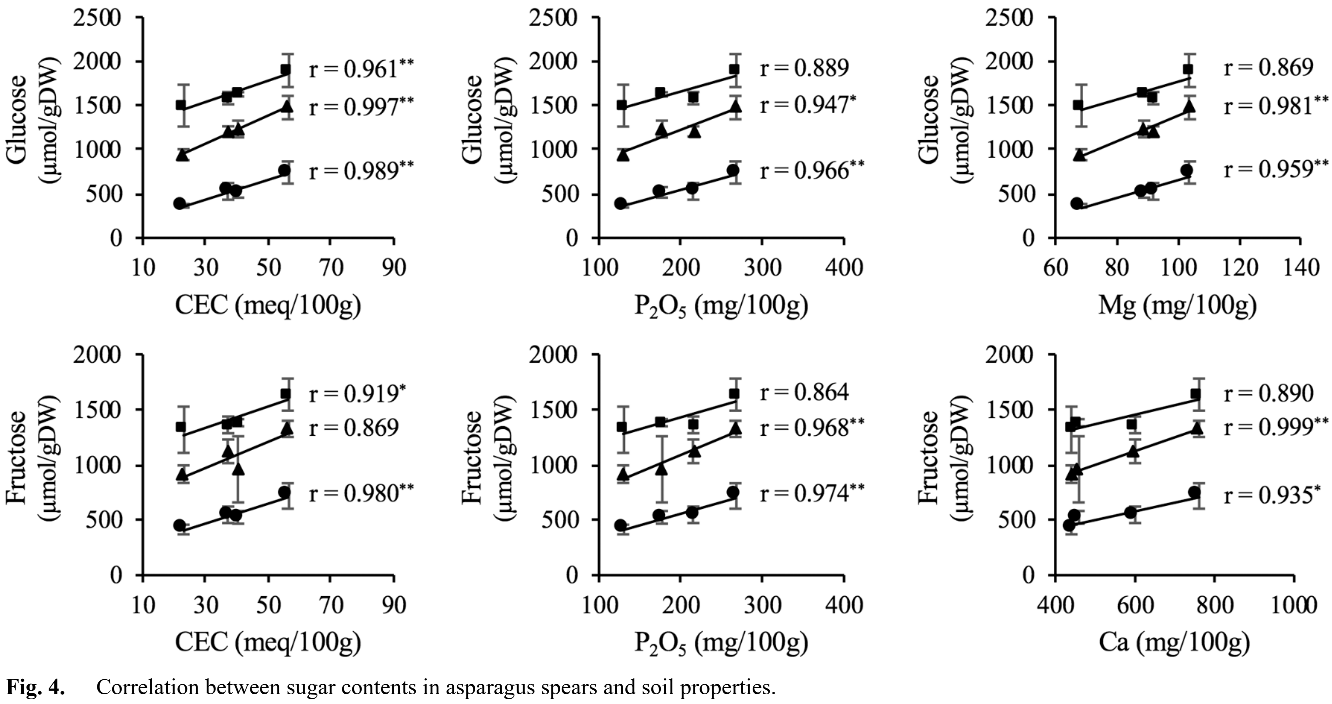

Fig. 4. Correlation between sugar contents in asparagus spears and soil properties.
Sugar concentrations in apical (circles), middle (triangles), and basal (squares) sections were plotted against soil property values. Pearson's correlation coefficient (r) values are also presented. Significant differences are shown with asterisks ($^{*}P < 0.1$; $^{**}P < 0.05$).

Tsutomu Oikawa, Mr. Kazuo Oikawa, Mr. Yoshihiko Takahashi, Mr. Takashi Takahashi, and Mr. Yoshiyuki Shibata of Kanegasaki-cho, Isawa County, Iwate Prefecture for providing the asparagus and helpful advice.

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