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Fructose in different apple varieties

Implications for apple consumption in persons affected by fructose intolerance

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Abstract

Fructose malabsorption (FM) and hereditary fructose intolerance (HFI) are pathological diseases that should be clearly distinguished from one another, but for both of which fructose is a relevant substrate. The treatment for both diseases consists of fructose restriction, but with a completely different focus for each. In the case of HFI, consumption of fructose must be avoided completely, but in the case of FM, a desensitization strategy can be adopted. This strategy exploits the mechanism of glucose-induced fructose transport. Thus, for FM (unlike for HFI) it is not necessary to abstain from consuming foods containing fructose completely.

Apples have a high fructose content, and also have an unfavorable fructose/glucose ratio of > 1, which means that at first glance, they appear unsuitable for patients with FM.

Our investigations have shown that depending on the variety, the fructose content of apples can vary considerably. Although in every variety of apple, the fructose content is higher than the glucose content, it is still not necessary to abstain from the consumption of apples completely in the case of FM. In addition to selecting an apple variety with the lowest possible fructose content, other recommendations that can help to improve fructose absorption can also be taken into account. The extent to which glucose promotes the absorption of fructose or improves the symptoms of FM by doing so requires further investigation.

Keywords: Food intolerances, fructose malabsorption, hereditary fructose intolerance, fructose/glucose ratio, fructose content, apples, fruit

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Introduction

Fructose intake has increased significantly in recent years [1] and this trend is partly responsible for the increasing prevalence of fructose malabsorption (FM) [2]. Fructose is also the substrate involved in diseases of fructose metabolism, such as hereditary fructose intolerance (HFI). Therefore, fructose content in food is an important issue for patients who have diseases in which fructose is a key factor.

Fructose malabsorption is often erroneously referred to in the media as fructose intolerance, which means that it can be easily confused with the metabolic disease hereditary fructose intolerance [2]. The different forms of fructose intolerance should be clearly distinguished from one another [3]. ◆ Table 1 provides a comparison of HFI and FM with regard to their pathomechanisms, symptoms, diagnosis, and treatment. In both of these diseases, treatment is based on nutritional therapy with fructose restriction playing a key role, but the focus of the treatment is completely different for each.

The main reason for the current trend of increasing fructose intake is (in addition to general nutritional recommendations promoting a high fruit and vegetable intake), the wide range of foods available [2]. However, the increasing use of high fructose corn syrup (HFCS) in the food industry has had a particular impact in terms of increased intake of fructose from non-natural sources [1]. This sweet syrup made of maize consists of up to 90% fructose. It is a cheap alternative to sucrose that is used for sweetening [4]. HFCS is often used to make soft drinks, bread products, confectionery, and ketchup [5]. Fructose naturally occurs mainly in fruit, vegetables, and honey [3].

Foods with added HFCS, as well as fructose-rich fruits are key concerns for patients with diseases of fructose metabolism and impaired fructose absorption. While HFI treatment focuses solely on strict abstinence from

	fructose malabsorption (FM)	hereditary fructose intolerance (HFI)
general description	impairment of intestinal fructose absorption [10]	disease of fructose metabolism [11]
genetic defect	unknown [3]	mutation of the ALDOB gene [12]
heredity	unknown [13]	autosomal recessive [14]
prevalence	approx. 1:3 [13]	1:20000 [14]
pathophysiology	altered activity of the relevant transporters in the intestinal wall [15], incomplete absorption of fructose with subsequent fermentation in the colon [3]	deficiency of the enzyme fructose-1-phosphate-aldolase (aldolase B) of genetic origin [14] → toxic accumulation of fructose-1-phosphate, especially in the cells of the liver, the intestines, and the proximal tubule [16], and disorder of fructose metabolism with blocking of glycolysis and glucogenesis [14]
symptoms	gastrointestinal symptoms [3, 10]	symptoms of persistent hypoglycemia, liver and kidney damage, failure to thrive, reduced blood coagulation, edema, and ascites [14]
diagnosis	hydrogen breath test after oral intake of fructose [3]	genetic analysis using DNA sequencing [14]
treatment	three-step model [17]: - significantly reduced fructose intake on a temporary basis, especially free fructose (abstinence phase) [3], - followed by gradual reintroduction of fructose in order to increase fructose tolerance and to determine individual fructose tolerance (testing phase), - then, transition to long-term nutrition that is adapted to the patient's needs and requirements [17]	strict restriction of fructose, sucrose, and FODMAPs [3]
prognosis	can be treated successfully through changes to the diet; taking account of individual preferences and avoiding nutrient deficiencies ensures preservation of quality of life [17]	if the dietary recommendations are adhered to in a consistent manner, there is no reduction in life expectancy; if hereditary fructose intolerance is present but not detected, this can lead to death [3]

Tab. 1: **Comparison of fructose malabsorption with hereditary fructose intolerance**
FODMAPs = *fermentable oligo-, di-, monosaccharides and polyols* [1]

fructose as a treatment method, dietetic modification of FM aims to increase fructose tolerance. If glucose intake is increased at the same time as fructose intake, fructose can also be transported to the enterocytes via the GLUT2 transporters, which are expressed more strongly this case. This relieves some of the strain on GLUT5 transporters, which are the transporters that are primarily responsible for fructose absorption [3]. Therefore, tolerance of sucrose, as well as foods that have at least a balanced fructose/glucose ratio (≤ 1) is far better than tolerance of fructose alone [3]. This glucose-induced fructose transport is particularly useful during the abstinence phase.

Apples are the most popular fruit in Germany [6]. However, they have a high fructose content and an imbalance between fructose and glucose [7]. Therefore, at first glance, it appears that people with FM should be advised against eating this fruit. However, usually, little distinction is made between the sugar content of different varieties of apple, even though initial results show that there are indeed differences between the varieties [8, 9]. Mandarins and bananas are better tolerated alternatives to apples due to their more favorable fructose/glucose ratios [3].

Objectives

In order to better evaluate whether consumption of apples is feasible in the case of fructose intolerance if the individual variety is taken into account, the free fructose content and free glucose content of the apple varieties Elstar, Braeburn, and Jonagored was determined and compared to the respective contents of mandarins and bananas.

Method

For each variety of apple, five samples from various shopping outlets were investigated. The same procedure was followed for mandarins and bananas. Each of the measurements was done as a double determination.

The fruit was first peeled and homogenized. In order to perform the measurements, in each case, 1 g

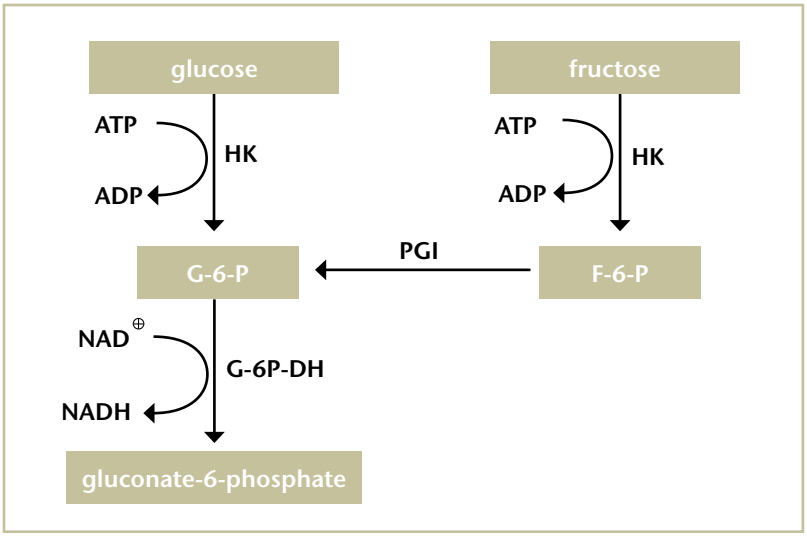

Fig. 1: **Diagram of reaction for the enzymatic determination of glucose and fructose** [18]
ADP = adenosine diphosphate; ATP = adenosine triphosphate; F-6-P = fructose-6-phosphate; G-6-P = glucose-6-phosphate; G-6P-DH = glucose-6-phosphate-dehydrogenase; HK = hexokinase; NAD(H) = nicotinamide adenine dinucleotide

of the homogenized material was suspended in demineralized water. After Carrez clarification for elimination of turbidity, 10 mL 0.1 M NaOH solution was added, and the solution was then topped up to 100 mL and centrifuged for 20 minutes at 4000 rpm.

The sugar in the supernatant was then determined. The Enzytec™ fluid glucose/fructose test kit from Thermo-Scientific was used for this. Fructose and glucose were first phosphorylated by the enzyme hexokinase. In the next step, glucose-6-phosphate was oxidized by NAD^+ to gluconate-6-phosphate after catalysis by the enzyme glucose-6-phosphate-dehydrogenase. The amount of NADH is equivalent to the original glucose amount and can be determined photometrically at 340 nm (measurement 1). After that, fructose-6-phosphate is converted by phosphoglucose isomerase to glucose-6-phosphate, which is further transformed by the glucose-6-phosphate-dehydrogenase that is already present (measurement 2) [18]. Fructose content can be calculated from the difference between measurement 1 and measurement 2.

◆ Figure 1 shows the reaction for the enzymatic determination of glucose and fructose.

Results

The measurements show that fructose and glucose content differs depending on the variety of apple. ◆ Figure 2 shows the mean values with information on the standard deviation of the glucose and fructose determination, as well as the fructose/glucose ratio (F/G-R) of the fruit varieties that were investigated (red and green boxes). Across all apple varieties, fructose content is significantly higher than glucose content. Unlike in the case of mandarins (F/G-R slightly > 1) and bananas (F/G-R always < 1), the ratio is significantly greater than one. The measured values differ significantly from the values reported for apples in general in the literature.

Discussion

FM and HFI are related in the sense that they both involve the substrate fructose, but their pathomechanisms are completely different. In the case of HFI, apples and other foods containing fructose must be strictly banned from the diet, whereas in the case of FM, fructose intake only needs to be restricted and removed from the diet in a more moderate fashion.

Since the literature only provides insufficient data on fructose and glucose content of various varieties of apple, these measurements were carried out using the three most commonly consumed varieties of apple in Germany in the years 2014 and 2015 [19].

The measurements show that the different varieties of apple differ in their fructose and glucose content. In every variety, there was more fructose than glucose. The values also differ significantly from those published in the literature. This trend is confirmed by a research project in the field of ecotrophology that was conducted at Münster University of applied sciences (FH Münster) and found the sugar content values for other apple varieties that are shown in ◆ Table 2 [20]. More exact verification would require further measurements. By way of comparison, the concentration of the two monosaccharides present in bananas and mandarins was measured and presented.

The fructose content of apples and fruit in general depends on exogenous factors [21]. In order to obtain representative data despite this, the samples were taken from different shopping outlets and measured using double determination. The relatively high variation in the five individual measurements is attributable to natural fluctuations. Larger sample sizes would be useful in order to unambiguously prove the variety-specific differences and to obtain the most stable values possible.

Despite the variations in fructose content, due to the extremely high fructose values, the varieties that were investigated should not be recommended in the case of FM in

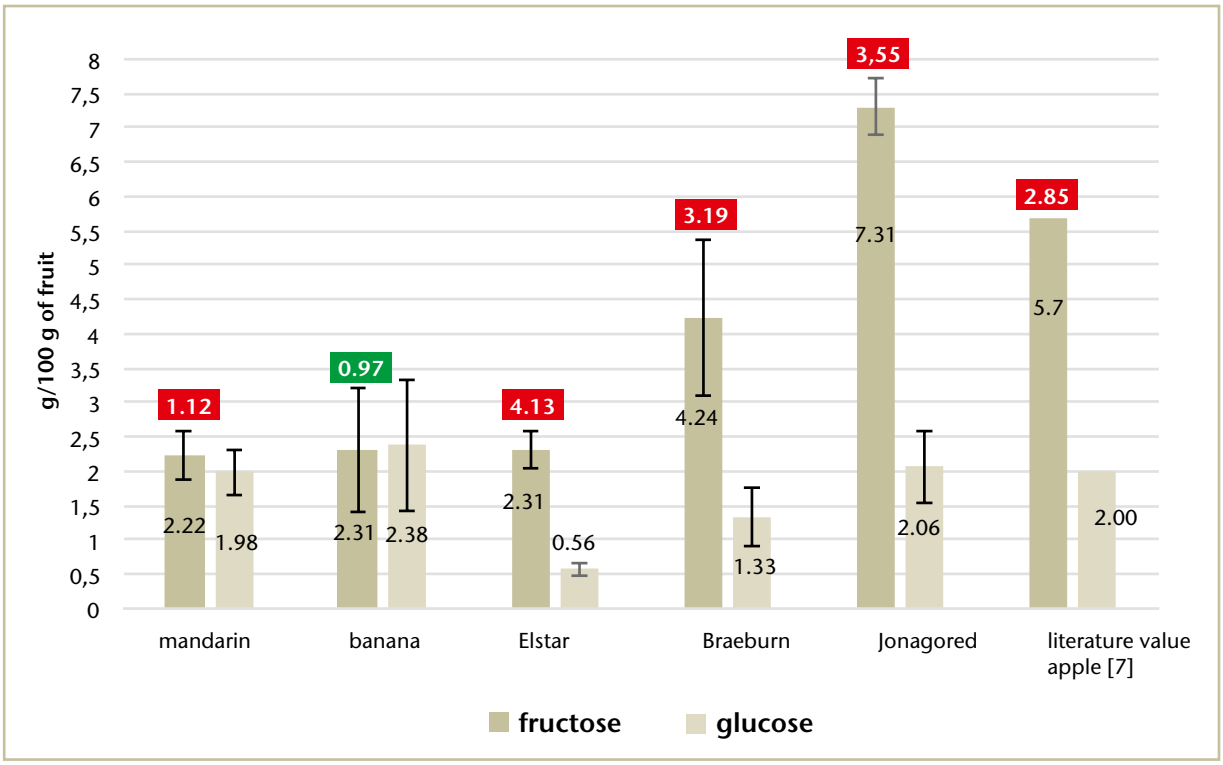

Fig. 2: **Fructose and glucose content of various apple varieties and of bananas and mandarins, along with the values for the concentration of each type of sugar in apples in general according to the literature**
The boxes indicate the fructose/glucose ratio (F/G-R): green box = F/G-R ≤ 1: tends to be tolerated by patients with fructose malabsorption; red box = F/G-R ≥ 1: tends not to be tolerated by patients with fructose malabsorption (n = 5)

apple variety	glucose content in g per 100 g of fruit	fructose content in g per 100 g of fruit	fructose/glucose ratio
Granny Smith	1.1[a]	2.3[a]	2.1
Boskop	1.4[a]	3.1[a]	2.2
Pink Lady	1.4[a]	4.8[a]	3.4
Golden Delicious	2.0[a]	5.2[a]	2.6
Royal Gala	2.3[b]	6.9[b]	3.0
Fuji	3.3[b]	7.7[b]	2.3

Tab. 2: **The fructose and glucose content and fructose/glucose ratio of different varieties of apple**[1]
[a] [20], [b] [9]

the abstinence phase or the testing phase. However, it is not necessarily essential to abstain from the consumption of apples completely. By choosing the variety with the lowest possible fructose content and simultaneously consuming glucose-rich foods, it is possible to balance out the unfavorable F/G-R. In addition, it would be interesting to investigate older varieties of apple in order to determine whether they may have lower fructose content.

According to the research results, the Elstar variety has a relatively low fructose content. This is comparable to the Granny Smith variety, which has an average fructose content of 2.33 g/100 g fruit [20].
◆ Table 2 shows the fructose and glucose contents and fructose/glucose ratios of some apple varieties found in the literature. Significant variations can be found here too, showing that the variety of apple selected can have a significant effect on the tolerability of the apple.
In addition, methods that may improve fructose absorption include spreading out fructose intake by consuming several small portions throughout the day, and above all, combining fructose consumption with main meals or having it as a dessert [17]. Furthermore, simultaneous consumption of fat and protein-rich meals leads to better tolerability of fructose due to the increased intestinal transit time [3].
Adding glucose to fructose-rich meals as a therapeutic measure to improve fructose absorption is coming under increasing criticism. The results of the study show that glucose does indeed demonstrably increase fructose absorption, but it could not be demonstrated that it improved gastrointestinal symptoms [22]. Since the assertions of

[1] The values taken from the literature have been rounded to one decimal place.

this study are not supported by their results diagrams, further investigations will be required before clear statements can be made about the effect of added glucose as a therapeutic measure in FM.

Conflict of Interest

The authors declare no conflict of interest.

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References

1. *Mansueto P et al. (2015) Role of FODMAPs in patients with irritable bowel syndrome. Nutr Clin Pract 30: 665–682*
2. *Schäfer C (2012) Fruktose: Malabsorption oder Intoleranz? Strategien für die Ernährungstherapie. Ernährungs Umschau 59: 694–700*
3. *Vogelreuter A. Nahrungmittelunverträglichkeiten. Wissenschaftliche Verlagsgesellschaft, Stuttgart (2012)*
4. *Gibson PR et al. (2006) Fructose malabsorption and the bigger picture. Aliment Pharmacol Ther 25: 349–363*
5. *Ristow M. Kohlenhydrate. In: Biesalski HK, Bischoff SC, Puchstein C (Hg). Ernährungsmedizin. Nach dem neuen Curriculum Ernährungsmedizin der Bundesärztekammer. 4. Aufl., Thieme Verlag, Stuttgart (2010)*
6. *Bundesministerium für Ernährung und Landwirtschaft. Zahl der Woche. Pressemitteilung Nr. 232 vom 15.08.2013. URL: www.bmel.de/SharedDocs/Pressemitteilungen/2013/232-Zahl-der-Woche-Obstverbrauch.html?nn=312878 Zugriff 11.03.16*
7. *Souci SW, Fachmann W, Kraut H. Die Zusammensetzung der Lebensmittel. Nährwert-Tabellen. 8. Aufl., Wissenschaftliche Verlagsgesellschaft, Stuttgart (2016)*
8. *Holland B, Unwin ID, Buss, DH. Fruits and nuts. The first supplement to McCane & Widdowson´s. The composition of foods. 5th ed., The Royal Society of Chemistry, Cambridge (1992)*
9. *Food Standards Australia New Zeeland. NUTTAB 2010 Online Searchable Database. Alphabetical list of foods. URL: www.foodstandards.gov.au/science/monitoringnutrients/nutrientables/nuttab/Pages/default.aspx. Zugriff 15.06.17*
10. *Ledochowski M, Fuchs D, Widner B (2000) Fruktosemalabsorption. J Ernährungsmed 2: 10–14*
11. *Böhles H et al. Angeborene Stoffwechselerkrankungen. In: Biesalski HK, Bischoff SC, Puchstein C (Hg). Ernährungsmedizin. Nach dem neuen Curriculum Ernährungsmedizin der Bundesärztekammer. 4. Aufl., Thieme Verlag, Stuttgart (2010)*
12. *Wilder-Smith CH et al. (2014) Fructose transporters GLUT5 and GLUT2 expression in adult patients with fructose intolerance. UEG Journal 2: 14–21*
13. *Schäfer C, Reese I, Ballmer-Weber BK (2010) Fruktosemalabsorption. Stellungnahme der AG Nahrungsmittelallergie in der Deutschen Gesellschaft für Allergologie und klinische Immolobie (DGAKI). Allegro Journal 19: 66–69*
14. *Steinmann B, Santer R, van den Gerghe G. Disorders of fructose metabolism. In: Fernandes J et al. (Hg). Inborn metabolic diseases. 4. Aufl., Springer-Verlag, Heidelberg (2006)*
15. *Karall D et al. Fruktosestoffwechselstörungen. In: Ledochowski M (Hg). Klinische Ernährungsmedizin. Springer-Verlag, Wien (2010)*
16. *Valadares ER et al. (2015) Hereditary fructose intolerance in Brazilian patients. MGM Reports 4: 35–38*
17. *Deutsche Gesellschaft für Ernährung e.V. (DGE) (Hg). Beratungs-Standards. 10. Aufl., graphoprint, Koblenz (2009)*
18. *Matissek R, Steiner G, Fischer M. Lebensmittelanalytik. 5. Aufl., Springer-Verlag, Heidelberg (2014)*
19. *Statista GmbH. Sortenanteile der wichtigsten Apfelsorten in Deutschland in den Jahren 2007/8 bis 2014/15. URL: http://de.statista.com/statistik/daten/studie/29118/umfrage/bedeutende-apfelsorten-in-deutschland-nach-sortenanteil/ Zugriff 11.03.16*
20. *Hartmann R, Weiss D. Apfelgenuss trotz Fruktoseintoleranz? Messung der Fruktosegehalte in modernen Apfelsorten. Projektarbeit im Fachbereich Oecotrophologie an der Fachhochschule Münster (2016)*
21. *Heimann W. Grundzüge der Lebensmittelchemie. Springer-Verlag, Berlin (1969)*
22. *Tuck CJ et al. (2016) Adding glucose to food and solutions to enhance fructose absorption is not effective in preventing fructose-induced functional gastrointestinal symptoms: randomised controlled trials in patients with fructose malabsorption. J Hum Nutr Diet 30: 73–82*

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