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Corrigendum: The effects of soluble corn fibre and isomaltooligosaccharides on blood glucose, insulin, digestion and fermentation in healthy young males and females

Authors:
Ryan P. Lowery[1,2]
Jacob M. Wilson[2]
Andrew Barninger[2]
Matthew H. Sharp[2]
Christopher Irvin[2]
Matthew Stefan[2]
William A. Wallace[2]
Gabriel J. Wilson[3]
Michael D. Roberts[4]
Ronald Wagner[1]

Affiliations:
[1]Department of Health and Human Performance, Concordia University Chicago, United States

[2]Applied Science and Performance Institute, United States

[3]Maximum Human Performance, United States

[4]Molecular and Applied Sciences Lab, School of Kinesiology, Auburn University, United States

Corresponding author:
Ryan Lowery,
rlowery@theaspi.com

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In the title of this article published earlier, the spelling of 'isomaltooligosaccharides' was unintentionally misprinted as 'isomaltooligosacharides'. The authors sincerely regret this error. The title should be corrected as follows: The effects of soluble corn fibre and isomaltooligosaccharides on blood glucose, insulin, digestion and fermentation in healthy young males and females.

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[3]Maximum Human Performance, United States

[4]Molecular and Applied Sciences Lab, School of Kinesiology, Auburn University, United States

Corresponding author:
Ryan Lowery,
rlowery@theaspi.com

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Dietary fibre refers to nutrients in the diet that gastrointestinal enzymes do not digest. If properly labelled, dietary fibres should not significantly elevate blood glucose or insulin and should ferment in the large intestine. Because of the recent rise in low-carbohydrate products on the market, consumers use these various fibres without adequate knowledge concerning whether or not these ingredients affect any blood parameters and constitute a dietary fibre. The aim of this study was to examine the impact of isomaltooligosaccharides (IMO) as compared to soluble corn fibre (SCF) consumption on blood glucose, insulin and breath hydrogen responses in healthy young men and women. After an overnight fast, nine individuals consumed 25 g of either placebo (PLA), IMO or SCF. Breath hydrogen was significantly higher in the SCF condition than in the IMO and PLA at 90, 120, 150 and 180 min ($p < 0.0001$). Blood glucose and insulin were higher in the IMO condition ($p < 0.0001$) at 30 min compared to the SCF or PLA conditions, which were not significantly different from each other. These data suggest that IMO does not constitute a dietary fibre and instead should be explored as a slow-digesting carbohydrate.

Introduction

Dietary fibres are non-digestible carbohydrates in the diet that, when consumed, pass through the small intestine into the large intestine where colonic microflora may partially or wholly ferment them.[1,2] While fibre intake is associated with lower body fat and decreased occurrence of diabetes and heart disease, less than 5% of the United States population meets the standard general recommendation of 25 g to 30 g daily.[2] As a solution to the problem, scientists have attempted to add novel forms of dietary fibres to various food sources called functional fibres.[3] Two popular sources that have risen in the food and supplement industry are isomaltooligosaccharides (IMO) and soluble corn fibre (SCF).

Isomaltooligosaccharides primarily derive from exposure of the maltose-rich syrup to the transglucosidase enzyme[4] resulting in an isomaltose-rich syrup, high in digestion-resistant 1,6 alpha bond linkages. *In vitro* resistance to pancreatic enzyme digestion has led nutrition companies to list IMO as a fibre.[5] However, previous research has demonstrated that isomaltose itself is almost completely digested (83% or more) by enzymes on the small intestinal border.[4,6] Soluble corn fibre is a newer digestion-resistant substance that still allows for the versatility of IMO in various food preparations.[7] Soluble corn fibre forms first through exposing corn syrup to a suite of pancreatic and brush border enzymes for 48 h or more, which leaves a stream of sugars and digestion-resistant carbohydrates.[3] This syrup is then filtered repeatedly until the substance is composed of virtually all non-digestible fibres.[8,9]

Numerous companies and nutrition products include and list both IMO and SCF as fibre sources. However, to date, research has not examined the comparison of these two carbohydrates *in vivo* in the same setting. Based on the criteria of fibre previously stated, for nutrition products to list IMO or SCF as a fibre, individuals should experience all of the following criteria succeeding consumption: (1) a non-significant change in blood glucose, (2) a resultant non-significant change in blood insulin levels and (3) the demonstration of fermentation via the elevation of the collected breath hydrogen samples. Given these criteria, the purpose of this study was to investigate the impact of IMO compared to SCF consumption on blood glucose, insulin and breath hydrogen responses in healthy young men and women.

Research methods and design

Study design

A randomised, double-blind, crossover study was performed to assess the impact of IMO as compared to SCF consumption on blood glucose, insulin and breath hydrogen responses in healthy young men and women. Subjects reported to the laboratory on five separate occasions (two familiarisations and three experimental days). On occasions one and two, subjects familiarised themselves with the breath hydrogen testing protocol. On occasions three to five, subjects were divided randomly into three conditions consisting of a non-calorie water-based placebo PLA, a bolus of IMO or SCF.

Study population and sampling strategy

Ten men and women (aged 27.1 ± 2.7 years, body mass of 81.2 kg ± 4.4 kg, and an average height of 176.7 cm ± 2.8 cm) in the Tampa Bay, Florida, area were recruited for this study. No subject had any physical or medical health complications according to past health examinations, and all subjects were non-smokers for inclusion in this study. Participants were required to abstain from consuming any fibre supplements for one month prior to and during the washout period. The subjects completed a 12 h, overnight fast before the morning of the study and were instructed to avoid high-fibre items (> 5 g per serving) for 24 h before the experimental conditions. The IntegReview IRB (Austin, TX) #8100 approved all procedures for the study, which was carried out at the Applied Science and Performance Institute.

Intervention

Randomly-assigned participants consumed a non-calorie water-based PLA, 25 g of IMO syrup (Tate & Lyle, PLC, United Kingdom) or 25 g of SCF syrup (Tate & Lyle, PLC, United Kingdom). Participants consumed both syrups as a liquid formulation by mixing 25 g of syrup with eight ounces of water and stirred until the solution was clear. A one-week washout period existed between experimental conditions. The identity of the conditions that were given to the participants remained unknown to both the participants and the primary researchers for the entire study. These solutions were labelled as A, B or C and given to the researchers working directly with the subjects to maintain a double-blinded method.

Data collection

Subjects' blood and breath hydrogen were taken at baseline and at 30, 60, 90, 120, 150 and 180 min following consumption of their respective solutions. Next, venous blood was collected from the antecubital vein using a 21-gauge needle into a 4 mL EDTA tube (BD Vacutainer®, Becton, Dickinson and Company, Franklin Lakes, NJ) by a certified phlebotomist. Then, blood was prepped and assayed following the 180-min experiment for blood glucose and insulin. Finally, breath hydrogen was gathered in real time using a Gastro+ Gastrolyzer® (coVita LLC, Santa Barbara, CA) according to the manufacturer's instructions.

TABLE 1: Baseline values of dependent variables.

Variable	SCF	IMO	PLA	*p*
Breath hydrogen (ppm)	4 ± 3	4 ± 3	3 ± 3	0.699
Blood glucose (mg/dL)	82 ± 8	83 ± 9	86 ± 9	0.635
Insulin (IU/mL)	3.8 ± 2.3	4.1 ± 2.4	4.0 ± 2.8	0.908

IMO, isomaltooligosaccharides; PLA, placebo; SCF, soluble corn fibre.

Statistical analysis

Before carrying out the parametric statistical analysis, dependent variables were examined for a normal distribution and outliers through investigation of boxplots and a normality test (e.g. Shapiro Wilk). No outliers were detected and data pasted normality testing (Table 1). Repeated measures analysis of variance (ANOVA) were used to scrutinise the effects of supplementation on dependent variables assuming group (SCF, IMO and PLA) and time (0, 30, 60, 90, 120, 150 and 180 min) as fixed factors (GraphPad Prism 7®, La Jolla, CA). Whenever a significant F-value was obtained, a post-hoc test with a Tukey's adjustment was performed for multiple comparison purposes. The significance level was previously set at $p < 0.05$. Results are expressed as mean ± standard error mean.

Results

Of the 10 subjects, nine completed the trial, while one withdrew from the study because of nausea associated with measures taken during baseline testing. Thus, all data are reported based on the final subject pool. A group by time interaction was demonstrated for breath hydrogen response ($p < 0.0001$) and post-hoc analysis revealed that SCF was significantly higher than IMO and PLA at 90, 120, 150 and 180 min (Figure 1a and Table 2). No significant differences occurred throughout the trial between PLA and IMO for breath hydrogen. A group by time interaction was demonstrated for blood glucose response ($p < 0.0001$) and post-hoc analysis revealed that IMO was significantly higher than SCF at 30 min ($p < 0.0001$; Figure 1b and Table 3). There were no significant differences between SCF and PLA throughout the trial for blood glucose. A group by time interaction was noted for insulin ($p < 0.0001$), whereby IMO was significantly higher than SCF and PLA at 30 and 60 min (Figure 1c and Table 4). No significant differences in blood glucose were detected between SCF and PLA throughout the trial. In addition, Figures 2, 3 and 4 represent the individual responses for breath hydrogen, blood glucose and insulin, respectively.

Discussion

The purpose of this study was to investigate the impact of IMO as compared to SCF consumption relative to the PLA on blood glucose, insulin and breath hydrogen responses in healthy men and women. The primary findings of this study

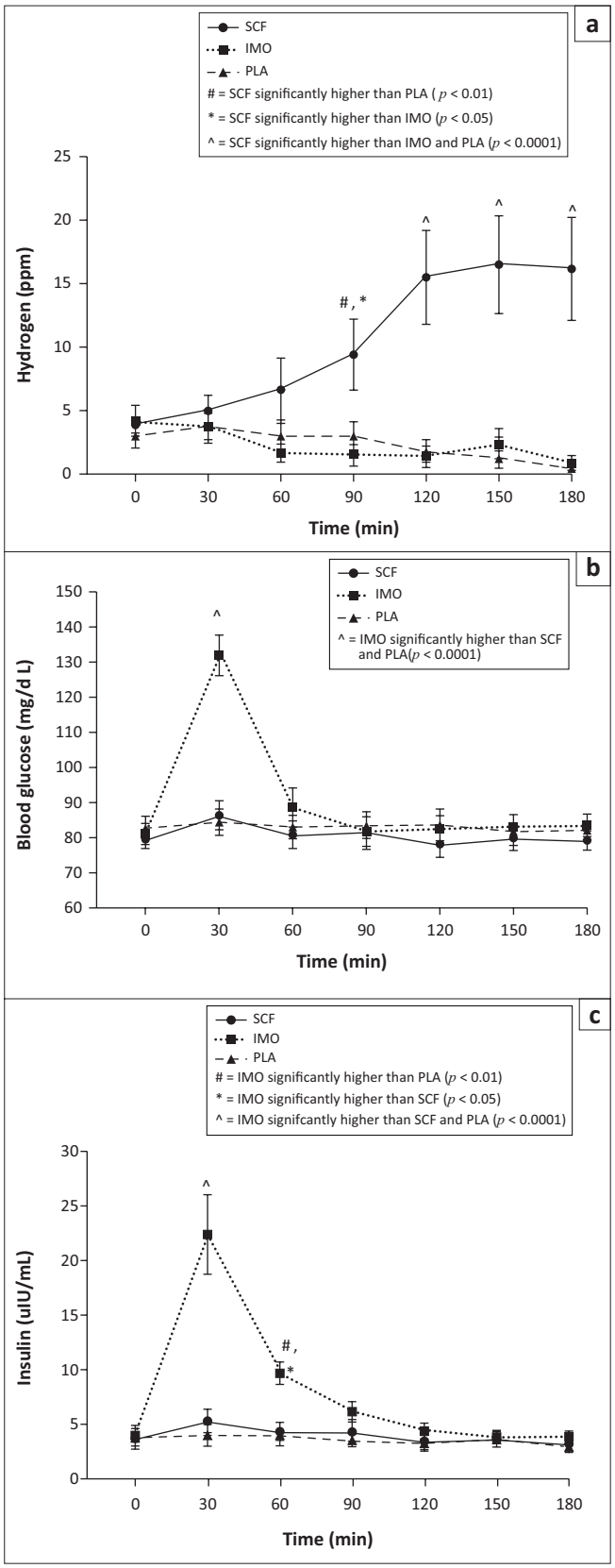

FIGURE 1: (a) Group hydrogen responses, (b) glucose group responses (c) insulin group responses.

were that SCF did not raise either blood glucose or insulin as compared to PLA. However, SCF produced a significant rise in breath hydrogen, indicating that it arrived in the large intestine intact and was fermented by bacteria. In contrast, IMO produced a robust rise in blood glucose and insulin 30 min after meal consumption and did not increase breath hydrogen. Following is a discussion of each of these variables.

TABLE 2: Group breath hydrogen response in parts per million (ppm).

Condition	0 min	30 min	60 min	90 min	120 min	150 min	180 min
SCF	4 ± 1	5 ± 1	7 ± 2	9 ± 3[a,b]	16 ± 4[c]	17 ± 4[c]	16 ± 4[c]
IMO	4 ± 1	4 ± 1	2 ± 1	2 ± 1	1 ± 1	2 ± 1	1 ± 0
PLA	3 ± 1	4 ± 1	3 ± 1	3 ± 1	2 ± 1	1 ± 1	0 ± 0

IMO, isomaltooligosaccharides; PLA, placebo; SCF, soluble corn fibre.
[a] SCF significantly higher than PLA ($p < 0.01$).
[b] SCF significantly higher than IMO ($p < 0.05$).
[c] SCF significantly higher than IMO and PLA ($p < 0.0001$).

TABLE 3: Group blood glucose response in mg/dL.

Condition	0 min	30 min	60 min	90 min	120 min	150 min	180 min
SCF	82 ± 3	89 ± 4	83 ± 4	84 ± 5	81 ± 4	82 ± 4	82 ± 3
IMO	83 ± 3	132 ± 6[a]	91 ± 6	84 ± 4	85 ± 4	85 ± 4	86 ± 3
PLA	86 ± 3	88 ± 4	86 ± 3	87 ± 4	87 ± 4	85 ± 4	85 ± 3

IMO, isomaltooligosaccharides; PLA, placebo; SCF, soluble corn fibre.
[a] IMO significantly higher than SCF and PLA ($p < 0.0001$).

TABLE 4: Group insulin response in µIU/mL.

Condition	0 min	30 min	60 min	90 min	120 min	150 min	180 min
SCF	3.8 ± 0.8	5.4 ± 1.2	4.5 ± 0.9	4.5 ± 0.9	3.5 ± 0.9	3.8 ± 0.8	3.3 ± 0.8
IMO	4.1 ± 0.8	22.0 ± 3.7[a]	9.4 ± 1.1[b,c]	6.0 ± 0.9	4.3 ± 0.8	3.9 ± 0.5	3.9 ± 0.5
PLA	4.0 ± 0.9	4.2 ± 1.0	4.2 ± 1.0	3.7 ± 0.6	3.4 ± 0.7	3.7 ± 0.7	3.0 ± 0.5

IMO, isomaltooligosaccharides; PLA, placebo; SCF, soluble corn fibre.
[a] IMO significantly higher than SCF and PLA ($p < 0.0001$).
[b] IMO significantly higher than PLA ($p < 0.01$).
[c] IMO significantly higher than SCF ($p < 0.05$).

Blood glucose and insulin responses

Regulation of blood glucose is highly sought after in our society. With the resurgence of low-carbohydrate, high-fat, ketogenic diets, it is essential to identify ingredients that do not significantly impact blood glucose or insulin. Our results demonstrated that IMO consumption led to a rise of nearly 50 mg/dL in blood glucose, with a concomitant five-fold rise in insulin at 30 min. However, no change was seen in SCF in either variable. Consequently, these results agreed with that of Kohmoto et al.[4,] who found that IMO were nearly 85% digested. Moreover, Cervantes-Pahm et al.[8] and Kendall et al.[9] found virtually no digestion in SCF, both *in vivo* and *in vitro*.

Fermentation

This study operationalised fermentation through the breath hydrogen technique. Resting levels of breath hydrogen are typically below 10 ppm; however, resting values in our study were approximately 4 ppm in all conditions. Our results demonstrated no change in the IMO condition relative to the PLA. Nevertheless, SCF increased to nearly four-fold to 120 min, and remained as such throughout the experiment. These results agreed with previous research, which demonstrated no change in breath hydrogen over 180 min following IMO consumption.[10] It is important to note that two subjects showed no breath hydrogen response, which had previously been demonstrated to occur in over 15% of

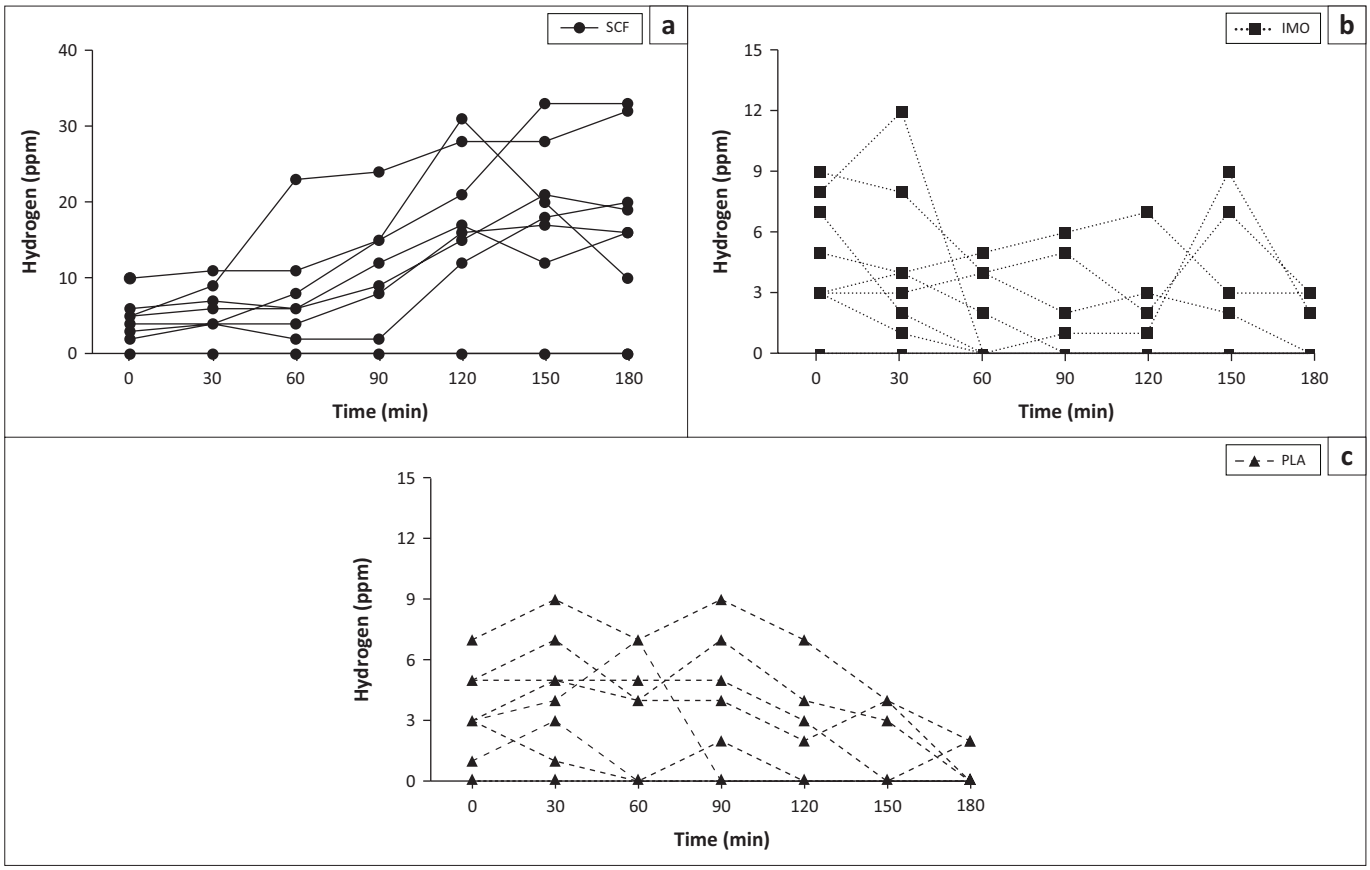

FIGURE 2: Individual breath hydrogen responses to (a) soluble corn fibre, (b) isomaltooligosaccharides and (c) placebo.

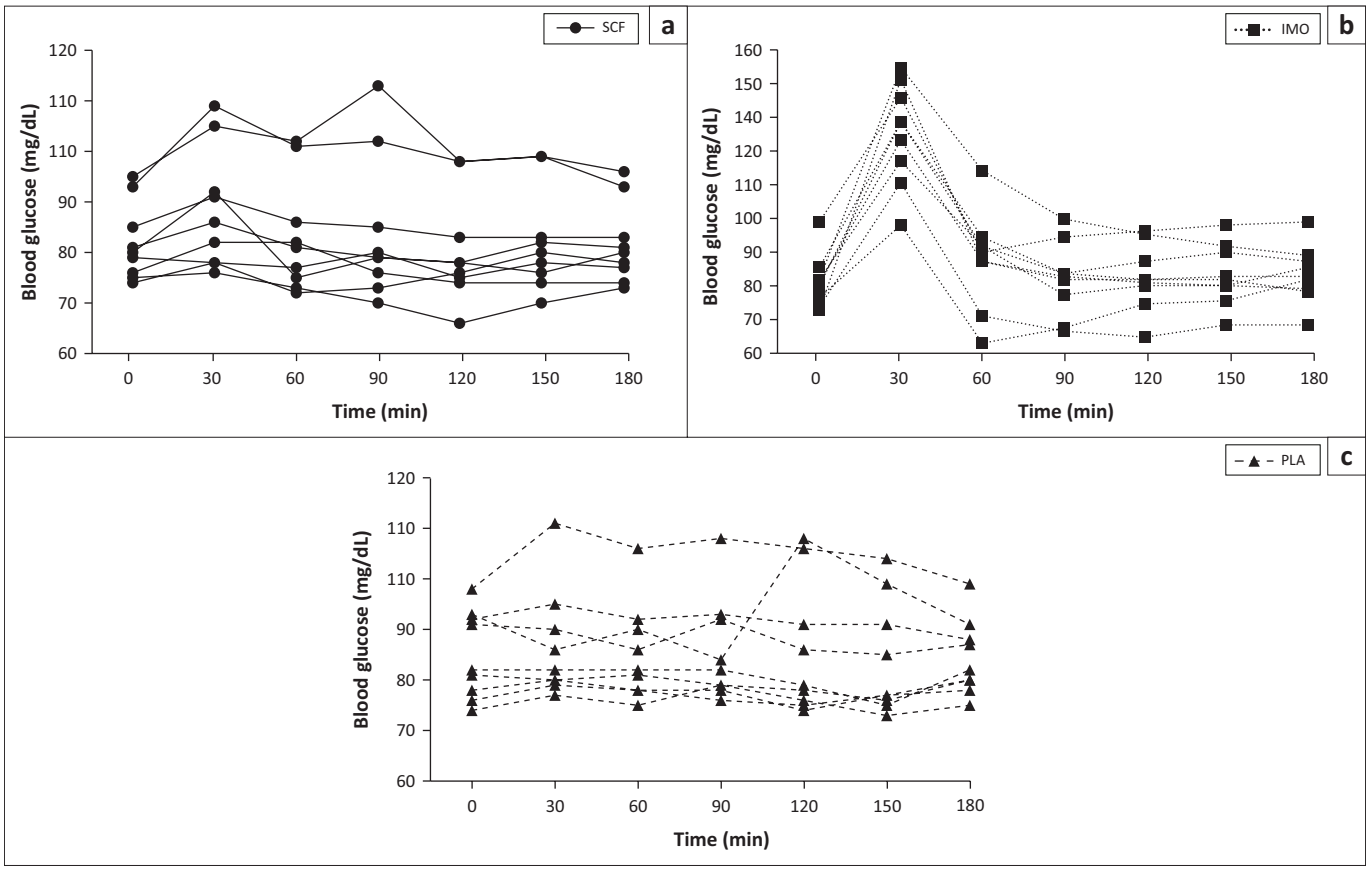

FIGURE 3: Individual blood glucose responses to (a) soluble corn fibre, (b) isomaltooligosaccharides and (c) placebo.

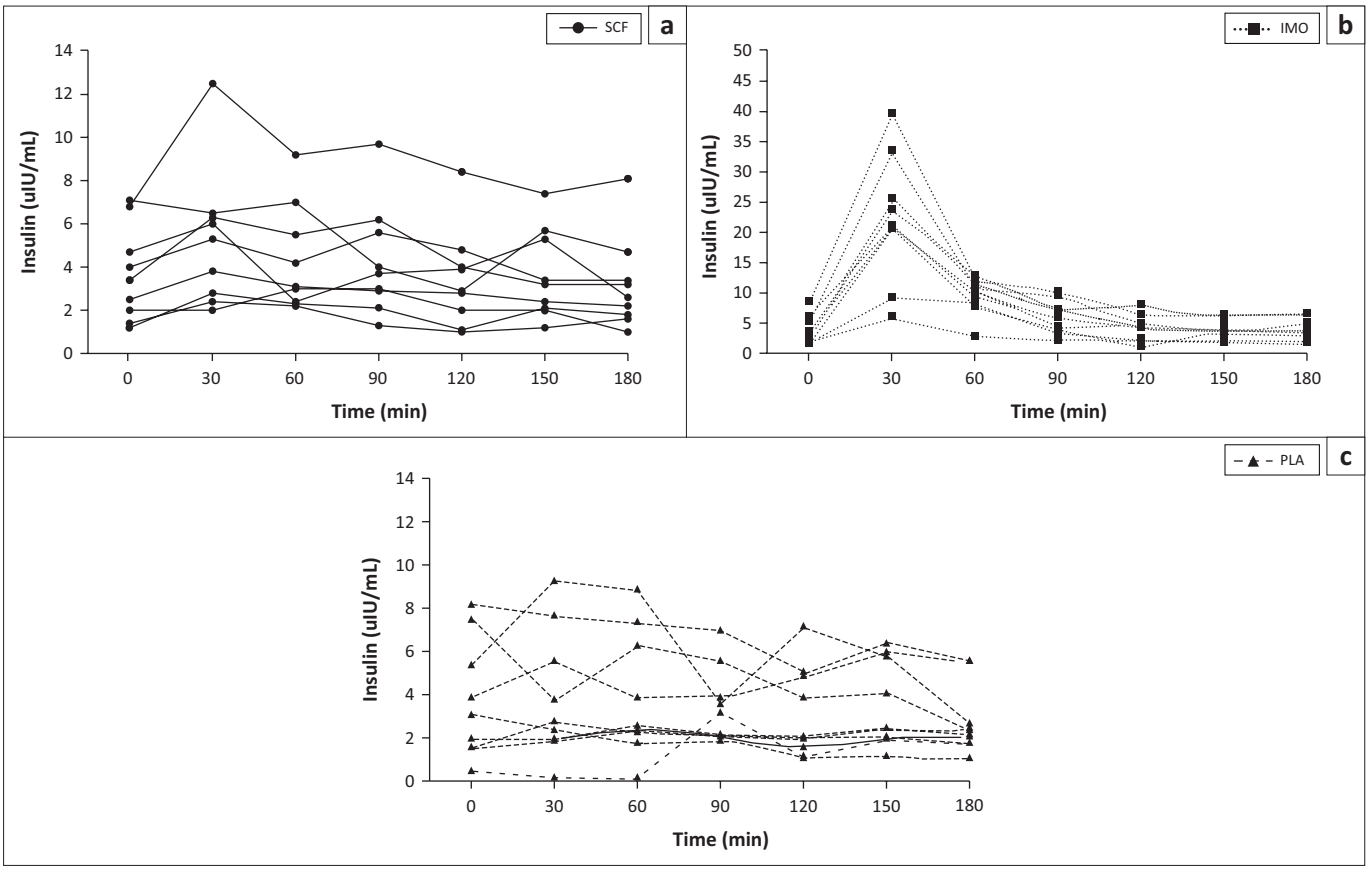

FIGURE 4: Individual insulin responses to (a) soluble corn fibre, (b) isomaltooligosaccharides and (c) placebo.

the population.[11,12] Also, prebiotic activity is indicative of digestibility. Using inulin as a standard, Oku et al.[10] found very little prebiotic activity with IMO. More specifically, IMOs were 14 times less effective than inulin. In contrast, SCF was found to be equal to inulin in prebiotic activity and three to four times more tolerable.[7]

Conclusions

Previous research combined with this study's results collectively indicate that of the two carbohydrate sources examined, SCF – but not IMO – can be listed on food labels as a dietary fibre source. Given its versatility in food preparation, SCF appears to be a viable option for manufacturers to produce high-fibre, palatable food-based products that would support a low-carbohydrate, ketogenic diet.

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Competing interests

The authors declare that they have no financial or personal relationships which may have inappropriately influenced them in writing this article.

Authors' contributions

R.P.L. was the project leader. J.M.W assisted with experimental and project design. A.B., M.H.S., C.I., W.A.L., and M.S assisted with experimental and project design and helped with data collection. G.J.W, M.D.R. and R.W. helped oversee the draft and final version of the manuscript.

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