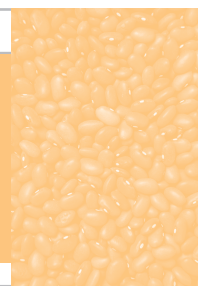


The effect of extrusion processing on the glycaemic index of dry bean products



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Background. Both wheat pasta and dry beans have low glycaemic indices (GIs). However, it has been shown that several factors, including method of processing, may influence the GI of a food. Extrusion of dry beans is a relatively new dry cooking process and provides a convenient alternative to the ingestion of dry beans.

Objective. To determine the GI of pasta and muffins made from extruded dry-bean flour.

Methods. Ten healthy male and 10 healthy female students participated in this study. The subjects resided in the Metabolic Unit of North-West University during the period of testing. Subjects randomly consumed test meals of glucose (reference), bean muffins, whole-wheat muffins and pasta (men only) on different days. The Englyst method was used to determine the 50 g glycaemic carbohydrate portion. Fasting capillary blood samples were taken, the test foods were administered, and further capillary samples were taken at 15, 30, 45, 60, 90 and 120 minutes after the subjects had started to ingest the test meals. The area under the glycaemic response curve for each test and subject was calculated where the GI is based on the area under the blood glucose response curve above the baseline value only.

Results. The GI of the muffin baked with extruded dry-bean flour (mean 53, 95% confidence interval (CI) 42 - 64) was not significantly different from that of the whole-wheat muffin (mean 55, 95% CI 42 - 69). The mean GI of the extruded dry-bean pasta was 83 (95% CI 58 - 108). Both the extruded dry-bean muffins and the whole-wheat muffins fell in the top border of the low-GI category, while the GI of the extruded dry-bean pasta fell within the high-GI category.

Conclusion. Several factors may have contributed to the high GI of the dry-bean pasta. The composition of the pasta and the extrusion process (which seems to alter particle size, antinutrient activity and resistant starch content), are most likely to have influenced the GI of the extruded dry-bean products.

The glycaemic index (GI) refers to the blood glucose raising potential of carbohydrate foods.¹ The GI ranks foods according to their postprandial blood glucose response with respect to an equivalent carbohydrate portion of a reference food.¹ Carbohydrates consumed in isoglycaemic amounts produce different glycaemic responses depending on the nature of the food or food mixtures and the type and extent of food processing. Reducing the rate of carbohydrate absorption by means of a low-GI diet has several health benefits. These include reduced insulin demand, improved blood

glucose control and improved blood lipids, all factors that may play important roles in the prevention or management of several chronic diseases of lifestyle including diabetes, coronary heart disease, obesity and possibly certain cancers (reviewed by Augustin *et al.*²).

Whole and cooked dry beans generally have low GIs (GI < 55) (baked beans 48; butter beans 31; kidney beans 27; haricot beans 38; soy beans 18).³ Factors that may contribute to the low GI of dry beans include high content of soluble fibre, resistant starch (RS), anti-

nutrients and protein, a relatively high amylose/amylopectin ratio, and the fact that the carbohydrates in dry beans are intact and therefore not easily accessible by digestive enzymes.^{4,5} In addition, because of the nutrient composition and specific role of dry beans in health, they have been included in the Food Based Dietary Guidelines for South Africans. The health benefits of dry beans include their hypocholesterolaemic effects, improved metabolic and lipid control in diabetics, their contribution to the health of the large intestine and their possible role in maintaining optimal body weight and as an adjunct to an effective weight loss diet.^{4,5}

Because dry beans have low glycaemic indices it could readily be assumed that the GI of food products made with dry beans as ingredient should also be low. In recent years extrusion cooking has become one of the most popular new processes developed by the food industry.⁶ Extrusion occurs at relatively low moisture and high temperature and shear conditions applied for short periods of time.⁷ Extrusion of dry beans is a relatively new process and provides a convenient alternative to the ingestion of dry beans, which requires a few hours of conventional cooking.⁷ In extrusion cooking raw dry beans are first subjected to a grinding process and moistened to 16 - 18% moisture before entering the extruder, where they are subjected to high pressure and temperature for a short period. The extruded product leaves the extruder as a cooked, relatively dry product.

Breakfast is considered to be the most important meal of the day. Starting the day with a low-GI meal may result in a lower blood glucose and insulin response that may prolong the period of satiety and may enhance mental performance.⁸ However, bread and most conventional breakfast cereals are high-GI foods.³ Muffins are eaten by many South Africans and may be an ideal alternative for breakfast, especially if the GI of the muffins is low.

The first objective of this study was therefore to determine whether muffins baked with extruded dry-bean flour would have a lower GI than muffins baked with wheat flour.

The Dry Bean Producers Organisation in co-operation with the Department of Consumer Science, University of Pretoria, has also recently developed pasta from extruded dry-bean flour. The second objective of this study was (on request of the Dry Bean Producers Organisation) to determine the GI of the pasta made from extruded dry beans.

Methods

Subjects

Twenty healthy volunteers (10 men, 10 women) between 19 and 23 years of age with a body mass index

(BMI) between 20 and 28 kg/m² participated in the study. The exclusion criteria were fasting capillary blood glucose concentrations of ≥ 5.5 mmol/l as well as diabetes mellitus, pregnancy or kidney problems. The study was conducted in the Metabolic Unit of North-West University, Potchefstroom, South Africa.

The Ethics Committee of North-West University has approved nutritional studies on subjects in the lipid clinic/metabolic ward (Ethics No. HHK3M3-92). All subjects gave signed informed consent to participate in the study. The parents of subjects younger than 21 years gave informed consent for their participation.

GI test procedure

All subjects arrived at the Metabolic Unit at 19h00 on the evening prior to the GI testing. Upon arrival they filled out the necessary informed consent and indemnity forms. All rules and procedures regarding their overnight stay were carefully explained to them. After this a standard evening meal was served to standardise the possible effects that the previous meal might have on the GI.⁹ The subjects spent the evening relaxing or watching television and were instructed to be in bed by 23h00. The following morning the subjects were woken up at 06h30 and while lying in bed, their fasting capillary glucose concentrations were determined. The subjects then consumed the test meal within 10 minutes together with 200 ml of water. Exactly 15 minutes from when they started to eat, the capillary glucose concentration was measured a second time. It was measured again at 30, 45, 60, 90 and 120 minutes.

Test meals

The test foods were extruded dry-bean muffins, whole-wheat muffins and extruded dry-bean pasta. Glucose was used as reference food. The test meals consisted of exactly 50 g glycaemic carbohydrate. The test foods were consumed on separate occasions and the order in which the test meals were consumed was randomly determined using the Latin square model. The pasta, however, was consumed on the same day, and because of the volume of pasta that had to be eaten, it was only consumed by the 10 men. The reference food, namely glucose, was taken twice by each subject and the mean was calculated. The test meals, as well as the glucose solution, were consumed together with 200 ml of water. The macronutrient content of the three test meals is summarised in Table I.

The meals were prepared as follows:

Muffins

The muffins were baked in bulk the week before the study using the ingredients listed in Table II and frozen. The muffins contained 25% extruded dry-bean flour. All ingredients were from the same batch to eliminate possible batch variations. The evenings before the GI tests the appropriate number of muffins for the day were taken out of the freezer to thaw and reach

Table I. The macronutrient content of the test meals (g/100 g)*

Nutrient	Extruded dry-bean muffins	Whole-wheat muffins	Extruded dry-bean pasta
Carbohydrate [†]	47.8	49.8	20.9
Fat*	10.9	11.6	8.2
Protein*	11.1	7.9	11.9
Fibre*	2.7	1.9	1.4
Moisture*	27.9	28.7	55.4

*Determined by the laboratory of Senwesko Feeds, Viljoenskroon, South Africa.
[†]Determined by Englyst Carbohydrates Research and Services Ltd, Southampton, UK.

shown in Table III. The pasta contained 12% dry-bean mixture (11% dry beans + 1% soy), 39% other starches (tapioca, potato, corn and modified starch), and protein, fat, water and salt.

The pasta was cooked on the morning of the test according to standardised instructions and served within 15 minutes.

Determination of glycaemic carbohydrate

For determination of the GI exactly 50 g of glycaemic carbohydrate must be consumed. Glycaemic carbohydrate is defined as the carbohydrate available for metabolism from the small intestine.¹⁰ In practice, glycaemic carbohydrate is often determined as the total carbohydrate minus dietary fibre. In this study the carbohydrate composition of the test foods was very accurately determined with the Englyst method¹¹ by Englyst Carbohydrates Research and Services Ltd, Southampton, UK. According to the literature dry beans have a high RS content (11.1 ± 1.2% for white beans)¹² and the inclusion or exclusion thereof may therefore have a large impact on the GI value. The amount of cooked test foods needed to supply 50 g glycaemic carbohydrate was calculated as 104 g extruded dry-bean muffins, 100 g whole-wheat muffins and 238 g extruded dry-bean pasta. The test foods were prepared in exactly the same way for the carbohydrate analysis as for the GI tests.

Table II. Ingredients of muffins

Amount	Ingredient
200 ml	Extruded dry-bean flour/nutty wheat
10 ml	Baking powder
2 ml	Salt
50 ml	Sugar
50 ml	Cake flour
125 g	Pitted raisins
2	Over-ripe bananas, mashed (200 g)
60 ml	Oil (sunflower oil)
2	Eggs
10 ml	Vanilla flavouring
60 ml	Water

Table III. Ingredients of extruded dry-bean pasta (685 g, uncooked)

Amount	Ingredients
80 g	Extruded dry-bean flour mixture (90/10 dry beans/soy mixture)
100 g	Tapioca starch
50 g	Potato starch
100 g	Corn starch
15 g	Modified starch
5 g	Gelatin
2.5 ml	Salt
200 g	Large eggs
15 ml	Sunflower oil
120 ml	Water

ambient temperature. The muffins were not reheated before consumption. The same recipe and procedures were followed for the extruded dry-bean and whole-wheat flour muffins. The extruded dry-bean flour was simply replaced with nutty wheat for the whole-wheat muffins.

Extruded dry-bean pasta

The pasta was prepared in bulk by the Department of Consumer Science, University of Pretoria, using the same batches of ingredients to eliminate possible batch variations. The pasta consisted of the ingredients

Capillary whole-blood glucose determination

Three experienced researchers were trained and standardised in measuring capillary whole-blood glucose using a lancet, glucose test strips (Lifescan, Surestep) and glucometers (Lifescan, Surestep). This procedure was done in strict compliance with the protocol recommended by the manufacturer as well as good laboratory practice. The glucometers were calibrated before each test day and the same glucometer was used for the same subject for the duration of the test.

Statistics

The computer software package Statistica® was used for the statistical analysis. The incremental area under the curve (IAUC) and GI values as well as the statistical analysis of the data were done by the Statistical Consultation Service, North-West University, Potchefstroom. The data are expressed as means, standard deviations (SDs) and 95% confidence intervals (CIs). Differences between dry-bean and whole-wheat muffins were determined by using the *t*-test for dependent samples.

Results

The characteristics of the subjects ($N = 20$) are summarised in Table IV.

The main findings of the study are summarised in Table V. The GI of the muffin baked with extruded dry-bean flour (mean 53, 95% confidence interval (CI) 42 - 64) was not significantly different from that of the whole-wheat muffin (mean 55, 95% CI 42 - 69). The mean GI of the bean pasta was 83 (95% CI 58 - 108). This is about twice the GI reported for white spaghetti made from wheat (42 - 44).³

The GI can be categorised as follows (using glucose as reference):¹³ low GI – below 55; intermediate GI – between 55 and 70; high GI – more than 70.

Both the extruded dry-bean and whole-wheat muffins fell in the top border of the low-GI category. The mean GI of the extruded dry-bean pasta fell within the high category for GI.

It is well known that glycaemic responses vary substantially within as well as between subjects. Because of this variability it may be more useful to

Table IV. Mean characteristics of subjects

Variable	Total group	Men	Women
Age			
Mean	20.7	20.8	20.5
SD	0.9	1.0	0.7
BMI			
Mean	23.4	24.6	22.1
SD	2.8	2.9	2.08

SD = standard deviation; BMI = body mass index.

Table V. The GIs of the test foods

	Extruded dry-bean muffins	Whole-wheat muffins	Extruded dry-bean pasta
Total group			
N	20	20	-
Mean GI (%)	53	55	-
95% CI	42 - 64	42 - 69	-
SD	24	29	-
Men			
N	10	10	10
Mean GI (%)	52	57	83
95% CI	36 - 69	39 - 76	58 - 108
SD	23	25	35
Women			
N	10	10	-
Mean GI (%)	54	54	-
95% CI	35 - 72	29 - 78	-
SD	26	34	-

GI = glycaemic index; CI = confidence interval; SD = standard deviation. The 95% CI is the range of values between which it can be assumed with 95% certainty that the true mean GI of a particular GI lies.

assign a range within which the GI of a food product may vary rather than to assign a single number (a mean) to a product. The 95% CI may be used for this range. Looking at the 95% CI in Table V, it can be said with 95% confidence that the true mean GI for extruded dry-bean muffins lies between 42% and 64% (low to intermediate category), for whole-wheat muffins between 42% and 69% (low to intermediate category), and for extruded dry-bean pasta between 58% and 108% (intermediate to high category).

Discussion

The main findings of this study were that extruded dry-bean muffins and whole-wheat muffins had comparable GIs, falling within the low to intermediate categories, and that extruded dry-bean pasta had a GI that fell within the intermediate to high category.

During food processing, physico-chemical treatments may have a profound impact on the profile of digestibility and consequently the GI of the food product.⁸ The high GI of the pasta and the unexpected finding that extruded dry-bean muffins did not have a lower GI than the whole-wheat muffins may be ascribed to the extrusion of the dry beans. Extrusion cooking involves transformation of starch and protein into restructured and texturised convenience foods. Shearing, coupled with high temperatures and low water content, causes some of the large starch molecules to be dextrinised, broken into shorter chains exhibiting greater solubility in water.⁷

Firstly, extrusion cooking affects particle size,¹⁴ whereby disruption of cell wall components takes place.¹⁵ This effect renders a higher glycaemic response as seen in this study, consistent with numerous studies by Järvi *et al.*¹⁶ with ground red kidney beans, Jenkins *et al.*¹⁷ with milled flour breads made from whole grains, Liljeberg *et al.*¹⁸ with breads baked with whole-meal barley flour and white wheat bread, and Behall *et al.*¹⁹ and Holt and Brand Miller²⁰ with breads baked with varying grades of wheat which all exhibited higher glycaemic responses due to the reduced particle size.

Secondly, extrusion leads to partial gelatinisation of the starch,^{7,14} causing high glycaemic and insulinaemic responses^{21,22} which are consistent with the results of this study.

Thirdly, the less digestible fraction of legume starch is in the soluble whey, which probably includes anti-

nutrients such as phytic acid, tannins and lectins that are present in the highest concentrations in this fraction.²³ Extrusion cooking has dramatic results on the above factors, as most of the so-called anti-nutrients are destroyed and trypsin inhibitors in particular are reduced to negligible levels.²⁴ This has been reflected in the results of this study.

Finally, extrusion cooking may have a marked effect on the solubility of fibre and the amount of RS.^{14,15,25} Dehulling of legumes causes changes in the total content and composition of fibre, as the teguments are richer in cellulose, hemicellulose and lignin (so-called insoluble fibre), while the cotyledons are richer in pectic polysaccharides (so-called soluble fibre).¹⁴ Lintas *et al.*²⁶ have shown that the total dietary fibre content in raw and extruded dry beans was approximately the same, but a redistribution from an insoluble to a more soluble fibre fraction was observed with extrusion. Thermal treatment and shear force action of the extrusion process seems to have the greatest effect on the pectins. The increase in soluble fibre seems to be caused by the partial solubilisation of insoluble pectic substances, although moderate changes also occur in the hemicellulose fractions.^{14,26} It is not known what changes took place in the bean flour, since neither soluble nor insoluble fibre fractions were measured, but the rapidly available glucose (RAG) fractions, which were 26.6%, 30.1% and 19.6% in the bean muffin, whole-wheat muffin and bean pasta respectively, confirmed the hypothesis of Englyst *et al.*¹¹ that the RAG fraction is an important food determinant of the glycaemic response. It also supports the findings of Lintas and Cappelloni²⁵ that the RAG increased up to 89% during extrusion processing. The slowly available glucose (SAG) fractions for the bean muffin, whole-wheat muffin and bean pasta in this study were 1.8%, 1.5% and 0.5% respectively, which is minimal.

The RS fraction was also present in minimal quantities (1.6% for the bean muffin, 0.8% for the whole-wheat muffin and 0.8% for the bean pasta). Recently Wolever¹⁰ recommended that RS should be excluded from the portion size. In practice, however, this is difficult because the analytical method for the determination of RS is not widely available and the RS content of most foods is therefore unknown. According to Elmstahl,¹² intact dry beans have a high RS content (11.1% for white beans) and the inclusion thereof, as has been the case in the past, may have a large impact on the GI value, underestimating the GI of dried beans substantially.

It is not clear which factors dominated in having had the most dramatic effect in increasing the glycaemic response of the bean muffins. In spite of the altered physico-chemical and structural changes brought about by the extrusion process, the GI of the bean muffin (53) is still categorised as a low-GI food, whereas the whole-wheat muffin (GI of 55) falls into the lower end of the

intermediate category. Both the bean and whole-wheat muffins consisted of exactly the same ingredients, apart from the two different flours.

The addition of protein and fat would also not elicit a lower glycaemic response as the latter ingredients constituted only 11.1 g, 7.9 g and 11.9 g protein as well as 10.9 g, 11.6 g and 8.2 g fat for the bean muffin, whole-wheat muffin and bean pasta, respectively. According to the studies of Nuttall *et al.*²⁷ and Wolever,²⁸ 30 - 50 g of protein and 22 g of fat are the amounts that lead to reduction in glucose response after 50 g carbohydrate load.

Both the bean and the whole-wheat muffins had high fructose content (37% and 35%, respectively). It is likely that the high fructose content could have contributed to the relatively low GI values observed with the muffins.¹

The high GI of the extruded dry-bean pasta may be explained further by the high content of other starches in the pasta. The pasta only contained 12% of the extruded dry-bean flour and 39% of other starches (tapioca, potato, corn and modified starches). Dry beans contain a relatively high amylose/amylopectin ratio that is associated with a low GI. The linear shape of amylose is more resistant to digestion than the open, branched structure of amylopectin.²⁹ In contrast to dry-bean starch, other starches in the dry-bean pasta had high amylopectin contents and could therefore have contributed to the product's high GI.³⁰ Furthermore, the high GI value of the dry-bean pasta correlated well with the very low SAG value of 0.5%. Most wheat pastas have high SAG and low GI values because in wheat pasta the food matrix is held together by the wheat gluten, which results in a slow physical dispersion and digestion of the starch.³¹ The tapioca and potato starch in the dry-bean pasta does not contain gluten to bind the pasta together, which probably explains the low SAG and high GI values.

Although the GI of the extruded dry-bean muffins did not differ from the whole-wheat muffins the GI fell within the low to intermediate category. These muffins are excellent choices for breakfast. The bean muffins offer an alternative to baked beans on toast and together with the bean pasta increase the amount of ways to include dry beans in the prudent diet. Although this particular dry-bean pasta has a much higher GI than canned baked beans, cooked dry beans and wheat pasta, it can still be recommended as part of a healthy diet. Oosthuizen *et al.*³¹ reported decreased plasminogen activator inhibitor-1 (PAI-1) levels in hyperlipidaemic men who included 110 g/d of extruded dry beans in the form of baked goods in their normal diet for 4 weeks compared to a control period. Increased levels of PAI-1 are associated with increased risk for coronary heart disease.³² Even though extruded dry beans did not have hypocholesterolaemic effects,³¹

dry beans form an important part of the hypocholesterolaemic diet, because they are a rich and economical source of plant protein, soluble and insoluble dietary fibre components and a variety of minerals, vitamins and isoflavones and are low in energy and fat content.^{4,5} Furthermore, extruded dry-bean flour may be used for patients with coeliac disease or wheat allergy. The prevalence of coeliac disease among type 1 diabetics in the UK varies between 1 in 20 and 1 in 50.³³ The range of extruded dry-bean baked products in the study of Oosthuizen *et al.*³¹ included corn savoury bread, chocolate cake, banana bread and raisin muffins. It can be extended further to include other types of bread, pizza bases, biscuits and rusks (a traditional item in the Afrikaner diet).

Björck *et al.*³⁴ recently stated that 'to fully exploit the metabolic potential of a low-GI diet, a wider range of low-GI foods are necessary'. The shortage of low-GI alternatives is particularly pronounced among bread and breakfast cereals. The technological means exist to provide such foods, and the development of low-GI foods is a challenge for the food industry. Furthermore, the GI should be tested and if it is found to be intermediate or high, additions such as beta-glucan³⁵ can be made to lower the GI. It is also necessary that the sensory acceptability of these products should be evaluated.

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