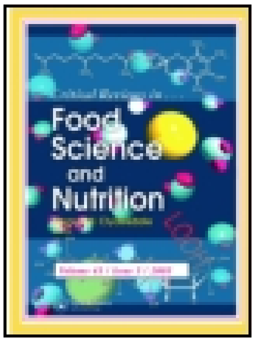

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REVIEW

Glycemic index of pulses and pulse-based products: a review

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ABSTRACT
Pulses are a major source for plant-based proteins, with over 173 countries producing and exporting over 50 million tons annually. Pulses provide many of the essential nutrients and vitamins for a balanced and healthy diet, hence are health beneficial. Pulses have been known to lower glycemic index (GI), as they elicit lower post prandial glycemic responses, and can prevent insulin resistance, Type 2 diabetes and associated complications. This study reviews the GI values (determined by *in vivo* methodology) reported in 48 articles during the year 1992–2018 for various pulse type preparations consumed by humans. The GI ranges (glucose and bread as a reference respectively) for each pulse type were: broad bean (40 ± 5 to 94 ± 4, 75 to 93), chickpea (5 ± 1 to 45 ± 1, 14 ± 3 to 96 ± 21), common bean (9 ± 1 to 75 ± 8, 18 ± 2 to 99 ± 11), cowpea (6 ± 1 to 56 ± 0.2, 38 ± 19 to 66 ± 7), lentil (10 ± 3 to 66 ± 6, 37 to 87 ± 6), mung bean (11 ± 2 to 90 ± 9, 28 ± 1 to 44 ± 6), peas (9 ± 2 to 57 ± 2, 45 ± 8 to 93 ± 9), pigeon peas (7 ± 1 to 54 ± 1, 31 ± 4), and mixed pulses (35 ± 5 to 66 ± 23, 69 ± 42 to 98 ± 29). It was found that the method of preparation, processing and heat applications tended to affect the GI of pulses. In addition, removal of the hull, blending, grinding, milling and pureeing, reduced particle size, contributed to an increased surface area and exposure of starch granules to the amylolytic enzymes. This was subsequently associated with rapid digestion and absorption of pulse carbohydrates, resulting in a higher GI. High or increased heat applications to pulses were associated with extensive starch gelatinization, also leading to a higher GI. The type of reference food used (glucose or white bread) and the other nutrients present in the meal also affected the GI.

KEYWORDS
Pulses; processed pulses; glycemic index

Introduction

Pulses

Pulses are defined as "annual leguminous crops", in the legume family, that exist within a pod, used for feed and food (FAO 2017). The average worldwide annual production of pulses is estimated at 55 million metric tons as of 2017 (Statista 2019). There are over 173 countries that produce and export pulses, with India, Canada, China, Myanmar, and Nigeria among the world's top producers (Pulses 2020). The Food and Agriculture Organization (FAO) of the United Nations classifies pulses into 16 categories: adzuki bean, bambara groundnut, broad bean, chickpea, common bean, cowpea, hyacinth bean, lentil, lima bean, lupine, mung bean, mungo bean, peas, pigeon peas, moth bean and rice bean (FAO 2017). Table 1 explains these pulse classifications, including their scientific and common names.

Pulses promote health as they are high in dietary fiber, protein and slow release carbohydrates, which plays a role in reducing insulin resistance (Fujiwara, Hall, and Jenkins 2017; Hettiaratchi et al. 2011). Furthermore, nutrients including protein, fiber and fat, are believed to aid in weight management, delay gastric emptying, lead to reduced hunger, and a sense of fullness, and satiety (Schneeman 2002). Consumption of pulses have also been linked to the reduction of myocardial infarction rates and prevention of cardiovascular disease (Anderson and Major 2002; Kabagambe et al. 2005). Currently, there is an increased demand for plant-based proteins. They are often preferred due to their low impact on the environment, animal welfare, and for religious, cultural and or health reasons.

Glycemic index (GI)

The concept of GI was first introduced by Jenkins et al. (1981) and is used to rank carbohydrate foods depending on how the blood's postprandial blood glucose level is affected. The main factors that affects GI are the digestion and absorption rate of a food's carbohydrates (Goñi and Valentín-Gamazo 2003). GI is calculated from the incremental area under the blood glucose response curve (iAUC), after the consumption of a test food, divided by the iAUC of a reference food (glucose or white bread) of equivalent carbohydrate content (Dodd et al. 2011). A low GI is 55 or less, medium GI is 56–69, while a high GI is 70 or more (Diabetes Canada 2013).

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Table 1. Pulse categories and classifications (FAO 2017).

Pulse Category	Scientific Name	Common Names
Adzuki Bean	*Vigna angularis (Willd.) Ohwi & H. Ohashi*	Adanka bean, azuki bean, Chinese red bean, red gram[a]
Bambara Groundnut	*Vigna subterranea (L.) Verdc.*	Bambara beans, jugo beans, Bambara nut[b]
Broad Bean	*Vicia faba L.*	Faba bean, fava bean
Chickpea	*Cicer arietinum L.*	Bengal gram
Common Bean	*Phaseolus vulgaris L.*	Kidney beans, navy beans, black bean, pinto bean, black eye, cranberry
Cowpeas	*Vigna unguiculate (L.) Walp.*	Southern peas, crowder peas, black eye peas[c]
Hyacinth Bean	*Lablab purpureus (L.) Sweet*	Egyptian bean, field bean, Indian bean, tonga bean, wild bean, sweet pulse.[d]
Lentil	*Lens culinaris Medik*	Black lentils, brown lentils (sabut masoor), green lentils, red lentils (masoor dal).[e]
Lima Bean	*Phaseolus lunatus L.*	Butter bean, Burma bean, java bean, sugar bean.[f]
Lupines	*Lupinus spp.*	Lupin, bitter white lupin, broad-leaved lupin, termis seeds, while lupines.[g]
Mung Bean	*Vigna radiata (L.) R. Wilczek*	Green gram, golden gram, Chinese mung bean.[h]
Mungo Bean	*Vigna mungo (L.) Hepper*	Black gram, urd bean, black mung bean, black matpe.[i]
Peas	*Pisum sativum L.*	Garden pea, field pea, green pea, common pea, English pea.[j]
Pigeon Peas	*Cajanus capan (L.) Huth*	Red gram, yellow dhal, no eye pea, angola pea.[k]
Moth Bean	*Vigna aconitifolia (Jacq.) Maréchal*	Mat bean, Turkish gram, papillon.[l]
Rice Bean	*Vigna umbellata (Thunb.) Ohwi & H. Ohashi*	Climbing mountain bean, mambi bean, oriental bean.[m]

[a](Adzuki beans facts and health benefits 2017).
[b](BamNetwork 2018).
[c](SARE 2018).
[d](Hyacinth beans- Lablab purpureus 2017).
[e](A visual guide to pulses 2019).
[f](“Lima beans facts and health benefits 2017).
[g](Health benefits of lupin beans 2017).
[h](Mung bean facts and health benefits 2017).
[i](Organic black gram seeds (Vigna Mungo)) 2019).
[j](Pavek 2012).
[k](Pigeon peas facts and health benefits 2017).
[l](Facts and benefits of moth bean 2017).
[m](Heuzé and Tran 2016).

The incorporation of low GI foods in diets, may reduce insulin resistance, and hyperglycemia between meals (Hettiaratchi et al. 2011). The Canadian Diabetes Association (CDA) and the American Diabetes Association (ADA) recommend low GI food consumption as a means to control and manage diabetes (Augustin et al. 2015). Lower GI has a number of effects on the body’s metabolism and physiological functions including: the reduction of insulinemic and glycemic responses to food, and the protection against colon cancer (Björck, Liljeberg, and Östman 2000; Cassidy, Bingham, and Cummings 1994).

Objective

This paper aims to review the glycemic index (GI) of various pulse categories in human subjects (*in vivo* studies), and the effect of processing, cooking, and reference methods on the GI of pulses.

This review is important as it looks at the glycemic properties of each kind of pulse preparation determined by *in vivo* methods; which would be helpful in meal planning to achieve favorable post meal glycemic responses.

Search criteria

Electronic databases: Google Scholar, Scholars Portal, PRIMO, and MEDLINE, were searched with no date limitations. Literature and journal articles were retrieved from searches specific to each pulse categories, including their common names and scientific name related to “glycemic index,” “glycaemic index,” “*in vivo*,” “beans” and “legumes.” Articles were identified as relevant based on whether they were (1) Original Articles, (2) tests performed in vivo and, (3) studies on human subjects, after the consumption of pulses, or pulse-based meals. Only articles that (4) specifically addressed and indicated GI scores were included in the final analysis. In the end, 48 articles, comprising of 154 entries, were found relevant to this review.

Inclusion and exclusion criteria

Pulse type and groups

The following 16 categories were reviewed for their GI: adzuki bean, bambara groundnut, broad bean, chickpea, common bean, cowpea, hyacinth bean, lentil, lima bean, lupine, mung bean, mungo bean, peas, pigeon peas, moth bean and rice bean (FAO 2017) as per Table 1. Using the FAO categorizations, pulses and pulse-based meals were grouped into 10 categories: broad bean, chickpea, common bean, cowpea, lentil, mung bean, peas, pigeon peas, mixed bean and other pulses (Bambara groundnut, lima bean, lupine, and mungo bean). The “mixed bean” category was used for meals that included and incorporated multiple pulses, while the “other pulses” category included pulses which were only mentioned in a few reports (1 or 2 entries). There were no *in vivo* studies, found in the existing literature for: adzuki bean, hyacinth bean, moth bean and rice bean. The nutrient content, as it relates to protein, fat, total dietary fiber and carbohydrate, of each pulse type was retrieved from the U.S. Department of Agriculture (USDA) Nutrient Database and outlined in Table 2.

In vivo or in vitro

Traditionally GI has been measured *in vivo*, however, these tests are thought to be time consuming (Brand-Miller and Holt 2004). As such, *in vitro* enzymatic assays have been

Table 2. Nutrient content of pulses (raw- boiled without salt) (g/100 g) USDA 2019.

Pulse Category	Protein	Fat	Total Dietary Fiber	Carbohydrate, by difference
Adzuki Bean	19.87	0.53	12.7	62.9
Bambara Groundnut	–	–	–	–
Broad Bean	26.12	1.53	25	58.29
Chickpea	20.47	6.04	12.2	62.95
Common Bean *(Kidney Bean)*	23.58	0.83	24.9	60.01
Cowpeas	23.52	1.26	10.6	60.03
Hyacinth Bean	23.90	1.69	25.6	60.74
Lentil	24.63	1.06	10.7	63.35
Lima Bean	21.46	0.69	19	63.38
Lupines	36.17	9.74	18.9	40.37
Mung Bean	23.86	1.15	16.3	62.62
Mungo Bean	25.21	1.64	18.3	58.99
Peas	23.12	3.89	22.2	61.63
Pigeon Peas	21.70	1.49	15	62.78
Moth Bean	–	–	–	–
Rice Bean	–	–	–	–

(USDA 2019).

researched as possible mechanisms to model carbohydrate digestion and glucose absorption (Brand-Miller and Holt 2004). *In vitro* tests allow researchers to control various aspects of the study, that cannot be controlled *in vivo* (Bornhorst and Singh 2014). It is for this reason that many researchers prefer the *in vitro* method over the *in vivo* one. However, Brand-Miller and Holt (2004) advise against using in vitro GI values as a measurement of GI for food labeling due to the inconsistent associations between *in vitro* and *in vivo* results. Various factors affect gastric emptying including: meal nutrition, and gastric motility (Bornhorst and Singh 2014) which cannot be predicted *in vitro*. As GI, by definition, is the glycemic response measurement *in vivo* (Brand-Miller and Holt 2004), this study only examined these studies.

Blood sampling type

Capillary and/or venous blood samples are used to test the GI of foods *in vivo*. The current recommendations indicate that, while venous blood samples are adequate to determine GI, capillary blood is preferred (FAO, 1998). The studies by Wolever et al. (2003) and Hätönen et al. (2006) found a difference in the blood glucose levels obtained from capillary and venous blood. These studies found that venous blood tended to have a wider variance within-subjects compared to capillary blood (Hätönen et al. 2006; Wolever et al. 2003) and impacted the GI of the test foods, which tended to be smaller when capillary blood was used (Hätönen et al. 2006). Therefore, this review looks at studies that included both capillary and/or venous blood.

Reference food

Bread and glucose are known to be the best reference foods for testing GI (Hätönen et al. 2006). The FAO (1998) also recommends using either white bread or glucose as a standard reference food, but it is known that white bread has approximately 1.4 times glucose. However, white bread may also provide inconsistent GI results due to its intra-individual and inter-individual variability (Vega-López et al. 2007). To be inclusive, this review looks at studies that used both bread and glucose as the standard or reference foods.

Subject characteristics

When intra-individual variability of GI was tested based on age, sex, BMI (obesity) and ethnicity, there were no significant variances seen (Mooy et al. 1996; Wolever et al. 2003). As such, the subject's characteristics are not expected to have a significant impact on GI values. However, GIs are expected to be higher for diabetic individuals as glycemic response may be affected by the degree of insulin resistance and the glucose absorption time (Hettiaratchi et al. 2011). Therefore, subject characteristics as it relates to, age, sex, BMI (obesity) and ethnicity, were not examined. Instead, subjects were grouped as being healthy or having diabetes.

Results and discussion

Glycemic indices of pulses by category

Broad beans

Broad beans, also known as faba beans, fava beans and bell beans are a good source of vitamins and minerals. The global production for dry broad beans was 6.72 million tons in 2018 (FAOSTAT 2019) and its global consumption is expected to rise (Hexa Research 2019). The GI range of broad bean and broad bean meals, with glucose as a reference, was 40.0 ± 4.5 to 94.0 ± 4.0. The lowest GI of broad bean, 40.0 ± 4.5, was seen in the study by (Turco et al. 2016) where 13 healthy adults consumed a broad bean pasta. Compared to other broad bean meals listed in Table 3, the total dietary fiber of the broad bean pasta meal, was highest. When broad beans were consumed by participants with non-insulin dependent diabetes (NIDDM), it was found that the meal did not significantly lower GI, compared to white bread consumption (Darabi et al. 2000). In fact, the highest GI of broad beans, 94.0 ± 4.0, was seen in the Darabi et al. (2000) study, where 10 NIDD subjects consumed boiled broad beans. This suggests that broad beans may not be effective in reducing the glycemic response in diabetic subjects. Darabi et al. (2000) stated that this observation may be due to the high calcium content of the kernels, which are thought to increase amylase activity, and thus the digestion.

Furthermore, there was a difference in the GI of broad beans cooked at high and low temperatures. In the study by

Table 3. GI of broad beans and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat (g)	Nutrient info- protein (g)	Nutrient info- Total Dietary fiber (g)	Study participants type and number	Reference food used, duration of study	Reference Food available carbohydrate (g)	Type of blood sample (venous/capillary)	GI (Glucose =100)	GI (Bread = 100)	
Broad Bean, cooked	Broad Bean, water, salt	2% salt solution was added, beans were peeled and boiled for 1 hour	197	25	0.6	22.9	1.3	Non insulin dependent diabetes mellitus (NIDDM), 10	Glucose, 2 hours	25	Venous blood	94 ± 4	–	Darabi et al. (2000)
Pasta, cooked at low temperature	35% faba bean flour	Boiled, 10.5 min	195	50	0.6/100	6.1/100	4.6/100	Healthy adults, 15	Glucose solution, 3 hours	50	Capillary blood	41.9 ± 5.7	–	Greffeuille et al. (2015)
Pasta, cooked at high temperature	35% faba bean flour	Boiled, 13.5 min	206	50	0.5/100	6.3/100	4.8/100	Healthy adults, 15	Glucose solution, 3 hours	50	Capillary blood	49.4 ± 6.8	–	Greffeuille et al. (2015)
Broad Bean, cooked	Broad Bean, water, salt	Cooked, 3 hours	248	50	1.04	25.9	0.96	Healthy men, 21	Glucose, 2 hours (converted to bread Glu x 1.41)	50	Capillary Blood	66	93	Thannoun, (2005)
Whole broad Bean, cooked	Whole broad Bean, water, salt	Cooked, 3 hours	267	50	1.43	25.5	6.41	Healthy men, 21	Glucose, 2 hours (converted to bread Glu x 1.41)	50	Capillary Blood	53	75	Thannoun, (2005)
Faba bean flour, pasta	35% Faba bean flour, egg, wheat	Dried at 60 degrees C, 14 hours	100	70.1 ± 1.2	3.4 ± 0.1	16.1 ± 0.3	6.8 ± 0.4	Healthy adults, 13	Glucose, 2 hours	50	Capillary Blood	40 ± 4.5	–	Turco et al. (2016)

(Greffeuille et al. 2015), pasta consisting of 35% broad bean flour, had a lower GI when cooked at a low temperature (55 °C), compared to a higher temperature (90 °C). The GI of broad bean pasta cooked at a low temperature was 41.9 ± 5.7, while that of the high temperature pasta was 49.4 ± 6.8. Enriching pasta with broad beans increased the lysine content, however, high temperatures resulted in a lysine loss (Greffeuille et al. 2015). Lysine-deficient diets have been associated with weight gain due to improved digestion (Ravindran et al. 2001) as satiety may be decreased. As digestion rate increases, the GI is also expected to increase. A study by Thannoun (2005) showed that broad bean kernels had a higher GI than whole broad beans with GIs of 66.0 and 53.0, respectively. This may be a result of the removal of the hull, which increased rate of digestion (Thannoun 2005), by increasing the availability of the meal to digestive enzymes.

Chickpea

Chickpea is a good source of protein and fiber, making it one of the most popular legume choices for vegans and vegetarians. In 2018, it was estimated that 17.21 million metric tons of chickpeas were produced globally, with India producing the highest volume, at 11.38 million metric tons (FAOSTAT 2019). The average GI range of chickpeas was 5.0 ± 1.0 to 45.0 ± 0.8 when glucose was used as a reference food, and 13.9 ± 3.0 to 96.0 ± 21.0 when bread was used as a reference. The lowest GIs (with glucose as a reference), were seen in the study by Mehio et al. (1997), which observed cooked chickpeas, consumed by 12 healthy adults, and the study by Trinidad, Mallillin, Loyola, et al. (2010), which observed boiled chickpeas consumed by 6 Type 2 diabetics, of 5.9 ± 3.8 and 5.0 ± 1.0, respectively (Table 4). When nutrient information was examined, it was found that the measured fat, protein and total dietary fiber was highest in the Mehio et al. (1997) meal entry, compared to all other chickpea studies that included nutrient information. This may account for the low GI observed in this study, as fat, protein and fiber are known to lower GI by reducing the carbohydrate absorption rate. There were no significant differences seen in GI when chickpeas were consumed by healthy and diabetic subjects in the studies by Trinidad, Mallillin, Loyola, et al. (2010) and Hettiaratchi et al. (2011). Indeed, these studies show that chickpeas may decrease the glycemic responses more effectively in diabetic subjects.

A study by Carreira, Lajolo, and De Menezes (2004) found that the GI of chickpeas consumed by 10 healthy adults was 34.0 ± 4.0 when cooked and consumed immediately, and 22.0 ± 2.0 when cooked, stored (−20 °C), reheated in a microwave and then consumed. Cooling has been linked to the formation of resistant starch (RS), due to retrogradation, which may decrease digestion (Carreira, Lajolo, and De Menezes 2004; Thompson 2000). In addition, there was a difference seen in the GI of fermented and unfermented chickpeas. In the study by Batra, Sharma, and Seth (1994), it was found that unfermented chickpeas had a lower GI than fermented chickpeas, 42.0 ± 0.6 and 45.0 ± 0.8, respectively. This difference, although small, may be due to

Table 4. GI of chickpeas and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat (g)	Nutrient info- protein (g)	Nutrient info- Total Dietary fiber (g)	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Hummus	Chickpeas	–	259	25	–	–	–	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	15 ± 3	–	Augustin et al. (2015)7
Chickpea, unfermented	Chickpea (Bengal gram), flour, water	Ground, cooked to form pancake	90	54.8	15	15.4	–	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	42 ± 0.6	–	Batra, Sharma, and Seth (1994)
Chickpea, fermented	Chickpea (Bengal gram), flour, water	Fermented 24hrs, ground, cooked to form pancake	90	54.8	15	15.4	–	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	45 ± 0.8	–	Batra, Sharma, and Seth (1994)
Chickpea, cooked	Chickpeas, water	Chickpeas were soaked in water at 4 °C for 12 hours and then pressure cooked for 70 min	–	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	34 ± 4	Carreira, Lajolo, and De Menezes (2004)
Chickpeas cooked, stored and reheated	Chickpeas, water	Chickpeas were soaked in water at 4 °C for 12 hours and then pressure cooked for 70 min. Stored for 30 days and reheated in a microwave	–	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	22 ± 2	Carreira, Lajolo, and De Menezes (2004)
Chickpea spaghetti with wheat	75% durham wheat flour, 25% chickpea flour, water	Spaghetti was boiled in water for 10 minutes	–	–	2.60 ± 0.02	17.0 ± 0.02	9.41 ± 0.16	Healthy adults, 12	Bread, 2 hours	50	Capillary Blood	–	58.9 ± 6.38	(Goñi and Valentín-Gamazo 2003)
Chickpea, cooked	Chickpea, coconut oil, onions	Chickpeas soaked, boiled and tempered with coconut oil	186	–	–	–	–	Type 2 diabetes, 11	Bread, 3 hours	25	Venous blood	–	40 ± 7	Hettiaratchi et al. (2011)
Chickpea flour, bread	Chickpea, water.	Served with margarine, apricot spread, and decaffeinated tea (skim milk)	401	50	7	11	5	Healthy adults, 11	Bread, 2 hours	50	Venous blood	–	78 ± 13	Johnson, Thomas, and Hall (2005)
Chickpea flour, extruded, bread	Extruded chickpea, water.	Served with margarine, apricot spread, and decaffeinated tea (skim milk)	401	50	7	11	6	Healthy adults, 11	Bread, 2 hours	50	Venous blood	–	96 ± 21	Johnson, Thomas, and Hall (2005)
Chickpea, cooked, salad dip	Chickpea, water	Cooked	237	50	46.7	22.8	23.9	Healthy adults, 12	Glucose, 2 hours	50	Venous blood	5.9 ± 3.8	–	(Mehio 1997)
Chickpea, cooked, boiled	Chickpea, water	Peas were soaked and boiled at a high setting for 5 minutes, boiled on low for 30 minutes	100	49.99	4.42%	19.72%	8.91%	Healthy adults, 11	Bread, 1 hour	50	Capillary Blood	–	13.87 ± 3.0	Panlasigui, Panlilio, and Madrid (1995)
Chickpea flour, atta mix, bengal gram flour	Bengal gram flour, water	Roti was prepared at 15 cm in diameter and cooked on hot girdle and direct flame	100	50.3	1.7	9.8	10.9	Healthy adults, 18	Glucose, 2 hours	55	Capillary Blood	27.3 ± 2.2	–	Radhika et al. (2010)
Chickpea, cooked	Chickpeas, water, salt	Cooked	212	50	4.15	17.6	2.79	Healthy men, 21	Glucose, 2 hours (converted to bread Glu x 1.41)	50	Capillary Blood	36	51	Thannoun, (2005)
Chickpeas, boiled	Chickpeas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50	–	–	–	Healthy adults, 7	Bread, 2 hours (converted to glucose x 0.7)	50	Capillary Blood	6 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Chickpeas, boiled	Chickpeas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50	–	–	–	Type 2 diabetes, 6	Bread, 3 hours (converted to glucose x 0.7)	50	Capillary Blood	5 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Chickpea, cooked	Chickpea, water	–	100	18.8	–	–	–	Healthy adults, 20	Glucose, 2 hours	25	Capillary Blood	35 ± 24	–	Venn et al. (2006)
Chickpeas, cooked	Chickpeas, 5g butter	Microwave for 90 seconds		50	–	–	–	Healthy females, 12	Bread, 2 hours	50	Capillary Blood	–	50	Zafar, Kabir, and Ghazaii (2011)

Table 5. GI of common bean and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info-protein	Nutrient info-Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/capillary)	GI (Glucose =100)	GI (Bread = 100)	
Beans with spaghetti orange	Beans, spaghetti, squash, carrot, onion, dehydrated vegetables, vegetable oil, orange		450	49.7	6.8 g	15.9 g	–	Healthy men, 10	Bread, 2 hours	50	Venous blood	–	76.8 ± 43.4	Araya et al. (2002)
Bean cooked, steamed, boiled and minced	Beans, spaghetti, squash, carrot, onion, dehydrated vegetables, vegetable oil, orange	Soaked for 14 hrs, steamed for 10 min and minced in a food processor	100	11	1.51 g	3.53 g	2.72g	Healthy men, 10	Bread, 2 hours	–	Venous blood	–	76.89 ± 43.4	(Araya et al. 2003)
Beans cooked	Beans, water	Beans were soaked in water at 4 °C for 12 hours and cooked for 36 minutes.	–	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	38 ± 4	Carreira, Lajolo, and De Menezes (2004)
Beans cooked, stored and reheated	Beans, water	Beans were soaked in water at 4 °C for 12 hours and cooked for 36 minutes. Stored for 30 days and reheated in a microwave	–	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	18 ± 2	Carreira, Lajolo, and De Menezes (2004)
Green bean dessert	Green bean	Cooked and steamed by hot water	333	50	1.1 g	8.3 g	5.3g	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	54 ± 6	–	Chen et al. (2010)
Red bean dessert	Red bean	Cooked and steamed by hot water	263	50	1 g	9.5 g	7.6g	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	75 ± 8	–	Chen et al. (2010)
Kidney bean, cooked	Kidney Bean, water, salt	2% salt solution was added, beans were boiled for 1.5- 2 hours	148	25	0.7g	9.9g	1.8g	Non insulin dependant diabetes mellitus (NIDDM), 10	Glucose, 2 hours	50	Venous blood	44 ± 3	–	Darabi et al. (2000)
Pinto beans cooked-Chilaqules (casserole)	Pinto beans, corn tortilla, vegetable oil, tomato sauce, fresh farmer's cheese	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 11	Bread, 2 hours (converted to glucose)	50	Capillary Blood	51 ± 9	71 ± 12	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)
Pinto beans cooked-Chilaqules (casserole) with nopales	Pinto beans, corn tortilla, vegetable oil, tomato sauce, fresh farmer's cheese, nopales	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 11	Bread, 2 hours (converted to glucose)	50	Capillary Blood	35 ± 8	50 ± 11	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)
Pinto beans cooked- Burritos	Pinto beans, scrambled egg, diced tomato, vegetable oil, flour tortilla	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 9	Bread, 2 hours (converted to glucose)	50	Capillary Blood	37 ± 4	53 ± 6	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)
Pinto beans cooked-Burritos with nopales	Pinto beans, scrambled egg, diced tomato, vegetable oil, flour tortilla, nopales	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 9	Bread, 2 hours (converted to glucose)	50	Capillary Blood	29 ± 3.2	41 ± 4.5	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)
Pinto beans cooked- Quesadilla	Pinto beans, flour tortilla, low fat monterey cheese, avocado	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 9	Bread, 2 hours (converted to glucose)	50	Capillary Blood	36 ± 3	50 ± 5	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)
Pinto beans cooked-Quesadilla, with nopales	Pinto beans, flour tortilla, low fat monterey cheese, avocado, nopales	Boiled pinto beans	–	–	–	–	–	Type 2 diabetes, 9	Bread, 2 hours (converted to glucose)	50	Capillary Blood	25 ± 3.5	35 ± 4.9	Bacardi-Gascon, Duẽ, and Jimenez-Cruz (2007)

Butter beans, boiled	Beans, butter, water	Butter beans, soaked overnight, boiled 50 min	150	74.7	–	–	–	Healthy adults, 8	Glucose, 2 hours	50	Capillary Blood	26 ± 7	–	Henry et al. (2005)
Red beans, boiled	Red kidney beans, water	Red kidney beans, soaked overnight and boiled 60 min	150	60.3	–	–	–	Healthy adults, 8	Glucose, 2 hours	50	Capillary Blood	51 ± 5	–	Henry et al. (2005)
Baked beans on potato	Beans, potato	Beans on potato, baked	–	–	–	–	–	Healthy adults, 40	Glucose, 2 hours	50	Capillary Blood	62 ± 6	–	Henry et al. (2006)
Baked beans on white bread	Beans, bread	Beans on white bread, baked	–	–	–	–	–	Healthy adults, 40	Glucose, 2 hours	50	Capillary Blood	50 ± 6	–	Henry et al. (2006)
Kidney bean, cookies	30% Kidney bean flour, 15% foxtail millet flour, 15% arrowroot flour, margarine, egg yolks, maltitol, salt	Dough was baked at 140 degrees C for 30 min.	100	43.91 ± 0.16 %	23.24 ± 0.28 %	10.10 ± 0.12 %	14.48 ± 0.32 %	Healthy adults, 12	Glucose, 2 hours	25	Capillary Blood	37.6	–	Lestari, Huriyati, and Marsono (2017)
Beans, stew	Bean, plantain	Stew	–	75	31.1 g	17.2 g	18.8 g	Healthy adults, 10	Glucose, 3 hours	75	–	48.36	–	Mbanya et al. (2003)
Beans, cooked	Bean, cassava	Koki beans cooked	–	75	30.2 g	19.4 g	23.5 g	Healthy adults, 10	Glucose, 3 hours	75	–	51.99	–	Mbanya et al. (2003)
Beans, boiled, meal	Beans, corn, pepper, onions, salt, stock, crayfish, palm oil, spinach	Beans were soaked overnight, boiled and cooked	150	14.42	5.3 g	18.94 g	9.15 g	Healthy adults, 100	Glucose, 2 hours	50	Venous blood	33.00 ± 1.25	–	Nnadi and Keshinro (2016)
Black bean, cooked, boiled	Black bean, water	Beans were soaked and boiled at a high setting for 5 minutes, boiled for 35 minutes	100	50.27	1.01%	22.68%	10.97%	Healthy adults, 11	Bread, 1 hour	50	Capillary Blood	–	27.91 ± 4.0	Panlasigui, Panlilio, and Madrid (1995)
White bean, cooked, boiled	White bean, water	White bean were soaked and boiled at a high setting for 5 minutes, boiled for 12 minutes	100	45.33	1.48%	19.18%	15.44%	Healthy adults, 11	Bread, 1 hour	50	Capillary Blood	–	19.48 ± 4.9	Panlasigui, Panlilio, and Madrid (1995)
Kidney Bean cooked	Kidney Bean, water, salt	Cooked	215	50	1.55 g	19.4 g	4.15 g	Healthy men, 11	Glucose, 2 hours(converted to bread Glu x 1.41)	50	Capillary Blood	26	37	Thannoun, (2005)
Red beans, boiled	Red kidney beans, water	Beans were soaked for 20 mins and boiled for 70 min	252	–	2.7 g	19.6 g	17 g	Healthy adults, 10	Bread, 2 hours	30	Capillary Blood	–	43.7 ± 8.4	Tovar, Granfeldt, and Bjoerck (1992)
Red beans, autoclaved	Red kidney beans, water	Beans were soaked for 20 mins and autoclaved at 20 min at 1.05 kg/cm○2, 121 degrees C	273	–	2.7 g	19.6 g	–	Healthy adults, 10	Bread, 2 hours	30	Capillary Blood	–	57.9 ± 7.8	Tovar, Granfeldt, and Bjoerck (1992)
Red beans, pre-cooked flour, porridge	Red kidney beans, water	Beans were soaked for 20 mins and boiled for 70 min, then freeze dried. It was then made into a porridge	83	–	2.6 g	19 g	16.8 g	Healthy adults, 10	Bread, 2 hours	30	Capillary Blood	–	61.8 ± 8.8	Tovar, Granfeldt, and Bjoerck (1992)
Red beans, flour containing free starch, cake	Red kidney beans, water	Raw beans were milled, flour suspended and heated for 70 min with steam at 96 degrees C	264	–	2.6 g	19 g	–	Healthy adults, 10	Bread, 2 hours	30	Capillary Blood	–	76.2 ± 12.5	Tovar, Granfeldt, and Bjoerck (1992)
Common beans, boiled	String beans, water, seasoning	Seasoned to taste	200	10	–	–	2.2 g	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	23 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Kidney beans, boiled	Kidney beans, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Healthy adults, 7	Bread, 2 hours (converted to glucose x 0.7)	50	Capillary Blood	13 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Kidney beans, boiled	Kidney beans, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Type 2 diabetes, 6	Bread, 3 hours (converted to glucose x 0.7)	50	Capillary Blood	9 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
White kidney bean, capsule (1500 mg)	1500 mg capsule, bread, butter	Capsule served with bread and butter	1.5 mg	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	61.9 ± 2.6	Udani et al. (2009)

(continued)

Table 5. Continued.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info-protein	Nutrient info-Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/capillary)	GI (Glucose =100)	GI (Bread = 100)	
White kidney bean, capsule (2000 mg)	2 mg capsule, bread, butter	Capsule served with bread and butter	2	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	45.1 ± 14.6	Udani et al. (2009)
White kidney bean, capsule (3000 mg)	3 mg capsule, bread, butter	Capsule served with bread and butter	3	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	46.8 ± 12.5	Udani et al. (2009)
White kidney bean, powder (1500 mg)	1.5 mg powder, bread, butter	Powder served with bread and butter	1.5	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	43.6 ± 15.7	Udani et al. (2009)
White kidney bean, powder (2000 mg)	2 mg powder, bread, butter	Powder served with bread and butter	2	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	45.2 ± 14.1	Udani et al. (2009)
White kidney bean, powder (3000 mg)	3 mg powder, bread, butter	Powder served with bread and butter	3	–	–	–	–	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	39.1 ± 20.2	Udani et al. (2009)
Navy bean, Canadian, canned	Canadian navy beans, water	Soaked for 3 hours, 29 degrees C, blanched 6 min at 80 degrees C, canned 73 min at 121 degrees C	–	50	1.4 g	17.6 g	15.5 g	Healthy men, 14	Glucose, 2 hours	50	Capillary Blood	54 ± 6	–	Wong et al. (2009)
Navy bean, UK, canned	UK navy beans, water	Blanched 16-28 minutes at 85 degrees C, canned 20 min at 125 degrees C	–	50	3.1 g	14.6 g	11 g	Healthy men, 14	Glucose, 2 hours	50	Capillary Blood	56 ± 6	–	Wong et al. (2009)
Navy bean, homemade (baked)	UK navy beans, water	Baked beans. Soaked 60 min, simmered 90 min, baked 60 min at 204 degrees C	–	50	2.0 g	13.7 g	13.3 g	Healthy men, 14	Glucose, 2 hours	50	Capillary Blood	44 ± 4	–	Wong et al. (2009)
Navy bean, canned, in tomato sauce	Canned navy beans, water, tomato sauce	–	–	50	1.4 g	17.6 g	15.5 g	Healthy men, 14	Bread, 2 hours	50	Capillary Blood	–	65 ± 4	Wong et al. (2009)
Navy bean, canned, Maple style	Canned navy beans, water, maple sirup	–	–	50	1.6 g	14.5 g	11.3 g	Healthy men, 14	Bread, 2 hours	50	Capillary Blood	–	99 ± 11	Wong et al. (2009)
Navy bean, canned, with pork and molasses	Canned navy beans, water, pork, molasses	–	–	50	2.6 g	15.6 g	14.7 g	Healthy men, 14	Bread, 2 hours	50	Capillary Blood	–	85 ± 8	Wong et al. (2009)
Navy bean, canned, with pork and molasses (homemade)	Canned navy beans, water, pork, molasses	–	–	50	3.4 g	18.7 g	13.3 g	Healthy men, 14	Bread, 2 hours	50	Capillary Blood	–	50 ± 4	Wong et al. (2009)

the fact that fermentation leads to the breakdown of complex carbohydrates, to monosaccharides and disaccharides (Batra, Sharma, and Seth 1994). This increase in simple carbohydrates subsequently increases blood glucose, and thereby leads to a higher GI. Finally, the highest GI was observed for two chickpea flour meals; one using regular chickpea flour and the other using extruded chickpea flour (Johnson, Thomas, and Hall, 2005). The GI for these two meals, when bread was used as a reference, were 78.0 ± 13.0 and 96.0 ± 21.0, respectively. This may have been due to the low incorporation rate as well as the finer particle size of chickpea flour (which affects digestion rate) (Johnson, Thomas, and Hall, 2005). The study found that the extruded flour meal had a higher GI, which may be explained due to extensive starch hydrolysis, as part of the extrusion process, leading to a higher GI (Johnson, Thomas, and Hall, 2005). Thus, it is clear that the nutrient content and preparation methods of chickpeas affects the GI. Table 4 reviews all chickpeas studied in this analysis.

Common bean

The common bean, also known as *Phaseolus vulgaris L.* is one of the most prevalent legumes consumed globally (Jones 1999). Common beans have a large variability, as there are over 40,000 varieties, with variations in seed characteristics, growth conditions, ability to adapt and maturity (Jones 1999). Common bean, as classified by the FAO, has many species under this pulse category. Some of these species, as indicated by Table 1, include, but are not limited to: kidney beans, navy beans, black beans, and pinto beans. Due to the large number of varieties, it is difficult to observe global trends in production, however it is estimated that 12 million tons are produced annually (FAO 2019). These beans are important as they provide one of the best alternative non-meat sources of iron, with 20–30% of the recommended daily intake coming from a single serving (Jones 1999). The average GI range of common bean was 9.0 ± 1.0 to 75.0 ± 8.0, when glucose was used as a reference, and 18.0 ± 2.0 to 99.0 ± 11.0, when bread was used as a reference.

The study by Udani et al. (2009), as reviewed in Table 5, found that as more beans are consumed along with white bread, the GI decreases. Udani et al. (2009) found that white kidney bean powder, spread on white bread decreased GI more than when taken in as a capsule after the meal. This suggests that common bean plays a role in lowering GI when consumed as part of a meal. In addition, each bean species, had different GIs. The lowest GI for common bean was seen in red beans, as reviewed by Trinidad, Mallillin, Loyola, et al. (2010) with GIs (converted to glucose) of 9.0 ± 1.0 and 13.0 ± 1.0, when 6 diabetic adults, and 7 healthy adults were tested, respectively. Furthermore, Canadian navy beans showed almost similar GIs as that of UK navy beans (glucose as reference) [54.0 ± 6.0 and 56.0 ± 6.0, respectively] (Wong et al. 2009). Canadian navy beans also had a higher fat and protein content than UK navy beans (Wong et al. 2009).

A study by Tovar, Granfeldt, and Björck (1992) found that, various processing methods affected the insulin and glucose responses to starches in legumes. Compared to boiling, all other processing methods significantly increased GI response. Autoclaving showed a higher insulin and glucose response due to changes in the cell wall integrity (Tovar, Granfeldt, and Björck, 1992). In the Tovar, Granfeldt, and Björck (1992) study, red bean cake, made from free starch flour, showed an increased rate of digestion, and subsequently had the highest GI. Furthermore, the study by Carreira, Lajolo, and De Menezes (2004) found that beans that were boiled, stored in the refrigerator and reheated, had a lower GI than beans which were consumed immediately after boiling. As indicated in section "Chickpea" above, the low GI seen after storage in the refrigerator may be attributed to the formation of resistant starch, which is activated by cooling (Carreira, Lajolo, and De Menezes 2004; Thompson 2000). This subsequently decreases digestion and lowers GI.

Cowpeas

Cowpeas (*Vigna unguiculata*) is a grain legume and a cheap source of protein, carbohydrate, fiber and other nutrients (Akinlua, Sedodo and Victoria 2013; Oboh and Agu 2010). It is an important food in Africa (Ghana), Southeast Asia, Latin America and other tropical countries (Akinlua, Sedodo and Victoria 2013; Nyankori et al. 2002) with an estimated global production of 7.25 million tons as of 2018 (FAOSTAT 2019). Cowpeas have a high protein content, at approximately 25–29% of the daily recommended intake (Chinma, Alemede, and Emelife 2008), which makes it a valuable food to protect against hunger and food shortages (Akinlua, Sedodo and Victoria 2013). The GI range of cowpeas was 6.0 ± 1.0 to 56.0 ± 0.2 when glucose was used as a reference. Table 6 summarizes all studies reviewed in this paper. The lowest GI, when glucose was used as a reference, was 6 ± 1 when a meal of boiled cowpeas were consumed by 6 Type 2 diabetics (Trinidad, Mallillin, Loyola, et al. 2010). The study by Oboh and Agu (2010) looked at the GIs of various species of cowpeas and found a range of GIs. This suggests that the GI of cowpeas may be species dependent. The highest GI was seen in the study by Akinlua, Sedodo and Victoria (2013), at 56.0 ± 0.2, for a bean stew, where beans were soaked and milled into a paste. This indicates that processing methods may affect GI as the milling of cowpeas into a paste increases its surface area for digestion, subsequently causing a higher glycemic response. This was also seen in the study by Oboh and Agu (2010) where whole cowpeas had a lower GI than meals that were milled into a paste.

The study by Onimawo et al. (2007) showed that diabetic subjects had a higher GI, when cowpeas were consumed, than healthy adults. However the study by Trinidad, Mallillin, Loyola, et al. (2010) showed the opposite findings and found that non-insulin dependent diabetic (NIDD) subjects had a lower GI than non-diabetic subjects, which, according to the Trinidad, Mallillin, Loyola, et al. (2010) paper, may be attributed to the higher protein content in their diet. As indicated prior, high dietary protein, in the range of 20 to 30 g, tended to reduce the glycemic responses

Table 6. GI of cowpeas and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat (g)	Nutrient info- protein (g)	Nutrient info- Total Dietary fiber (g)	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/capillary)	GI (Glucose =100)	GI (Bread = 100)	
Beans soaked and milled into a paste	Cowpeas, water	Beans were soaked (15-20 min in cold water, hull removed and milled into paste	180	27	–	–	–	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	56 ± 0.19	–	Akinlua, Sedodo and Victoria (2013)
Akara: Beans soaked and milled into a paste and fried	Cowpeas, water, onion, pepper	Fried in deep hot fat for 3 mins to balls which were golden brown crisp.	180	54	–	–	–	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	44 ± 0.15	–	Akinlua, Sedodo and Victoria (2013)
Moin-moin: Beans soaked and wrapped in banana leaves and steamed	Cowpeas, water, onion, pepper, crayfish	Seeds were dehulled, grounded into paste and steamed for about 1.5 hours	180	30.9	–	–	–	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	41.14 ± 0.61	–	Akinlua, Sedodo and Victoria (2013)
Ofuloju: Beans soaked and made into a paste	Cowpeas, water	Beans soaked in water for 20 minutes and made into a paste, and cooked	180	45.3	–	–	–	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	54 ± 0.39	–	Akinlua, Sedodo and Victoria (2013)
Cowpea, boiled and cooked (white)	White cowpeas, water, spices, red palm oil	Cowpeas boiled in water until tender	180	27.73/100	17.5 ± 0.0	20.3 ± 0.05	1.5 ± 0.01	Healthy adults, 35	Glucose, 3 hours	50	Capillary Blood	41 ± 10	–	Oboh and Agu (2010)
Cowpea, boiled and cooked (white and black)	White and black cowpeas, water, spices, red palm oil	Cowpeas boiled in water until tender	182	27.50/100	18.15 ± 0.05	19.95 ± 0.05	1.5 ± 0.01	Healthy adults, 35	Glucose, 3 hours	50	Capillary Blood	30 ± 11	–	Oboh and Agu (2010)
Cowpea, boiled and cooked (brown)	Brown cowpeas, water, spices, red palm oil	Cowpeas boiled in water until tender	175	28.66/100	15.50 ± 0.02	20.66 ± 0.01	1.5 ± 0.01	Healthy adults, 35	Glucose, 3 hours	50	Capillary Blood	29 ± 9	–	Oboh and Agu (2010)
Cowpea, boiled (brown)	Cowpea, water, onions, salt, ground pepper, red palm oil	Seeds were washed and brought to a boil for 2 hours	163.61	30.56g/100	15.9 ± 0.01	16.88 ± 1.08	1.79 ± 0.02	Healthy adults, 10 (30 participants total)	Glucose, 3 hours	50	Venous blood	46.64 ± 9.78	–	Oboh and Agu (2010)
Cowpea, soaked, dehulled and steamed- Moin Moin	Cowpea, water, groundnut oil, onions, salt, pepper	Seeds were soaked for 30 min and dehulled and ground into smooth paste	169.89	29.43g/100	21.54 ± 0.03	14.48 ± 0.19	0.53 ± 0.002	Healthy adults, 10 (30 participants total)	Glucose, 3 hours	50	Venous blood	50.98 ± 15.74	–	Oboh and Agu (2010)
Cowpea, soaked, dehulled and fried- Akara	Cowpea, water, groundnut oil, onions, salt, pepper	Seeds were dehulled, ground into thick paste and deep fried for a few minutes	156.1	32.03g/100	23.48 ± 0.05	21 ± 0.05	0.72 ± 0.002	Healthy adults, 10 (30 participants total)	Glucose, 3 hours	50	Venous blood	53.42 ± 29.5	–	Oboh and Agu (2010)
Cowpeas, steamed (moin-moin)	Cowpeas, water, onions, salt, red palm oil, maggi cubes, ground crayfish	Seeds were milled into a paste and steamed for 30 min	50	13.59	–	12.51	1.02	Type 2 diabetes, 10	Bread, 2 hours	50	Capillary Blood	–	65.5 ± 7.44	Onimawo et al. (2007)
Cowpeas, steamed (moin-moin)	Cowpeas, water, onions, salt, red palm oil, maggi cubes, ground crayfish	Seeds were milled into a paste and steamed for 30 min	50	13.59	–	12.51	1.02	Healthy adults, 7	Bread, 2 hours	50	Capillary Blood	–	38.33 ± 18.7	Onimawo et al. (2007)
Cowpeas, boiled	Cowpeas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Healthy adults, 7 (converted to glucose x 0.7)	Bread, 2 hours	50	Capillary Blood	11 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Cowpeas, boiled	Cowpeas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Type 2 diabetes, 6 (converted to glucose x 0.7)	Bread, 3 hours	50	Capillary Blood	7 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Cowpeas, boiled (Pole sitao)	Pole sitao, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Healthy adults, 7 (converted to glucose x 0.7)	Bread, 2 hours	50	Capillary Blood	9 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Cowpeas, boiled (Pole sitao)	Pole sitao, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	–	–	–	–	Type 2 diabetes, 6 (converted to glucose x 0.7)	Bread, 3 hours	50	Capillary Blood	6 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)

in NIDD subjects, which may explain the low GI in the results by Trinidad, Mallillin, Loyola, et al. (2010). However, these properties may not be retained in mixed meals, and may account for the higher GI seen in the Onimawo et al. (2007) study.

Lentil

Lentils, also called *Lens culinaris L.* are a popular source of protein globally. It is estimated that 6.5 million tons were produced globally in 2018, with Canada being the largest producer, accounting for 2.09 million tons (FAOSTAT 2019). The GI range of lentils was 10 ± 3 to 66 ± 6 when glucose was used as a reference, and 37.0 to 87.0 ± 6.0, when bread was used as a reference. Table 7 reviews the GI for all lentils reviewed in this study. The second highest GI (reference glucose) was 61.0 ± 6.0 for a curry lentil and wholemeal bread meal in a study performed by Hettiaratchi, Ekanayake, and Welihinda (2009) with 10 healthy adults. In this study, the GIs of white sliced bread, and wholemeal bread were found to be 77.0 ± 6.0, while the GI of ordinary white bread was 80.0 ± 4.0 (Hettiaratchi, Ekanayake, and Welihinda 2009). Therefore, lentils had an effect in lowering GI of bread. This may be because lentils have a higher fat and insoluble dietary fiber when compared to all other bread meals observed in this study (Hettiaratchi, Ekanayake, and Welihinda 2009). However, diabetic subjects, when compared to healthy adults, had one of the highest GIs after a lentil meal consumption at 64.0 ± 11.0 (reference bread) (Hettiaratchi et al. 2011). This may be observed as diabetic patients exhibit insulin resistance and delayed gastric emptying, which may affect glycemic response (Hettiaratchi et al. 2011).

The lowest GI was seen in the study by (Ramdath et al. 2017), where plain, boiled lentils were consumed by 10 healthy adults. This study looked at various species of lentils and found that Asterix species had the lowest GI, at 10.0 ± 3.0 (Ramdath et al. 2017). While there were no visible trends in the influence of dietary fiber, protein and/or fat on GI, it has been suggested that the polyphenolic compounds of lentils may influence starch digestion (Ramdath et al. 2017). Zhang et al. (2015) found that Asterix species had the highest content of condensed tannin, phenolic compounds, flavonoids, and exhibited an inhibitory effect on α-glucosidase, an enzyme involved in the digestion of starch. Furthermore, phenolic compounds affect starch hydrolysis, which may increase the content of resistant starch (Barros, Awika, and Rooney 2012). This may account for the low GI seen in the Ramdath et al. (2017) study as the resistant starch in Asterix was high.

Processing method also seems to affect the GI of lentils. In the (Ramdath et al. 2018) study, it was found that; as the processing methods of lentils varied, the GI increased or decreased subsequently. Boiled and pureed lentils had similar GIs at 25.0 ± 3.0 and 27.0 ± 4.0, respectively. However roasting, freezing and spray-drying lentils prior to cooking substantially increased GI. Spray-dried lentil flour had the highest GI, at 66.0 ± 6.0. This may be because of the smaller particle size of flour, leading to starch gelatinization and increased glycemic response (Ramdath et al. 2018). The effects of roasting and freezing on GI suggests that temperature also plays a role in GI response. It seems that exposure of a larger surface area does not affect GI of lentil, as the study by (Fujiwara, Hall, and Jenkins 2017) found no statistical difference in the GI of lentil in bread and lentil in pasta. However, this may be due to the incorporation percentage as more lentil flour in the bread meal, may have led to an observable difference.

Mung bean

Mung bean (*Vigna radiata*), also known as green gram, golden gram and Chinese mung bean is a legume consumed and produced primarily in South America, India, China and Southeast Asia ("Mung bean facts and health benefits," 2017). Its global production is estimated at 5.3 million tons for the 2015–2017 period (World Vegetable Center (WVC) 2019). Mung bean consumption has increased in recent years due to its high protein content and nutritional benefits. The GI range of mung beans was 11.0 ± 2.0 to 90.0 ± 9.0 when glucose was used as a reference. As outlined in Table 8, the lowest GI, when glucose was used as a reference was 11.0 ± 2.0 for a boiled mung bean meal (Trinidad, Mallillin, Loyola, et al. 2010). It is interesting that this low GI was observed in NIDDM patients as it was expected that the GI would be higher for these subjects. The study by (Urooj and Puttaraj 2000) however reported that diabetic subjects had a GI of almost twice as high as that of healthy adults. In the study by Urooj and Puttaraj (2000), a mung bean and chapatti meal had a GI of 44.0 ± 11.0, when 11 healthy adults were tested, whereas the same meal yielded a GI of 81.0 ± 12.0, for subjects with Type 2 diabetes. The same study found that healthy adults had a GI of 45.0 ± 7.0 when a mung bean and rice meal was consumed, whereas subjects with Type 2 diabetes, showed a GI of 90.0 ± 9.0 (Urooj and Puttaraj 2000). This is similar to the results found in lentils (section "Lentil"). Therefore, meal or recipe preparation of mung beans may affect the GI of individuals with diabetes.

As stated with other pulses, processing methods affect GI of mung beans. Unfermented mung beans had a lower GI than fermented beans, as seen in the study by (Batra, Sharma, and Seth 1994). Like the fermentation of chickpeas in section "Chickpea", fermentation may cause complex carbohydrates to break down into simpler sugars, resulting in a spike in blood glucose levels, and subsequently GI. This may account for the small increase in GI for fermented mung beans, compared to the unfermented meal. Thus, processing method may affect the GI of mung beans by increasing or reducing the access of resistant starch and carbohydrates to digestive enzymes.

Peas

Peas are grain legumes and the fourth-most important crop produced globally (Mordor Intelligence 2018). Dry peas are one of the most cultivated and produced legumes, behind soybeans, dry beans and peanuts (Mordor Intelligence 2018) with a global production of 15.06 million tons, as of 2018

Table 7. GI of lentils and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info- protein	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/capillary)	GI (Glucose =100)	GI (Bread = 100)	
Lentil soup orange	Lentils, onion, dehydrated vegetables, vegetable oil, orange	–	465	49.9	6.5	21.9	–	Healthy men, 10	Bread, 2 hours	50	Venous blood	–	49.3 ± 29.5	Araya et al. (2002)
Lentil, steamed, minced and boiled	Lentils, water, onion, dehydrated vegetables, vegetable oil, orange	Lentil grains were soaked in water for 14 h, cooked for 10 min in a steamed and minced	100	10.73	1.4	4.71	2.61	Healthy men, 10	Bread, 2 hours		Venous blood	–	49.3 ± 29.5	Araya et al. (2003)
Lentil focaccia bread	16% Green Lentil flour, olive oil, yeast, garlic powder, salt, pepper, and herb mix	Straight dough method	147	52.5 %	20.60%	16.60%	6.90%	Healthy adults, 10	Bread, 2 hours (converted to glucose)	50	Unknown	53 ± 5	N/A	Fujiwara, Hall, and Jenkins 2017)
Lentil Pasta	50% Red lentil flour	Boiled, single-screw processing	83	67.6%	3.30%	21.70%	6.10%	Healthy adults, 10	Bread, 2 hours (converted to glucose)	50	Unknown	55 ± 8	–	Fujiwara, Hall, and Jenkins 2017)
Lentils, boiled	Lentils, water	Lentils, red, split, boiled 25 min	150	77	–	–	–	Healthy adults, 8	Glucose, 2 hours	50	Capillary Blood	21 ± 7	–	Henry et al. (2005)
Whole meal bread and lentil, curry	Lentils, water, condiments, coconut milk	Boiled, 15 min	100	11.8 ± 0.51	3.4 ± 0.19	8	6.3 ± 0.37	Healthy adults, 10	Bread and glucose, 2 hours	50	Capillary Blood	61 ± 6	87 ± 6	Hettiaratchi, Ekanayake, and Welihinda (2009)
Lentil, curry	Lentils, water, spices, coconut milk, green chili, curry leaves, onions and garlic. Served with rice and salad	Lentils were boiled in water and spices for 10 min	38	–	–	–	–	Type 2 diabetes, 11	Bread, 3 hours	25	Venous blood	–	64 ± 11	Hettiaratchi et al. (2011)
Lentil flour, baked, muffin	7% Lentil flour, sucrose, soft wheat flour, 5% resistant starch, 3% dextrin	Baked at 240 degrees C for 7 min	–	–	–	–	–	Healthy adults, 18	Glucose, 3 hours	50	Unknown	39.14 ± 18.22	–	(Ferrer-Mairal et al. 2012)
Lentil, boiled and cooked (immigreen)	Raw immigreen seeds, water	Placed on hot plate and boiled for 11 min	158.2	36.7	0.6 g	14.0 g	11.7 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	14 ± 3	–	Ramdath et al. (2017)
Lentil, boiled and cooked (asterix)	Raw asterix seeds, water	Placed on hot plate and boiled for 11 min	170.1	36.7	0.4 g	14.2 g	11.7 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	10 ± 3	–	Ramdath et al. (2017)
Lentil, boiled and cooked (impower)	Raw impower seeds, water	Placed on hot plate and boiled for 11 min	153.4	36.7	0.7 g	13.5 g	11.7 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	17 ± 4	–	Ramdath et al. (2017)
Lentil, boiled and cooked (improve)	Raw improve seeds, water	Placed on hot plate and boiled for 11 min	206.6	42.4	0.8 g	16.7 g	17.4 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	15 ± 5	–	Ramdath et al. (2017)
Lentil, boiled and cooked (Redberry)	Raw Redberry seeds, water	Placed on hot plate and boiled for 11 min	200	42.8	1.0 g	17.9 g	17.8 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	13 ± 2	–	Ramdath et al. (2017)
Lentil, boiled and cooked (Greenland)	Raw Greenland seeds, water	Placed on hot plate and boiled for 11 min	192.3	40.8	0.6 g	15.6 g	15.8 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	23 ± 5	–	Ramdath et al. (2017)
Lentil, boiled and cooked (Redcliff)	Raw Redcliff seeds, water	Placed on hot plate and boiled for 11 min	188	41	0.8 g	15.5 g	16 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	18 ± 3	–	Ramdath et al. (2017)
Lentil, boiled and cooked (Redbow)	Raw Redbow seeds, water	Placed on hot plate and boiled for 11 min	204.9	43.8	0.4 g	17.6 g	18.9 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	18 ± 3	–	Ramdath et al. (2017)
Lentil, boiled and cooked	Green lentil, 40g filtered water	Boiled for 36 min at medium heat.	321.8	72.1	1.4 g	24.3 g	22 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	25 ± 3	–	Ramdath et al. (2018)
Lentil, boiled and puree	Green lentil, 40g filtered water	Boiled and grinded to form puree	365.3	70.1	1 g	24.6 g	20.1 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	27 ± 4	–	Ramdath et al. (2018)
Lentil, Frozen, cooked puree	Green lentil, 40g filtered water	Food was frozen at -40 degrees C until use	346.7	69.5	1.1 g	24.5 g	19.4 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	44 ± 6	–	Ramdath et al. (2018)
Lentil, roasted flour	Green lentil, 40g filtered water	Lentils were roasted at 120 degrees C for 20 min	113	72.6	1.7 g	27 g	22.6 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	38 ± 8	–	Ramdath et al. (2018)
Lentil, spray-dried flour	Green lentil, 40g filtered water	Lentils were mixed for 30 min at 95 degrees C, then spray dried	100.7	65.7	1.7 g	24.9 g	15.7 g	Healthy adults, 10	Bread, 2 hours (WB GI = 71)	25	Capillary Blood	66 ± 6	–	Ramdath et al. (2018)
Lentils, cooked	Lentils, water, salt	Cooked	218	50 g	1.16 g	21.8 g	1.53 g	Healthy men, 11	Glucose, 2 hours (converted to bread Glu x 1.41)	50	Capillary Blood	22	31	Thannoun, (2005)
Lentil, pre-cooked flour, porridge	Lentils, water	Lentils were soaked for 20 mins and boiled for 70 min, then freeze dried.	70	–	2.4 g	17.6 g	11.1 g	Healthy adults, 10	Bread, 2 hours	30	Capillary Blood	–	62.8 ± 8.8	Tovar, Granfeldt, and Bjoerck (1992)

Table 8. GI of Mung bean and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info- protein	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Mung bean, unfermented	Mung bean (green gram), flour, water	Ground, cooked to form pancake	90	51.0	15 g	21.6 g	–	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	36 ± 0.6	–	Batra, Sharma, and Seth (1994)
Mung bean, fermented	Mung bean (green gram), flour, water	Fermented 24hrs at 25-30 degrees C, ground, cooked to form pancake	90	51.0	15 g	21.6 g	–	Healthy adults, 15	Glucose, 2 hours	50	Capillary Blood	38 ± 0.7	–	Batra, Sharma, and Seth (1994)
Mung bean fiber	Mung bean starch	–	–	–	–	–	–	Healthy men, 8	Glucose, 4 hours and 10 min	–	Venous blood	51 ± 13	–	Lang et al. (1999)
Mung bean , noodles, boiled	Mung bean noodles, water	Boiled	100	93.5 ± 0.1	0.00 ± 0.1 g	0.0 ± 0.0 g	15.7 ± 0.5 g	Healthy adults, 10	Bread, 2 hours	50	Capillary Blood	–	28 ± 0.5	Lin et al. (2010)
Mung bean, cooked, boiled	Mung bean, water	Soaked and boiled at a high setting for 5 minutes, then boiled on low for 15 minutes	100	53.29	0.22%	22.58%	9.38%	Healthy adults, 11	Bread, 1 hour	50	Capillary Blood	–	44.38 ± 5.8	Panlasigui, Panlilio, and Madrid (1995)
Mung beans, boiled	Mung beans, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50	–	–	–	Healthy adults, 7	Bread, 2 hours (converted to glucose x 0.7)	50	Capillary Blood	15 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Mung beans, boiled	Mung beans, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50	–	–	–	Type 2 diabetes, 6	Bread, 3 hours (converted to glucose x 0.7)	50	Capillary Blood	11 ± 2	–	Trinidad, Mallillin, Loyola, et al. (2010)
Green gram dhal and chapatti	Wheat flour, oil, green gram dhal	Flour kneaded into dough, rolled and baked on a griddle	–	50	16 g	10.8 g	14.2 g	Healthy adults, 11	Glucose, 2 hours	50	Venous blood	44 ± 11	–	Urooj and Puttaraj (2000)
Green gram dhal and chapatti	Wheat flour, oil, green gram dhal	Flour kneaded into dough, rolled and baked on a griddle	–	50	16 g	10.8 g	14.2 g	Type 2 Diabetes, 8	Glucose, 2 hours	50	Venous blood	81 ± 12	–	Urooj and Puttaraj (2000)
Green gram dhal and rice (pongal)	Rice, oil, green gram dhal	Dhal was lightly roasted, pressure cooked	–	50	13.4 g	7.4 g	10.8 g	Healthy adults, 8	Glucose, 2 hours	50	Venous blood	45 ± 7	–	Urooj and Puttaraj (2000)
Green gram dhal and rice (pongal)	Rice, oil, green gram dhal	Dhal was lightly roasted, pressure cooked	–	50	13.4 g	7.4 g	10.8 g	Type 2 Diabetes, 10	Glucose, 2 hours	50	Venous blood	90 ± 9	–	Urooj and Puttaraj (2000)

Table 9. GI of Peas and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info- protein	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Split peas, cooked	Split peas, water, salt	Boiled, 1.5- 2 hours	117	25	1.3 g	9 g	0.8 g	Non insulin dependent diabetes mellitus (NIDDM), 10	Glucose, 2 hours	25	Venous blood	31 ± 3	–	Darabi et al. (2000)
Green peas, cooked	Green peas, water, salt	Boiled, 1 hour	192	25	1g	14 g	4.1g	Non insulin dependent diabetes mellitus (NIDDM), 10	Glucose, 2 hours	25	Venous blood	57 ± 2	–	Darabi et al. (2000)
Peas, plain	Peas (plain), frozen	–		25 g	0.2 g	1.8 g	0.8 g	Healthy adults, 30	Glucose, 2 hours	25	Capillary Blood	29	–	Dodd et al. (2011)
Potato and Peas, meal	Peas, potato, sweet potato, peas, carrots, tomato sauce	Cooked		50 g	0.2 g	1.8 g	0.8 g	Healthy adults, 30	Glucose, 2 hours	50	Capillary Blood	53	–	Dodd et al. (2011)
Rice and Peas, meal	Peas, rice, sweet potato, peas, carrots, tomato sauce	Cooked		50 g	0.2 g	1.8 g	0.8 g	Healthy adults, 30	Glucose, 2 hours	50	Capillary Blood	38	–	Dodd et al. (2011)
Spaghetti and Peas, meal	Peas, spaghetti, sweet potato, peas, carrots, tomato sauce	Cooked		50 g	0.2 g	1.8 g	0.8 g	Healthy adults, 30	Glucose, 2 hours	50	Capillary Blood	38	–	Dodd et al. (2011)
Cracker	9% Pea protein isolate, pastry flour	Ground in coffee grinder	144	35.7% TB/serving	23.10%	24.50%	12.00%	Healthy adults, 10	Bread, 2 hours	50	Bread, 2 hours (converted to glucose)	42 ± 3	–	Fujiwara, Hall, and Jenkins (2017)
Peas, boiled	Peas, water	Peas were split, dried, soaked overnight, boiled 55 min	150	84.9	–	–	–	Healthy adults, 8	Glucose, 2 hours	50	Capillary Blood	25 ± 6	–	Henry et al. (2005)
Banana Bread	Whole yellow pea flour	–	67.8	52 g	15.2 g	9.3 g	8.1 g	Healthy adults, 19	Bread, 3 hours	50	Capillary Blood	–	50.3 ± 8	Marinangeli, Kassis, and Jones (2009)
Biscotti	Whole yellow pea flour	–	86	51.7 g	13.3 g	12.2 g	10.1 g	Healthy adults, 19	Bread, 3 hours	50	Capillary Blood	–	45.4 ± 8.2	Marinangeli, Kassis, and Jones (2009)
Pasta	Whole yellow pea flour	–	90	51.1 g	1.6 g	7.4 g	8.1 g	Healthy adults, 19	Bread, 3 hours	50	Capillary Blood	–	93.3 ± 9.4	Marinangeli, Kassis, and Jones (2009)
Peas (Green), boiled	Peas (Green), water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50 g	–	–	–	Healthy adults, 7	Bread, 2 hours (converted to glucose x 0.7)	50	Capillary Blood	9 ± 2	–	Trinidad, Mallillin, Loyola, et al. (2010)
Peas (Green), boiled	Peas (Green), water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50 g	–	–	–	Type 2 diabetes, 6	Bread, 3 hours (converted to glucose x 0.7)	50	Capillary Blood	9 ± 2	–	Trinidad, Mallillin, Loyola, et al. (2010)

(FAOSTAT 2019). Similar to other legumes, peas are high in protein and rich in amino acids, vitamins and minerals. Table 9 summarizes all peas studies reviewed in this paper. The GI range of peas was 9.0 ± 2.0 to 57.0 ± 2.0 when glucose was used as a reference. When GI was analyzed, with bread as a reference, a GI range of 45.4 ± 8.2 to 93.3 ± 9.4 was found. The highest GI (93.3 ± 9.4), with bread as a reference, was seen in the study by Marinangeli, Kassis, and Jones (2009),when whole yellow pea flour (WYPF) was reformulated to pasta and consumed by 22 healthy adults. This study showed the effect that processing and cooking has on GI. Marinangeli, Kassis, and Jones (2009) allowed peas to dry on the vine and then milled into flour, to create three different products: bread, biscotti and pasta. The bread and biscotti meals showed low GIs at 50.3 ± 8.0 and 45.4 ± 8.2, respectively; which may be a result of the lower surface area exposed to heat and reduced starch gelatinization. Marinangeli, Kassis, and Jones (2009) inferred that the pasta meal showed a high GI as its surface area was more exposed to the high cooking temperature of boiling water. This may cause starch granules to swell, leading to gelatinization, and subsequent digestion by enzymes (Marinangeli, Kassis, and Jones 2009). This gelatinization may not have been seen in the two other meals examined in this study as water was not added. In addition, according to Marinangeli, Kassis, and Jones (2009), the addition of 30% WYPF may not have been adequate to affect the glycemic response of wheat flour, and hence failed to reduce the GI.

However, when whole peas were added to a spaghetti meal, as seen in the study by Dodd et al. (2011), there was a reduction in GI from 56.0 (for spaghetti) to 38.0 (for spaghetti and peas). This was also seen in the reduction of GI from 72.0 (for potato) to 53.0 (for potato and peas) and 48 (for rice) to 38.0 (for rice and peas) (Dodd et al. 2011). This suggests peas may reduce the overall GI when added to meals. In addition, the type or species of peas may affect GI. Darabi et al. (2000) found that split peas had a lower GI than green peas. Split peas also resulted in a lower GI for diabetic subjects and may be more efficient than green peas, in controlling blood glucose and glycemic response (Darabi et al. 2000). There were no noticeable trends in GI increase or decrease for studies that reported fiber and protein information. It seems that processing method, cooking and type of peas may be the key indicators of the GI of peas.

Pigeon pea

Pigeon pea (*Cajanus cajan*) is a versatile legume with an estimated global production of 5.96 million tons as of 2018 (FAOSTAT 2019), grown primarily in India, Africa and Central America (Heuzé et al. 2016; Oboh and Agu 2010). Pigeon peas are high in fiber and contains approximately 24% protein (Gbenga-Fabusiwa et al. 2018). As such, it is expected to have a low GI. In fact, the GI of pigeon peas, when glucose was used as a reference ranged from 7.0 ± 1.0 to 54.5 ± 0.6. Table 10 outlines the pigeon pea entries reviewed in this paper. The study by Gbenga-Fabusiwa et al. (2018) looked at the substitution of wheat flour (WF) with pigeon pea flour (PPF). The study found that as the percentage of PPF was increased (as a substitute for WF), the GI of the meal decreased (Gbenga-Fabusiwa et al. 2018). Therefore, pigeon pea can be utilized to reduce glycemic response in meals.

Furthermore, it is interesting to note that as the amount, or percentage, of PPF was increased in the recipe used by Gbenga-Fabusiwa et al. (2018), the meal's overall content of protein, fat and fiber also increased in correlation. This may infer that a higher amount of protein, fat and/or fiber inversely affects GI. The highest GI, 54.5 ± 0.6 was seen in the Gbenga-Fabusiwa et al. (2018) study where the recipe contained 75% WF and 25% PPF. The increased WF content may be the reason for this higher GI since WF had a GI of 67.0 ± 2.4 (Gbenga-Fabusiwa et al. 2018). Also, the percentage of amylose increased as PP increased, and amylopectin percentage decrease subsequently (Gbenga-Fabusiwa et al. 2018). As such, the amylose/amylopectin ratio for 100% PPF was higher than 75%PPF > 50% PPF > 25% PPF (Gbenga-Fabusiwa et al. 2018). Therefore, this ratio points to the benefits of pigeon peas. Finally, the study by Oboh and Agu (2010), examined two species of pigeon peas, cream and brown. The study found no significant differences in the GI between the two species of pigeon peas (Oboh and Agu 2010). However, the brown variety of peas had a higher amount of protein, ash and fiber, while the cream variety had a larger fat content (Oboh and Agu 2010).

Mixed pulses

Mixed beans may aid in reducing glycemic responses and GI by adding additional nutrients and antinutrients to meals. For example, adding peanuts to beans have been shown to lower the overall GI due to the increase in fiber and protein (Mbhenyane et al. 2005). When pulses or beans are combined, it is expected that the GI may be lowered from the higher GI reported bean. The GI of mixed bean meals, when glucose was used as a reference ranged from 35.0 ± 5.0 to 65.9 ± 23.4. Table 11 summarizes all studies reviewed in this paper. The study by Fujiwara, Hall, and Jenkins (2017) used pulse protein in baked products, but found no significant difference for the GI of green lentil and pea protein granola bars. This was attributed to the extrusion process of the pulse protein included in the granola bars. When the GI of cookies were examined, the study found that fortifying the recipe with pulse protein decreased the GI from 42 ± 4 to 38 ± 3 (Fujiwara, Hall, and Jenkins 2017). The study by Sumathi et al. (1997), found that wheat malt, popped flour (blend of wheat and legumes) and roller dried flour (blend of wheat and legumes) each produced a different GI (glucose reference) of 65.9 ± 25.5, 40.4 ± 20.8 and 59.8 ± 24.2, respectively. This is to be expected since wheat flour has a higher GI than pulse-based flours. Roller dried flour may have a lower reported GI since the amount of heat used is less than the popped flour recipe. As heat disrupts carbohydrate integrity, a higher rate of digestion may be seen for foods processed at higher temperatures. Finally, the study by Mbhenyane et al. (2005) found that mixed beans with samp had a higher GI than stewed mixed beans. This is not surprising since the samp-meal GI may be

Table 10. GI of pigeon pea and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info- protein	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Pigeon Pea (100%), biscuits	100% Pigeon pea flour, ginger, aspartame, cocoa butter, skimmed milk, water, egg albumin	Ingredients were baked at 220 degrees C for 15 min	100	52.97 ± 0.01 %	15.32 ± 0.08 %	18.5 ± 0.02 %	1.47 ± 0.01 %	Healthy adults, 50 total (10 in each group)	Glucose, 3 hours	50	Capillary Blood	48.63 ± 0.31	–	Gbenga-Fabusiwa et al. (2018)
Pigeon Pea (75%), biscuits	75% Pigeon pea flour, 25% whole wheat flour, ginger, aspartame, cocoa butter, skimmed milk, water, egg albumin	Ingredients were baked at 220 degrees C for 15 min	100	55.38 ± 3.61 %	14.66 ± 0.08 %	18.03 ± 0.04 %	1.42 ± 0.01 %	Healthy adults, 50 total (10 in each group)	Glucose, 3 hours	50	Capillary Blood	51.67 ± 0.53	–	Gbenga-Fabusiwa et al. (2018)
Pigeon Pea (50%), biscuits	50% Pigeon pea flour, 50% whole wheat flour, ginger, aspartame, cocoa butter, skimmed milk, water, egg albumin	Ingredients were baked at 220 degrees C for 15 min	100	58.48 ± 0.01 %	13.73 ± 0.09 %	16.97 ± 0.04 %	0.85 ± 0.01 %	Healthy adults, 50 total (10 in each group)	Glucose, 3 hours	50	Capillary Blood	53.12 ± 1.22	–	Gbenga-Fabusiwa et al. (2018)
Pigeon Pea (25%), biscuits	25% Pigeon pea flour, 75% whole wheat flour, ginger, aspartame, cocoa butter, skimmed milk, water, egg albumin	Ingredients were baked at 220 degrees C for 15 min	100	59.37 ± 1.17 %	12.47 ± 0.08 %	16.30 ± 0.04 %	0.63 ± 0.04 %	Healthy adults, 50 total (10 in each group)	Glucose, 3 hours	50	Capillary Blood	54.47 ± 0.55	–	Gbenga-Fabusiwa et al. (2018)
Pigeon pea, boiled and cooked (cream variety)	Cream pigeon pea, water, spices, red palm oil	Pigeon pea boiled in water until tender	198	25.32/100 g	18.85 ± 0.02 g	21.35 ± 0.11 g	4.5 ± 0.01 g	Healthy adults, 25	Glucose, 3 hours	50	Capillary Blood	24 ± 3	–	Oboh and Agu (2010)
Pigeon pea, boiled and cooked (brown variety)	Brown pigeon pea, water, spices, red palm oil	Pigeon pea boiled in water until tender	190	26.33/100 g	15.85 ± 0.01 g	21.53 ± 0.02 g	5.0 ± 0.01 g	Healthy adults, 25	Glucose, 3 hours	50	Capillary Blood	24 ± 10	–	Oboh and Agu (2010)
Pigeon pea, cooked, boiled	Pigeon pea, water	Peas were soaked and boiled at a high setting for 5 minutes, and on low for 40 minutes	100	46.44	1.07%	21.42%	11.76%	Healthy adults, 11	Bread, 1 hour	50	Capillary Blood	–	30.99 ± 4.1	Panlasigui, Panlilio, and Madrid (1995)
Pigeon peas, boiled	Pigeon peas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50 g	–	–	–	Healthy adults, 7	Bread, 2 hours (converted to glucose x 0.7)	50	Capillary Blood	9 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)
Pigeon peas, boiled	Pigeon peas, water	Legumes were soaked in water overnight and boiled the next day for 20-45 min	–	50 g	–	–	–	Type 2 diabetes, 6	Bread, 3 hours (converted to glucose x 0.7)	50	Capillary Blood	7 ± 1	–	Trinidad, Mallillin, Loyola, et al. (2010)

Table 11. GI of mixed pulses and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat	Nutrient info- protein	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Green Lentil + Pea Protein Concentrate + Pea Protein Fiber Granola Bar	9% Green lentil flour and 4% puff (29.5% corn, 35% green lentil flour, 30% Pea Protein Concentrate, 5% Pea Fiber	Ground in coffee grinder	85	61.9%	20.10%	10.20%	6.30%	Healthy adults, 10	Bread, 2 hours (converted to glucose)	50	Unknown	35 ± 5	–	Fujiwara, Hall, and Jenkins (2017)
Green Lentil + Pea Protein Concentrate + Pea Protein Fiber Cookie	11% Green lentil flour, 0.6% Pea Protein concentrate, and 0.9% Pea fiber	Ground in coffee grinder	89	57.1%	31.10%	6.90%	3.10%	Healthy adults, 10	Bread, 2 hours (converted to glucose)	50	Unknown	38 ± 3	–	Fujiwara, Hall, and Jenkins (2017)
Cowpeas + Bambara groundnut with samp	Cowpeas, bambara groundnut	Cooked	–	50.02 g	0.8 g	12.6 g	11.4 g	Healthy adults, 10	Bread, 2 hours	50	venous blood	–	98.4 ± 29.1	Mbhenyane et al. (2005)
Cowpeas + Bambara groundnut stew	Cowpeas, bambara groundnut	Cooked	–	50.01 g	29.3 g	26.3 g	8.1 g	Healthy adults, 10	Bread, 2 hours	50	Venous blood	–	68.5 ± 42.1	Mbhenyane et al. (2005)
Mung bean + Chickpea + Mothbean-Wheat malt flour chapati	10 % Mung bean, 5%, Chickpea, 5% Mothbean, 75% Wheat malt, skim milk powder	Legumes were toasted, wheat was pulverized into flour	100	63.7	1.8 g	16.2 g	8.7 g	Healthy men, 7	Glucose, 2 hours	50	Capillary Blood	65.9 ± 25.5	–	Sumathi et al. (1997)
Mung bean + Chickpea + Mothbean-Popped flour chapati	10 % Mung bean, 5%, Chickpea, 5% Mothbean, 75% Wheat malt, skim milk powder	Legumes were toasted, wheat was pulverized into flour	100	59.4	2.6 g	15 g	12.2 g	Healthy men, 7	Glucose, 2 hours	50	Capillary Blood	40.4 ± 20.8	–	Sumathi et al. (1997)
Mung bean + Chickpea + Mothbean-roller dried flour chapati	10 % Mung bean, 5%, Chickpea, 5% Mothbean, 75% Wheat malt, skim milk powder	Legumes were toasted, wheat was pulverized into flour, roller dried	100	62.9	2.2 g	14.8 g	11.3 g	Healthy men, 7	Glucose, 2 hours	50	Capillary Blood	59.8 ± 24.2	–	Sumathi et al. (1997)

influenced by cooking, heat, and the low nutrient percentages (Mbhenyane et al. 2005).

Other pulses (bambara groundnut, lupin, Lima bean, mungo bean)

The GI of Bambara groundnut, lupin, lima beans and mungo beans are outlined in Table 12. Lupin was mentioned in two studies, with GIs of 72.0 ± 10.0, when glucose was used as a reference (Feldman et al. 1995), and 74.0 ± 9.6, when bread was the reference food (Hall, Thomas, and Johnson 2005). Only one study looked at lima beans, which had a reported GI of 16.0 ± 2.0 (Trinidad, Mallillin, Loyola, et al. 2010), when boiled and seasoned with salt. Lastly, one study looked at mungo beans, with a GI (glucose as reference) of 60.0 ± 7.0 when consumed by healthy adults, and 77.0 ± 7.0 when consumed by Type 2 diabetics (Urooj and Puttaraj 2000). It is important to note that all these studies, apart from the lima bean study, reviewed pulses as part of a mixed meal. As such, this may account for the higher than anticipated GIs. These sample sizes are too small to draw any significant conclusions. Therefore, further *in vivo* studies should be done to understand the glycemic response of these pulses when consumed as part of a meal.

Comparison of glycemic index of pulses

Table 13 reviews the reported GI ranges for each pulse category, based on all studies reviewed in this paper. The GI ranges (glucose and bread as a reference respectively) for each pulse type were: broad bean (40.5 ± 4.5 to 94.0 ± 4.0, 75.0 to 93.0), chickpea (5.0 ± 1.0 to 45.0 ± 0.8, 13.9 ± 3.0 to 96.0 ± 21.0), common bean (9.0 ± 1.0 to 75.0 ± 8.0, 18.0 ± 2.0 to 99.0 ± 11.0), cowpea (6.0 ± 1.0 to 56.0 ± 0.2, 38.3 ± 18.7 to 65.5 ± 7.4), lentil (10.0 ± 3.0 to 66.0 ± 6.0, 37.0 to 87.0 ± 6.0), mung bean (11.0 ± 2.0 to 90.0 ± 9.0, 28.0 ± 0.5 to 44.4 ± 5.8), peas (9.0 ± 2.0 to 57.0 ± 2.0, 45.4 ± 8.2 to 93.3 ± 9.4), pigeon peas (7.0 ± 1.0 to 54.5 ± 0.6, 31.0 ± 4.1), and mixed pulses (35.0 ± 5.0 to 65.9 ± 23.4, 68.5 ± 42.1 to 98.4 ± 29.1).

Factors affecting glycemic index of pulses

Nutrient content

The slow release of glucose has been known to lower GI (Jenkins et al. 1981), when eaten alone or as part of a meal. There are two main mechanisms to decrease GI which are: increasing insulin release due to higher protein content, and a higher content of fiber or fat which reduces carbohydrate absorption rate (Augustin et al. 2015). Table 2 reviews the protein, fat and fiber values for each type of pulse. Protein content, in the range of 20–30 g, as seen in all pulses reviewed in this study, increases insulin responses and decrease glycemic responses (Nuttall et al. 1984; Trinidad, Mallillin, Loyola, et al. 2010; USDA 2019). Fiber forms a barrier to the digestive enzymes, limiting absorption and access to starch (Bornet et al. 1987). Furthermore, dietary fat has been shown to reduce early glucose response and slow carbohydrate absorption due to delayed gastric

Table 12. GI of Other pulses (Bambara groundnut, lupin, lima bean, mungo bean)and study parameters.

Food Description								Participant statistics	Study parameters			GI		Reference
Food form	Ingredients used	Method of preparation	Serve size of the food (g)	Available carbohydrate g/serve	Nutrient info - fat (g)	Nutrient info- protein (g)	Nutrient info- Total Dietary fiber	Study participants type and number	Reference food used, duration of study for each participant	Reference food available carbohydrate (g)	Type of blood sample (venous/ capillary)	GI (Glucose =100)	GI (Bread = 100)	
Bread, Australian sweet lupin flour	Australian Sweet lupin flour, water, yeast, salt, canola oil	Baked	401	50	7.3	12.8	4.9	Healthy adults, 9	Bread, 2 hours (converted to glucose)	50	Venous blood	52	74 ± 9.6	Hall, Thomas, and Johnson (2005)
Melawach with lupin fiber	Wheat flour, sugar, soyabean oil, margarine, salt, lupin fiber and water	Lupin beans were soaked and dried overnight at 50 degrees C	–	–	–	–	–	Non insulin dependent diabetes mellitus (NIDDM), 14	Glucose, 3 hours	50	Venous blood	72 ± 10	–	Feldman et al. (1995)
Bambara nut, puddin	Bambara nut, hot water, pepper, palm oil, salt, banana leaves	Boiling water was poured to make gelatinized pap, steamed 1 hour	160	17.57	12.05	7.70	3.78	Healthy adults, 100	Glucose, 2 hours	50	Venous blood	40.13 ± 2.86	–	Nnadi and Keshinro (2016)
Bambara groundnut, ground and steamed (Okpa)	Bambara groundnuts, water, onions, salt, red palm oil, maggi cubes, ground crayfish	Seeds were milled into a paste, and steamed for 30 minutes	50	12.17	–	11.38	0.95	Type 2 diabetes, 10	Bread, 2 hours	50	Capillary Blood	–	59.13 ± 15.76	Onimawo et al. (2007)
Bambara groundnut, ground and steamed (Okpa)	Bambara groundnuts, water, onions, salt, red palm oil, maggi cubes, ground crayfish	Seeds were milled into a paste, and steamed for 30 minutes	50	12.17	–	11.38	0.95	Healthy adults, 7	Bread, 2 hours	50	Capillary Blood	–	77.94 ± 12.95	Onimawo et al. (2007)
Lima beans, boiled	Lima beans, water, seasoning	Seasoned to taste	100	50	–	–	20.9	Healthy adults, 10	Glucose, 2 hours	50	Capillary Blood	16 ± 2	–	Trinidad, Mallillin, Loyola, et al. (2010)
Black gram dhal and rice (idli and chutney)	Black gram dhal, parboiled rice	Soaked (5 hrs) fermented overnight, and steam cooked	240	–	9.6	11	10.8	Healthy adults, 11	Glucose, 2 hours	50	Venous blood	60 ± 7	–	Urooj and Puttaraj (2000)
Black gram dhal and rice (idli and chutney)	Black gram dhal, parboiled rice	Soaked (5 hrs) fermented overnight, and steam cooked	240	–	9.6	11	10.8	Type 2 Diabetes, 10	Glucose, 2 hours	50	Venous blood	77 ± 7	–	Urooj and Puttaraj (2000)

Table 13. Summary of GI of pulses with respect to reference meals.

Pulse Category	Reported GI range (Glucose = 100)	Reported GI range (Bread = 100)
Broad bean	40.45 ± 4.5 to 94 ± 4	75 to 93
Chickpea	5 ± 1 to 45 ± 0.8	13.87 ± 3.0 to 96 ± 21
Common bean	9 ± 1 to 75 ± 8	18 ± 2 to 99 ± 11
Cowpeas	6 ± 1 to 56 ± 0.19	38.33 ± 18.7 to 65.5 ± 7.44
Lentil	10 ± 3 to 66 ± 6	37 to 87 ± 6
Mung bean	11 ± 2 to 90 ± 9	28 ± 0.5 to 44.38 ± 5.8
Peas	9 ± 2 to 57 ± 2	45.4 ± 8.2 to 93.3 ± 9.4
Pigeon peas	7 ± 1 to 54.47 ± 0.55	30.99 ± 4.1*
Mixed pulses	35 ± 5 to 65.9 ± 23.4	68.5 ± 42.1 to 98.4 ± 29.1

*Value of one study.

emptying (Bell et al. 2015). Postprandial glycemia is also affected by the addition of protein, especially when combined with carbohydrates (Bell et al. 2015). Legume proteins are made up of tightly bound carbohydrates which slows digestion, while the removal of protein from white flour showed an increased digestibility (Thorne, Thompson, and Jenkins 1983). This suggests that protein, fat and fiber, found in pulses, may play a significant role in the decrease of GI.

Preparation and processing method

GI may also be affected by the type of food processing method used. Canned or fermented pulses have been attributed with higher GIs. This is due to the chemicals and preservatives, like acids, which aid in the breakdown of carbohydrates and starch, and a faster digestion rate upon consumption. For example, a study by Hughes et al. (2009) found that chickpea starches were degraded, and acid hydrolysis occurred when HCL (hydrochloric acid) was added to chickpeas. Cooking also makes the starch molecule more available for digestion, and subsequently lead to glucose absorption (Augustin et al. 2015). Heat alters the properties of starch, leading to gelatinization, and subsequent digestion as it becomes more susceptible to digestive enzymes (Bishnoi and Khetarpaul 1993). Cooking also splits the starch granules, leading to increased digestion as they become more available to amylase (Thorne, Thompson, and Jenkins 1983). Studies have fund that roasting resulted in a lower digestion rate than boiling and pressure cooking (Thorne, Thompson, and Jenkins 1983). Storing pulses in the refrigerator (cooling) prior to consumption was associated with decreased GI due to resistant starch reformation, compared to pulses consumed immediately after cooking. In addition, studies have found that blending, grinding, milling and pureeing, reduced particle size, contributing to the digestion rate due to exposure of surface area to digestive enzymes (Thorne, Thompson, and Jenkins 1983). These pulse preparation methods have been associated with a higher GI. Therefore, particle size and heat application to pulses affects GI.

Reference food and blood sampling type

Of the 154 entries reviewed in this study, 83 entries used bread as the standard reference food, 70 entries used glucose as the standard reference, while 1 entry used both bread and glucose as the standard references (25 studies converted one food to the other). When the study that used both bread and glucose were analyzed, an inter-conversion ratio of approximately 1.36 was found (Hettiaratchi, Ekanayake, and Welihinda 2009). However, prior studies (section "Reference food") have found more intraindividual variability upon bread consumption than glucose consumption. This suggests that using bread as a standard reference, or converting one standard reference type to another, may not be adequate indicators of GI. Furthermore, of the 154 entries reviewed in this study, 31 studies used venous blood to test the GIs of both healthy and diabetic subjects. These 31 studies used both bread and glucose as the standard references, therefore no significant conclusion can be drawn as to whether variations are observed due to reference food or blood sample type. However, variations in GI may observed when glucose and bread are used as the standard reference foods.

Diabetic subjects vs healthy adults

While previous studies have indicated that protein and fat, added to meals, may reduce the glycemic impact upon consumption, there have been studies that contradict this finding (Thannoun 2005). Some researchers have found that high fat and protein diets may induce insulin resistance by delaying or impacting the glucose response peak (Thannoun 2005). As such, protein and fat content of meals, may impact the glycemic reducing properties of pulses, which is most evident in diabetic subjects. Diabetic subjects showed a higher GI for pulses incorporated into meals when compared to healthy individuals, however, low GIs were seen when chickpeas, cowpeas, mung beans and pigeon peas were eaten alone. This suggests that these pulse categories may be more effective in mediating the GI response for diabetic individuals.

Conclusion

In general, pulses reduced the GI of foods when incorporated as part of a meal. Cooking and preparation methods are thought to affect GI upon consumption. Boiling and minimal heat applications tended to decrease GI by limiting access to digestive enzymes. This subsequently decreased digestion and gastric emptying, while reducing the glycemic response. Diabetic subjects showed a lower GI than healthy individuals for chickpeas, cowpeas, mung beans and pigeon peas when eaten alone. However, when combined in meals, GIs were found to be higher than that seen in healthy adults.

Variability in GI value may depend on the type of reference food used. Furthermore, some pulses evoked a greater response in reducing GI, which may be attributed to their nutrient content. In addition, different species of the same pulse category showed varied GI measurements. This may be due to the varied nutrient content in each species. It is important to note that many studies reviewed in this paper did not measure nutrient content of pulses or meals. Therefore, more detailed research needs to be conducted on GI values in pulses and pulse-based meals, and the effects of protein, fat, fiber, and the impact of heat application/processing on digestion.

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