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In-vitro protein and starch digestibility of seeds in legumes

Sneha Mishra, Rattan Deep Singh*
School of Bioengineering and Biosciences, Lovely Professional University, Phagwara, Punjab, India

Abstract

Various *In vitro* techniques are being used to processes different types of legumes, some of these are heating, pressure cooking, Puffing, baking, germination. Germination accompanied by cooking has been tested for the effect on the protein digestibility of chickpeas, horse grams, and cowpeas. The digestibility of the protein was not greatly enhanced by any of the therapies in the majority of the studies published. However, an increase in protein digestibility was observed for horse grams and cowpea after some of the different processing procedures. The glycaemic index can be estimated using starch *in vitro* digestibility tests (GI). There are no universally accepted methods, and no single measure is appropriate for all food types. Six *in vitro* results were considered using four-grain foods with different particle sizes and soluble fibre content. The use of chewing or mincing, mincing in a restricted versus non-restricted method with or without amylase, and incubation were differences in the process. With the help of cooking, the protein digestibility was decreased in all pulses. There was an improvement in the *in vitro* digestibility of carbohydrates which was caused by all types of therapies, except for germination. The impacts of various processing techniques such as soaking, autoclaving, and storing of resistant starch content and *in vitro* digestibility of pulses is discussed in this paper. It was found that these processes reduced the content of resistant starch (RS) in the sample taken. Furthermore, autoclaving significantly raises the glycaemic index (pGI) and slowly digested starch, according to *in vitro* starch digestibility (SDS). After autoclaving, however, there were decreases in easily digested starch (RDS) and starch digestive index (SDI). The results indicate that after synthesis therapies, RS and RDS are transformed to SDS. Furthermore, due to its higher SDS content, current research indicates that refined pigeon pea, green gram, and black gram dhals may have the potential to promote good health.

Keywords: *in vitro* processing, protein digestibility, starch digestibility, legumes

Introduction

Legumes are extensively used in the diets of India. Legumes, along with many essential vitamins and minerals, are an outstanding source of calcium, carbohydrates, and fibre. They are eaten globally in South Asian countries, including India, and are used as a staple food. In several countries, legumes are primarily eaten as a source of protein. Their use has been linked to a variety of health benefits, including lower cholesterol and type 2 diabetes regulation, as well as the prevention of various cancers and heart diseases (Riboli, 2002) [36]. The antioxidant potential of seed legumes has been attributed to many of these beneficial effects. Also, for many leguminous protein hydrolysates, angiotensin-converting enzyme inhibitory activity responsible for the anti-hypertensive effect was identified (Carlos *et al*, 2018) [4]. They are consumed in various parts of India after being processed in various ways based on culture and taste. However, there is minimal evidence from detailed reviews of multiple methods of production. Legumes contain a significant proportion of 55 to 60 percent carbohydrates and 15-20 percent protein. In different legumes, the structure of the carbohydrate varies, while starch is the key constituent. One of the most important factors determining the amount of nutrients in protein foods is its digestibility. This can be done *in vitro* with efficient hydrolytic enzyme or in vivo with animal experiments (usually rats).

Chickpea, lentil, cowpea, and horse gram antioxidant properties, as well as their ability to inhibit ACE, were investigated before and after various processing conditions and *in vitro* protein digestion (IVPD) (Yadav B S, 2010) [42]. Chemical studies have shown that the highest antioxidant production was in unprocessed horse grams. The ferric ion reducing power (FRAP) and radical scavenging (RSA), and metal ion chelation activity were all lost in both legumes after soaking (MICA). In these operations, cooking of the soaked seeds led to further declines. In all legumes except for white peas, germination increased MICA in chickpeas and lentils as well as TAC. Compared to *in vitro* approaches, the in vivo procedures are time-consuming and costly, and so many employees have used the latter since the usually satisfactory agreement was reached within in-vivo findings from rat bioassays. (Hoffman, 2004).

One of the key ingredients of the Indian diet is pulses. 12 different pulse crops have been cultivated in India. Chickpea, pigeon pea, moong bean, lentil, field pea, black gram, and other pulses are examples of Indian pulses. They're a great source of vitamins, sugars, and proteins. Pulses, which contain almost all of the essential amino acids, are the source of protein in the vegetarian Indian diet. Legumes are nutritionally essential, but due to the prevalence of anti-nutritional factors, their dietary use is indicated to be minimal. In pulse plants, starch is the main carbohydrate, which accounts for 22-45 percent of the dry matter. In diabetic conditions, intake of legumes is usually advised since they have a low glycemic index (GI). By comparing the postprandial blood glucose reaction with a reference food, the GI of the food is normally obtained (Kim *et al*, 2010) [18].

There are also two kinds of starch: digestible and non-digestible starch. Non-digestible starch is also recognized as resistant starch (RS) and involves SDS (slowly digestible starch) and RDS (rapidly digestible starch). The production of short-chain fatty acids after fermentation in the large intestine is usually mediated by RS, which is nutritionally important these days because of its many health benefits. RS is further divided into four levels: RS1, RS2, RS3, and RS46. Inside whole or partially milled grains or native seeds, RS1 reflects physically trapped starch. RS2 is ungelatinized starch, which, because of its lightweight and anhydrated form, is inaccessible to amylolytic enzymes. Retrograded starch is in the category of RS3 and exists in heat-processed or cooked foods. Chemically transformed starch6, 7, & 8 is RS4. RS is a functionally important type of starch that has been found in cereals in increased quantity by moist heat processes, especially autoclaving and autoclaving-cooling cycles9, 10. Furthermore, soaking had been found to be effective in growing RS9 and RS11 substance. The aim of this study was to see how different processing methods, such as soaking, autoclaving, storage, affected the starch content and *in vitro* digestion of starch in certain pulses from India. (Zhao *et al*, 2009) [43].

Digestibility

Protein digestibility is determined by several influences, both internally as well as externally. Internal variables include amino acid, protein folding and cross-linking, while the external factors are pH, and ionic strength conditions, temperature, as well as the presence of secondary molecules. Food production has a direct influence on these variables and, as a result, protein digestibility. These factors lead to variations in the digestibility of protein, as well as the impact of processing on cereal protein digestibility. Growth environment (e.g., drought and heat stress) can influence plant development. The pre-harvest factors also impact plant protein digestibility. (Impa *et al*, 2019) [16]

Internal Factors

Peptidases have a high degree of accuracy when it comes to hydrolysing peptide bonds that are similar to a particular amino acid. Profiles of protein amino acid, therefore, assess the protein's susceptibility to hydrolysis by specific peptidases. Furthermore, the peptidases must have easy access to these bonds of peptide and amino acids. Stretches of proline on protein sequences are recognized for being resistant to peptidase hydrolysis and lowering the protein chain's stability (Martinez-velasco *et al*, 2018) [21]. Gluten proteins, for example, contain a lot of proline, which is why it has low digestive rate. Protein aggregation that is too tight limits entry to the peptide chain, which delays hydrolysis. Protein digestibility is determined by factors that impair protein solubility (Wellner *et al*, 2005) [41].

External Factors

Anti-nutritional environment in cellular structures that protect proteins from peptidases are examples of external factors that restrict protein digestibility. Protease inhibitors including trypsin and chymotrypsin, and phytates are well-known antinutritional elements found in plants that inhibit protein digestion (Kostekli *et al*, 2017) [19]. Some other examples include haemagglutinins or lectins which are present in legumes and cereals, glycosylates which is found in mustard and canola protein products, in cottonseed protein products ossypol is found, saponins is present in legumes, beans, and tea. Non-catalytic sugar proteins known as lectins obstruct the hydrolysis of protein and are known for their high tolerance against proteolysis over a wide range of pH. As a result, they can be present in both fresh and refined foods that we consume every day (Nikmaram, *et al* 2017) [26].

In-Vitro Protein Digestibility of Legumes

Several studies have been reported to explain the *in-vitro* digestibility of protein. Peas are a good source of plant protein for humans, but their proteins are not as easily digestible as animal protein. Eight pea types with a broad spectrum of protein content were used to determine in-vitro protein digestibility (IVPD) using a multienzyme system containing trypsin, chymotrypsin, and peptidase to determine the correlation between composition and in-vitro digestibility of pea proteins. The IVPD of eight raw pea seeds was found to be in the range of 79.9-83.5% with significant variations (Park *et al*. 2010) [32].

Chickpea albumins' *in vitro* protein digestibility (IVPD) was investigated, as well as its potential relationship with their composition and the existence of trypsin inhibitor activity (TIA). Under non-reducing conditions, trypsin digestion of the albumin component was inadequate, while reducing inter- and intramolecular disulphide bonds improved the accessibility of trypsin-digestible sites. Temperature and heating time had an effect on trypsin inhibitor activity in the chickpea albumin fraction. While heating the albumin fraction at 100 °C for 30 minutes decreased the TIA by more than 50% compared to the initial operation, heat-resistant trypsin inhibitor was responsible for a significant portion of the TIA rate. The decline in TIA was unrelated to a rise in IVPD rates (Clemente *et al*. 2000) [6].

Several studies have been conducted to improve the biological value of traditional bean proteins. Some of the methods used to increase bean nutritional content include genetic enhancement of cultivars with higher protein digestibility and decreased rates of anti-nutritional factors, as well as pre-processing of beans through soaking and cooking (Mesquita *et al*., 2007) [23]. Enzymatic hydrolysis of proteins will increase the nutritional benefits and sensory attributes of these molecules, which is essential in the food industry (Nielsen and Borchert, 2000). Bean's proteases were used to change the structure of proteins, such as in the hydrolysis of soybean proteins, the solubilization of fish protein, meat softening, milk casein hydrolysis, and improving cheese texture, all of which improve the consistency and nutritive quality of the final products (Paddon-jones, 2015) [33]

Table 1: Conditions for processing of chickpea, horse-gram, and cowpea.

Sr. No.	Processing Methods	Conditions
1	Boiling of legumes	Boiled in water until turned soft. Kept in through-flow air-dried at 60 °C. Cooking times of different legumes- for chickpea its 100 min, horse-gram is cooked for 150 min, and then cowpea for 35 min.
2	Pressure cooking of legumes	Pressure cooked at 15 lbs until turned soft and dried as mentioned above. Cooking times are chickpea for 40min horse-gram for 45min.
3	Puffing of legumes	For puffing they are soaked in water. A jute bag is used for 60 min then roasting is done in hot iron pan with sand at 250 °C for 30-40 sec.
4	Frying of legumes	Flours were then made into a dough, extruded with the help of a hand press, and then deep fried in oil at 230 °C for 2 min.
5	Germination of legumes	Soaked for 6-10 hours in water, then germinated for 24 hours at room temperature (28-30 °C) on a wet jute bag before being freeze dried.
6	Germination and cooking of legumes	Freeze-dried legume cooked in boiling water until soft and then dried. Cooking times are chickpea for 100 min, horse gram for 120min, and cowpea for 30 min.

In horse gram, as opposed to the raw batch, most of the treatments increased digestibility, only frying reduced digestibility. The most significant changes were seen in germinated and cooked samples, accompanied by frying, puffing, and cooking under fire. The protein digestibility of cowpeas was found to be similar to that of horse gram. Many of the heat treatments, with the exception of frying, increased digestibility. For legumes that were germinated and then roasted, optimum digestibility was observed. The digestibility was decreased greatly by frying.

In-Vitro Starch Digestibility of Pulses

In the human diet, starch is the most common carbohydrate. According to present understanding of starch's nutritional properties, the polysaccharide's bioavailability in foods may differ greatly (Bhattarai *et al*, 2015). As a result, a nutritional category of dietary starch has been introduced, which includes rapidly digestible, slowly digestible, and indigestible or resistant fractions, taking into consideration both the kinetic aspect and the completeness of its digestibility. In addition to starch, legumes are rich in dietary fibre, which is in a form that makes cell walls resistant to dissolution during cooking (Bravo *et al*. 1998) [3]. The poor digestibility of starch in pulses may be attributable to this, as well as the inclusion of some anti-nutrients.

In vitro starch digestibility of unprocessed legumes

The *in vitro* digestibility of starch, the expected glycemic index (eGI), and flours produced from pea, lentil, and chickpea cultivated in similar conditions in Canada were investigated. Compared to pea and chickpea flours, lentil flour had a higher protein content and higher gelatinization transition temperatures. Chickpea flour had a reduced amylose (10.8–13.5%), but a significantly higher lipid content (6.5–7.1%) and a melting enthalpy of 0.7–0.8 J/g for amylose–lipid complexes. The starch digestibility and gelatinization characteristics of chickpea flour from desi (Myles) and Kabuli forms were found to be different considerably *in vitro* (FLIP 97-101C and 97-Indian2-11). Compared to pea and chickpea flours, lentil flour hydrolyzed more slowly and to a lesser degree. Chickpea flour had the highest amount of slowly digestible starch (SDS), but the lowest level of resistant starch (RS). Of all the pulse flours, lentil flour had the lowest eGI (Chung *et al*. 2008) [5].

Effect of Processing Methods on *In vitro* Starch Digestibility

Legume starches are more resistant to degradation than other starches, making them low-GI foods and possible substrates for effective gastric fermentation. However, the existence of oligosaccharides limits the acceptability of different legumes. Since beans contain a significant amount of resistant starch (indigestible), therefore various methods of processing like cooking, soaking, dehulling, and germination are used to decrease the content of resistant starch and increase the bioavailability of beans (Niba *et al*.2003) [25].

Cooking

The starch digestibility of cooked powdered black beans, a popular product in Mexico and Central America, was studied *in vitro*. To compare the properties of a consumer product to those of an experimental material obtained by seed pressure cooking and milling, and then drum drying was done. The amount of available starch ranged from 29 to 35 percent, while the amount of retrograded resistant starch (RS) was between 2.7 and 3.7 percent. The RS values for the experimental product were the largest. Both types of samples, especially the commercial formulation, were slowly digested by α-amylase, indicating that these products can cause low glycemic responses (Tovar *et al*. 2005) [40].

The starch digestibility of four major bean cultivars was studied after they were cooked. Cooking times ranged from 2.55 to 5.92 hours. The amount of available starch (AS) in the beans declined as storage time increased, and the bean sample with the lowest AS content (control sample, no storage) had the quickest cooking time. A similar trend was discovered for resistant starch (RS); the varieties with the longer cooking time had the widest variety of RS values, which were calculated as the difference between the control sample and the calculated value in the 96-hour sample. Every starch's retrograded RS (RRS) was determined by its diversity and, more importantly, its molecular structure. The rate of *in vitro*-amylolysis declined with storage time, and the samples with the lowest hydrolysis percentage had the highest RS content. Based on the particular dietetic use of beans, these findings indicate that some bean varieties might be suggested (Hoover R, 2010) [15].

The impact of cooking on anti-nutrients and starch, as well as *in vitro* starch digestibility, was investigated in white and black Mucuna pruriens var. utilis. Cooking or autoclaving raw seeds and pre-soaked seeds in various solutions (water, tamarind extract, sodium bicarbonate, and citric acid) decreased total phenolics, phytic acid, trypsin inhibitor, and chymotrypsin inhibitor activities significantly (p 0.05). Cooking and autoclaving, as compared to germination and dry heat therapy, contributed in a more significant (p 0.05) rise in protein and starch digestibility (siddhuraju, 2001) [39].

Soaking

A research on green gram revealed that soaking reduced significantly overall reducing, and non-reducing sugars and starch levels, as well as enhanced *in vitro* starch digestibility. Dehulling soaked seeds increased starch digestibility even more. Dehulling soaked seeds changed the protein, fat, ash, crude fiber, and sugar content significantly (Osorio-Diaz, 2005). The result of various solutions on the proximate composition and antinutrients, starch hydrolysis index (HI), and glycaemic index (GI) of *Mucuna pruriens* var utilis seeds, including water, 0.07 percent sodium bicarbonate, 0.1 percent ascorbic acid, and 3 percent moringa leaf powder in water, as well as soaking followed by autoclaving, were investigated. After soaking, the activities of absolute phenolics, tannins, phytates, saponins, L-dopa, trypsin inhibitor (TI), chymotrypsin inhibitor (CI), and lectin were found to be reduced. As compared to the raw seed sample, soaking increases total (TS) and digestible (DS) starch content (351-361 and 303-315 g kg-1, respectively) while decreasing resistant starch (RS) content (46.1-48.1 g kg-1) marginally (P 0.05). The rate of *in vitro* starch digestion in freshly processed seed samples was also investigated, and the HI and GI values were found to be comparable to those found in similarly processed legumes such as moth bean and black gram (Siddhuraju *et al*. 2005).

Soaking for 12 hours, germination for 60 hours, and pressure cooking on starch and protein digestibility of four moth bean showed that all four processing procedures, soaking, dehulling, germination, and pressure cooking, greatly improved starch digestibility. However, germination (60 hours) of soaked seeds (12 hours) was the most effective method for increasing starch and protein digestibility, followed by dehulling and soaking (12 hours) (Negi *et al*.2001) [27].

Germination and Dehulling

In control, germinated and dehulled green gram, cowpea, lentil, and chickpea, the content of nutrients and anti-nutritional components as well as *in vitro* bioavailability of calcium and iron and *in vitro* digestibility of starch were measured. After germination, both legume samples showed significant increases in protein, thiamine, *in vitro* iron and calcium bioavailability, and *in vitro* starch digestibility (P0.05). After dehulling the germinated legumes, an increase in the factors described was observed. Phytic acid and tannin content was reduced by 18–21% and 20–38%, respectively, after germination, with dehulled samples indicating a significant decrease. (Rashmi S and Urooj, 2004) Rice bean (RB-32) had slightly more gross soluble sugars (5.6g/100g) and non-reducing sugars (5.0g/100g) than fababean (p 0.05) (VH-82-1). In the other hand, fababean (53.2g/100g; 608.7mg/100g) had higher levels of starch and lowering sugars than rice bean (50.7g/100g; 547.3mg/100g). Whole raw seeds and husks of rice bean and fababean had starch digestibility (mg maltose released/g meal) of 30.8; 6.3 and 42.1; 6.3, respectively. *In vitro* starch digestibility of rice bean and fababean improved significantly (p0.05) after washing, sprouting, and dehulling. Germination for 24 hours in rice bean and 48 hours in fababean was found to be the most efficient, increasing starch digestibility by 100 to 90% compared to the power. The starch digestibility of soaked, dehulled, and germinated cowpeas was tested *in vitro* in two different forms, CS-46 and CS-88. Soaking for 12 hours, dehulling soaked seeds, and germination for various times (24, 36, and 48 hours) all helped to increase in-vitro starch digestibility. With an increase in germination time, there was a gradual increase in starch digestibility. The most effective approach for decreasing anti-nutritive components and thereby raising starch digestibility was dehulling soaked seeds.

Effect of Processing Methods On *In vitro* Protein Digestibility

Because of the inclusion of antinutrients, kidney beans have a poor protein digestibility. Some of these antinutrients often reduce the bioavailability of trace elements and proteins. Antinutrients (such as trypsin inhibitors, phytic acid, saponins, phytohemagglutinins, and tannins) and -galactosidase (such as raffinose, stachyose, and verbascose) are two undesirable components in beans that may reduce protein use (Gilani *et al*, 2012) [9]. Inactivation and/or elimination of unwanted components has been shown to improve the nutritional content and organoleptic acceptability of beans, allowing them to be used more widely as human food and animal feed. To improve kidney bean consumption, various processing methods such as frying, soaking, dehulling, and germination have been used (Arija *et al*. 2006) [1].

Cooking

Cooking decreases the amount of anti-nutritional ingredients (tannins and polyphenols) in beans while increasing protein supply (Gulati *et al*, 2017) [22]. Cooking considerably increased the *in vitro* protein digestibility of faba bean and white bean cultivars, with a median value of 89.66 percent for faba bean cultivar and a minimum value of 48.10 percent for white bean cultivar. Cooking faba and white bean cultivars are found to increase albumin and glutelin metabolism (Abusin *et al*.2009). Chickpeas' nutritional composition and anti-nutritional factors were studied using microwave cooking as well as other conventional cooking methods such as boiling and autoclaving (Cicer arietinum L.). Antinutritional factors minerals, and B-vitamins all decreased dramatically after cooking. Lysine, tryptophan, entirely aromatic amino acids, and sulphur-containing amino acids all reduced in concentration after frying. Cooked chickpeas, on the other hand, had higher levels of lysine, isoleucine, and overall aromatic amino acids. (Han *et al*, 2019).

The results of dry heat (roasting) and moist heat (boiling) on the *in vitro* protein digestibility, protein fractions, as well as other biochemical properties of African breadfruit (Treculia Africana) seeds that influence their use as a human food supply were examined. Chemical findings show that the crude protein and fat content of the unprocessed (raw) seeds were 1 percent and 13.7 percent, respectively. The raw seed had a lower amount of phytic acid (1.19 mg/g) than other commonly eaten pulses in Nigeria. The main seed proteins of African breadfruit seed were discovered to be albumin and globulin protein fractions, which made up 67.8% of the total protein in the raw seed. (Marinangeli *et al*, 2017)**.**

Germination

The impact of germination and drying temperature on the *in vitro* protein digestibility and physicochemical properties of dry red bean flours was investigated. The impact of particle size on bean flour's water absorption ability was investigated. Additionally, the impact of integrating soybean and cowpea into red bean flour on functional properties was studied. Protein digestibility increased with germination and also with drying temperature, according to the findings (Liu *et al*, 2019).

Antinutrient elimination and *in vitro* protein digestibility of three varieties of Phaseolus vulgaris were studied using hydration, autoclaving, germination, cooking, and their combinations. Owing to variations in oligosaccharide solubility and diffusion rates, the hydration process was used to minimize the total number of -galactosides. Heat-sensitive saponins, trypsin inhibitors, and phytohemagglutinin were lowered to undetectable levels when heating processes (cooking and autoclaving) were used. Cooking/autoclaving was more effective in reducing trypsin inhibitors, saponins, and phytohemagglutinins than hydration and germination. Due to metabolic activity, the germination process reduced raffinose, phytic acid, and tannins. In this analysis, the combined effect of germination and autoclaving processes produced the best results. The protein digestibility of the Roba bean variety increased during processing, suggesting that it has a significant potential for use as a raw material in the manufacture of value-added products (Shimelis *et al*.2007).

Soaking

A research was conducted to determine the effects of soaking black grams in various salt solutions at various temperatures and times, as well as different cooking methods, on tannin content and protein digestibility. By soaking black grams at 30° and 100°C for different periods of time, the tannin content was reduced to varying degrees. Soaking at 100°C, on the other hand, increased the rate of tannin extraction and shortened the tannin extraction time. Tannins were decreased by 22.14 percent when black grams were soaked in water at 100°C for 45 minutes, and 2.5 times when black grams were soaked in sodium bicarbonate solution with or without sodium chloride. After soaking black grams in sodium bicarbonate solution, the highest increase in protein digestibility was observed. As a result of cooking, tannin levels were decreased even further, and protein digestibility improved. (Rehman and Shah 1996).

The three-enzyme method was used to evaluate the *in vitro* protein digestibility (IVPD) of lentils, chickpeas, peas, and soybeans treated with ultrasound or high hydrostatic pressure (HHP) during soaking and then heated for 30 minutes at 98°C (trypsin, chymotrypsin, and peptidase). Soybeans had an IVPD of 72 percent, while dry green peas had an IVPD of 83 percent. After soaking, lentils improved their IVPD, but other legumes did not. The IVPD of the legumes increased by 2–13 percent after they were heated Although the results of ultrasound or HHP on legume IVPD were mostly inconclusive or negligible, soaking legumes in HHP for 1 hour and then heating them at 98°C for 30 minutes significantly increased their IVPD. (Han *et al*. 2007).

Dehulling

The in-vitro protein digestibility of faba bean seed from Italy showed that after dehulling and flaking, the digestibility improved significantly (Omosebi *et al*, 2018). Another research looked at the effects of dehulling on phytic acid, trypsin, chymotrypsin, and -amylase inhibitory activities, as well as tannins, in ten dry bean cultivars (*Phaseolus vulgaris* L.). Whole bean phytic acid levels ranged from 1.16-2.93 percent. The phytic acid content of beans significantly increased after dehulling (range 1.63-3.67 percent). After dehulling, the inhibitory activities of trypsin, chymotrypsin, and -amylase in the beans increased as well. Tannin levels were 33.7-282.8 mg catechin equivalent/100g beans in whole beans and 10.0-28.7 mg catechin equivalent/100g beans in dehulled beans, respectively. After the seed coats were removed, the tannin content of beans was reduced by 68–95 percent. Tannins were not found in Sanilac cultivars with white seeds, Great Northern cultivars, or Small White cultivars. After dehulling, bean protein digestibility *in vitro* was significantly increased (Shumoy *et al*, 2018.) The hulls of Niger seeds were removed using a hot lye treatment. Dehulling niger seeds increased protein and fat content from 24 to 35 and 31–53 g/100 g, respectively, thus lowering crude fibre content from 16.9 to 2.2 g/100 g. The water and fat absorption capacities of the dehulled flour were higher. Nitrogen solubility, emulsification ability, and foaming properties, on the other hand, decrease. (Osman, 2007).

Conclusion

Different types of processing are beneficial in increasing the digestibility of legumes. Processes that involve cooking gelatinize the starch and thus improve its digestibility by amylase. As the cooking destroys the trypsin inhibitors and denatures the protein, proteolytic digestion is also improved. In foodstuffs in which trypsin inhibitors are highly active, the beneficial effect of cooking is high (e.g., horse gram and cowpea). Deep fat frying has been found to cause slightly lowered carbohydrate and protein digestibility as compared with other forms of cooking. The RS content of dhals of pulses pigeon pea, green gram, and black gram was substantially reduced by the processing methods. RS and RDS were transformed to SDS during autoclaving processing, according to the results of an *in vitro* starch digestibility analysis. The main findings of our current study are increased starch bioavailability, decreased RS material, and conversion of RS and RDS to SDS after processing treatments in pigeon pea, green gram, and black gram. This study's findings also indicate that processed pigeon pea, green gram, and black gram dhals may have additional health-promoting potential due to their high SDS content, especially in the treatment of diabetes.

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