Chemical Composition and Antinutritional Factors of Field Peas (*Pisum sativum*), Chickpeas (*Cicer arietinum*), and Faba Beans (*Vicia faba*) as Affected by Extrusion Preconditioning and Drying Temperatures

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ABSTRACT

Legumes are valuable plant sources of protein and energy and extrusion is one of the most common processing methods for manufacturing both human food and animal feeds. In the present study, three different legumes (field peas, chickpeas, and faba beans) were ground and processed in a pilot-scale extrusion line. Various preconditioning and dryer temperatures were applied to each legume separately that reflected or differed from standard manufacturing conditions. Although literature exists regarding the effects of extrusion temperature and moisture on legume antinutrients, no data are available on the respective effects of preconditioning and drying. The aim of the study was to evaluate the effects of processing on both nutritional and antinutritional factors for each processing combination. Proximate composition, starch, oligosaccharides, total nonstarch polysaccharides (NSP), soluble (S-NSP), and insoluble (I-NSP) levels were evaluated. The antinutritional factors phytic acid, tannins, and trypsin inhibitors were also determined. Chickpea and field pea NSP values were not drastically affected by processing, while for most processing conditions, total NSP, S-NSP, and I-NSP were slightly reduced in faba beans. Preconditioning before extrusion processing generally improved the nutritional value of the ingredients by significantly reducing trypsin inhibitor level. Phytate and total tannin levels were greatly reduced irrespective of the preconditioning and drying treatment. Wet preconditioning can be used in combination with extrusion to improve the nutritional value of legumes, while drying at 90–150°C does not significantly further reduce antinutritional factor levels.

Legumes such as faba beans, chickpeas, and field peas are valuable potential sources of both protein and energy for human consumption and in animal feeds. These crops are cultivated in the Mediterranean countries as well as in the rest of the world. However, it is well known that the use of legumes, especially as feed for monogastric animals, is limited due to the presence of various antinutritional factors (ANF).

Some of the most important ANF in legumes are trypsin inhibitors, phytic acid, tannins, and also oligosaccharides. Trypsin inhibitor is a crystalline globular protein that depresses the growth rate of mammals, chickens, and fish and also cause pancreatic hypertrophy (Hendricks 2002). Phytic acid is the hexaphosphate of myo-inositol and is a constituent of all cereals and oilseed meals. It has the capacity to tightly bind divalent cations such as calcium, magnesium, and zinc, rendering them unavailable to animals when ingested (Hendricks 2002). Tannins are secondary compounds of various chemical structures widely occurring in the plant kingdom and are generally divided into hydrolysable and condensed tannins. Their antinutritional effects include interference with digestive processes by binding enzymes or by binding to feed components such as proteins or minerals (Liener 1989). Tannins also reduce the absorption of vitamin B_{12} while they interact with other antinutrients. For instance, interaction between tannins and lectins seems to reduce the inhibitory action of tannins on amylase (De Boer and Bickel 1988) and interaction with cyanogenic glycosides reduces the deleterious effects of the latter (Bromley 1994)

Oligosaccharides are low molecular weight carbohydrates containing α-galactosidic and β-fructosidic linkages. Sucrose, and raffinose-series oligosaccharides (RSO, raffinose, stachyose, and verbascose) have been implicated as causative factors of osmotic effects in the intestine, and anaerobic fermentation of these sugars results in increasing gas production (Van Barnevelt 1999).

Monogastric animals typically lack the enzymes needed to degrade nonstarch polysaccharides (NSP) in the digestive tract such that they can be fermented only by intestinal flora (Dabrowski and Guderley 2002). The presence of soluble NSP (S-NSP) reduces evacuation rate and increases the residence time of digesta in the intestine (Van Der Klis and Van Voorst 1993), while insoluble NSP (I-NSP) causes opposite effects (Kirwan et al 1974). Pectins and gums tend to increase the viscosity of the digesta in chickens, resulting in lower digestibility and absorption (Choct et al 1995), probably by obstructing the ability of enzymes to act in the bulk of the digesta.

To overcome the problems caused by antinutritional factors, a variety of techniques has been examined already in plant materials such as soaking (Frias et al 2000), boiling (Marquez and Alonso 1999), autoclaving (Mansour et al 1993), microwaving (Marconi et al 2000), roasting, dehulling, germination, fermentation (Chitra et al 1996), supplementation with enzymes (Riche and Garling 2004), and extrusion cooking (Abd El-Hady and Habiba 2003).

To eliminate the effects of antinutritional factors and to improve the physical (texture and palatability) and chemical (starch gelatinization) characteristics of foods or feeds, modern technology applies extrusion processing (Björck and Asp 1983; Sorensen et al 2009). An extrusion processing line includes a series of different pieces of apparatus such as a grinder, preconditioner, extruder, dryer, and cooler that have a wide range of abilities and can differentiate the final product, depending on steam and water quantity, pressure, mechanical shear, temperatures, duration of application, and die dimensions (Thomas and van der Poel 1996; Thomas et al 1997).

Extrusion is effective in the inactivation of trypsin inhibitor (Aslaksen et al 2007), while temperature does not seem to improve bioavailability of minerals bound by phytic acid (Francis et al 2001). The positive effect of extrusion on digestibility of all nutrients in plant feedstuffs could be attributed to a partial degradation of NSP (Francis et al 2001). However, this degradation is not sufficient to consider NSP as heat-labile antinutritional factors (Alonso et al 2001).

The effects of extrusion conditions and in particular of extrusion temperature and moisture on some legume (peas, cowpeas, and beans) antinutritional factors (lectins and trypsin inhibitors) were studied previously (van der Poel 1992; Coffey et al 1993). The effects of certain extrusion conditions on the physical proper-

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ties of various legume extrudates have also been studied (Avin et al 1992; Bhattacharya and Prakash 1994).

Although there is literature on the effects of extrusion temperature and moisture on legume antinutrients, as previously discussed, there appear to be no data on how other extrusion conditions such as preconditioning and drying temperatures affect legume composition. The aim of the present research was to investigate how both the chemical composition and certain key antinutritional factors of peas, chickpeas, and faba beans are affected by two different preconditioning temperatures and three different drying temperatures.

MATERIALS AND METHODS

Processing System

Extrusion processing of raw legumes and diets took place at the BioMar Tec Centre (Brande, Denmark) using a Clextral BC 45 twin-screw extruder with a screw diameter of 55 mm, an overall active length of 800 mm, and turnaround time of 15 sec (Table I). All legumes were ground to a fine flour (1.5 mm) just before heat processing. Legumes and diets were precooked before entering the extruder in a homemade single-step conditioner (350 rpm) with a length of 120 cm and a diameter of 25 cm, distances between paddles of 8 cm, and a turnaround time of 20 sec. Legume flour was preheated and humidified for 20 sec (turnaround time) before entering the extruder. The temperature at the first part of the extruder, at the middle part, and at the outer die (4 mm) of the extruder was constant for each treatment. Extrudates were conveyed into a six-level Geelen dryer. After drying, pellets were put into a Geelen cooler to cool quickly to room temperature.

Processing of Tested Ingredients

Pea (P), chickpea (CP), and faba bean (B) whole seeds were ground to fine flour (grain diameter 1.5 mm) and processed separately. Each treatment combination was applied once.

Flours were first treated in the preconditioner. The temperature was 70°C for the low (Lp), 90°C for the middle (Mp), and 100°C for the high temperature preconditioner treatment (Hp). A sample was taken of each material during the middle preconditioner treatment (Mp/–), at the extruder exit, without being dried. These samples contained >20% moisture and they were freeze-dried before the analysis (Px, CPx, Bx).

The extruder was operated at 380 rpm and the feeder was set to deliver 107–116 g/min (wet basis). Moisture contents were consistent in both barrels with a water flow of 12.5 kg/hr in the extruder barrel. The extrudates were conveyed into a six-level dryer and the temperature lowered from 120 to 90°C for the low (Ld) and from 150 to 120°C for high dryer treatment (Hd) as measured just after the steam battery for the dryer (3 m beside the dryer) at two different points (between levels 1 and 2 and between levels 4 and 5) that explain the temperature drop from the steam battery to the dryer. Processing conditions are presented in Table II.

Seed samples, either extruded or not, were ground to pass a 0.5-mm sieve using a ball-mill to obtain a fine flour that was subsequently analyzed for chemical composition.

Chemical Analysis

Proximate composition of raw and extruded ingredients was determined. Dry matter, ash, and nitrogen (Kjeldahl method) were determined according to official methods (AOAC 1990). Crude protein was calculated as % nitrogen × 6.25. Total fat was determined by ether extract after prehydrolysis with hydrochloric acid (4.0*M*). Starch was measured by an enzymatic method using a total starch assay kit (AA/AMG) (Megazyme International, Ireland) (McCleary et al 1992) using thermostable α-amylase and amyloglucosidase. A slight modification of the DMSO methodology was followed to achieve better solubilization of starch. This included incubation of the samples for 15 min in DMSO in a boiling water bath under continuous stirring.

Total and insoluble nonstarch polysaccharides (NSP) were determined spectrophotometrically according to the method described by Englyst et al (1994) and S-NSP was calculated by the difference of I-NSP and total NSP. Quantification of NSP contents was achieved using a standard curve derived from a standard sugar solution consisting of arabinose, glucose, and galacturonic acid. The modified standard solution was based on the actual sugar proportions found in literature for peas, chickpeas, or faba beans (Knudsen 1997).

Oligosaccharides of the raffinose family (raffinose, stachyose, and verbascose) as well as the sucrose and glucose contents were measured spectrophotometrically with Megazyme raffinose-series oligosaccharides/D-glucose assay kit. Trypsin inhibitor activity was determined by the method of Smith et al (1980). Total tannins were extracted by the method described by Budini et al (1980) and measurement was based on the Prussian Blue method described by Graham (1992). Phytate was determined according to Latta and Eskin (1980) using an anion-exchange column (AEC) with resin (AGI-X4, 100–200 mesh chloride, Bio-Rad Laboratories). All analyses were conducted in triplicate.

Statistical Analyses

Differences in the composition of the studied legumes were examined by one-way analysis of variance (ANOVA). Two-way analysis of variance (MANOVA, General Linear Model) was conducted for each legume separately, using preconditioner and dryer temperature as the independent factors, to evaluate the effects of different processing conditions on the composition and antinutritional factors of legumes. Mean values were compared by Tukey HSD test with confidence levels of 95% (SPSS 16.0).

RESULTS

Chemical composition and antinutritional factors of the seeds depend on legume type (Tables III and IV). Raw faba beans had a higher protein content, followed by chickpeas and peas. Fat content was very low and similar for faba beans and peas and higher for chickpeas. Raw and processed faba beans had higher ash content compared to chickpeas and peas. The starch contents observed for peas and chickpeas were higher than that of faba beans.

Faba beans contained the highest levels of total NSP, followed by peas and chickpeas, while I-NSP to S-NSP (I/S) ratio in raw materials was similar for peas and chickpeas, which were both higher than faba beans. Faba beans contained the highest levels of phytate and tannins; raw chickpeas contained highest levels of TI.

Total oligosaccharide values were higher for raw peas followed by chickpeas and faba beans. The free glucose amount was negligible in all cases. Sucrose values were similar for raw chickpeas and peas and lower for faba beans, while raffinose-series oligosaccharides (RSO) were higher in raw peas, followed by chickpeas and faba beans.

TABLE I
Description of 800-mm Extruder Screws (pitch, length) from Feeder Side to Outlet Die

Extruder Clextral BC 45	Inlet Pitch/Length	Pitch/Length	Pitch/Length Twin Flight	Pitch/Length	Pitch/Length	Pitch/Length	Outlet Pitch/Length
mm	50/200	15/100	50/100	25/50	25/100	25/100	15/100

Trypsin inhibitors were significantly higher for raw chickpeas than peas and faba beans. Phytate values were higher for faba beans followed by chickpeas and peas, and total tannins were higher in faba beans followed by peas and chickpeas.

Thermal processing generally increased starch values of the processed materials but different results were observed for the NSP of each legume. Chickpea and field pea NSP were not much affected by processing, with only a small trend of reduction in total and I-NSP, while faba beans had similar results for only Mp/– processing. For all the other processing treatments in faba beans, total NSP, S-NSP, and I-NSP seem to be slightly reduced. Heat processing slightly reduced total oligosaccharides in most of the cases in peas and increased them in faba beans and chickpeas. TI was reduced for all processed products with the greatest reduction in chickpeas (86–92% reduction). Limited and nonlinear changes were observed for antinutritional factors such as phytate and tannins after heat treatment. Overall, phytate and total tannins were either little affected or unaffected by processing. Phytate values were reduced ≤22% for B, 16% for CP, and 18% for P, while total tannins reduced by ≤11% for B, 18% for CP, and 12% for P.

As a proportion of the total variation (Table V), preconditioner temperature affected the studied parameters more than dryer temperature, and interaction of the two had the least effect. In addition, faba beans parameters were affected more than chickpeas and peas. Insoluble NSP and TI were significantly affected only by precondition-extruder processing for the three legumes, while total tannins and phytic acid were affected by drying temperature.

TABLE II
Processing Conditions for Faba Beans (B), Chickpeas (CP), and Peas (P) in Preconditioner (p) and Dryer (d) at Low (L), Middle (M) or High (H) Temperature

	Processing Conditions								
	Lp/Ld B1	**Mp/Ld B2**	**Mp/Hd B3**	**Hp/Hd B4**	**Hp/Ld B5**	**Mp/– Bx**	**Lp/Ld CP1**	**Mp/Ld CP2**	**Mp/Hd CP3**
Preconditioner (ºC)	70.5	91	91	100	100	91	70.5	91.4	90.2
Extruder									
Extruder rpm	378	378	379	379	380	378	381	381	381
Ampere	19	20	21	22	19	19	19	18	20
Feeder (g/min)	110	113	111	115	113.5	119	116.1	107.5	111.3
Water (kg/hr)	14	15	14.9	14.9	14.9	15	12.6	12.5	12.5
Outlet die (°C)	108	111	113	112	108	116	110	110	110
Front (°C)	93.5	96	94.5	94.5	94	96	95.2	93.9	94.4
Middle (°C)	70	70	70.5	71	71.5	70	67.8	70.3	70.3
Dryer									
Steam between levels 1 & 2 (°C)[a]	120	121	147	147	122	121	120	120	150
Steam between levels 4 & 5 (°C)[a]	89	91	119	117	91	91	90	90	120
Level 1 (°C)	85	77	86	87	76	77	78	78	91
Level 2 (°C)	97	93	104	105	91	93	92	92	106
Level 3 (°C)	93	91	104	103	89	91	90	90	106
Level 4 (°C)	72	67	82	81	71	67	69	69	84
Level 5 (°C)	69	67	84	83	69	67	66	66	85
Level 6 (°C)	71	63	84	73	72	63	63	63	82
Cooling	YES	YES	YES	YES	YES	YES	YES	YES	YES

[a] Measured temperature just after steam battery for dryer (3 m beside the dryer) that explain temperature drop from steam battery to dryer.

TABLE II *(continued)*
Processing Conditions for Faba Beans (B), Chickpeas (CP), and Peas (P) in Preconditioner (p) and Dryer (d) at Low (L), Middle (M) or High (H) Temperature

	Processing Conditions								
	Hp/Hd CP4	**Hp/Ld CP5**	**Mp/– CPx**	**Lp/Ld P1**	**Mp/Ld P2**	**Mp/Hd P3**	**Hp/Hd P4**	**Hp/Ld P5**	**Mp/– Px**
Preconditioner (ºC)	99.9	100	91.4	70.5	91.4	90.2	99.9	100	91.4
Extruder									
Extruder rpm	381	381	381	381	381	381	381	381	381
Ampere	18	19	18	19	18	20	18	19	18
Feeder (g/min)	113.7	110.6	107.5	116.1	107.5	111.3	113.7	110.6	107.5
Water (kg/hr)	12.5	12.5	12.5	12.6	12.5	12.5	12.5	12.5	12.5
Outlet die (°C)									
Front (°C)	105	111	110	110	110	110	105	111	110
Middle (°C)	94.7	94.7	93.9	95.2	93.9	94.4	94.7	94.7	93.9
Dryer	69.4	70.7	70.3	67.8	70.3	70.3	69.4	70.7	70.3
Steam between levels 1 & 2 (°C)[a]									
Steam between levels 4 & 5 (°C)[a]	150	120	120	120	120	150	150	120	120
	120	90	90	90	90	120	120	90	90
Level 1 (°C)									
Level 2 (°C)	94	79	78	78	78	91	94	79	78
Level 3 (°C)	108	92	92	92	92	106	108	92	92
Level 4 (°C)	108	90	90	90	90	106	108	90	90
Level 5 (°C)	85	67	69	69	69	84	85	67	69
Level 6 (°C)	86	66	66	66	66	85	86	66	66
Cooling	YES	YES	YES	YES	YES	YES	YES	YES	YES

[a] Measured temperature just after steam battery for dryer (3 m beside the dryer) that explain temperature drop from steam battery to dryer.

DISCUSSION

The proximate composition of legumes varies considerably with species and also with climate and soil quality (Nikolopoulou and Grigorakis 2008). Field pea protein, starch, fat, ash, and NSP levels are within the range reported by Nikolopoulou et al (2007) for different pea cultivars. A wide variation in protein content (20–41%) has been reported, while whole dried seeds also contain 1.3% fat, 59.4% total carbohydrate, and 3.0% ash (Chavan et al 1989) in agreement with the present findings. The protein content of raw chickpeas in the present study was in the upper limit of the range reported by Abd El-Hady and Habiba (2003) of 25–26.5%, while starch values were toward the lower limit when compared to values of 43.5 and 52.6% reported by Rehman and Salariya (2005) and Frias et al (2000), respectively. Fat and ash levels of chickpeas were comparable to those reported in the literature (Singh et al 2004).

Trypsin inhibitor contents are overall higher for chickpeas than peas and faba beans (Guillamón et al 2008). Chickpea TI values in the present study were higher than for the other legumes, but also considerably higher than values in the literature (Frias et al 2000; Guillamón et al 2008). In contrast, Abd El-Hady and Habiba (2003), reported TI values for chickpea similar to those reported here. Such variations could be related to the legume cultivars and the different cultivation conditions. Phytic acid and total tannins were in the range of previously reported values (Peterson and Mackintosh 1994; Saini 1995; Nikolopoulou et al 2007).

Present findings agree with the literature ,where no protein, ash, or lipid content alteration was observed after extrusion of peas, chickpeas, and faba beans (Alonso et al 2000b; Abd El Hady and Habiba 2003).

Heat treatment of grains causes starch gelatinization where the crystalline structure of starch melts and is destroyed under high temperature; starch granules are ruptured and substrate becomes more accessible and readily hydrolyzed by enzymes (Alonso et al 2000a). Starch levels increased in the processed materials, possibly as a result of composition changes in the resistant starch and easier hydrolysis of extruded starch granules by amylase during analysis. Resistant legume starch corresponds to physically inaccessible starch that is entrapped in the cellular matrix (Englyst et al 1992) and, in most cases, this is broken down by processing (Gonzalez-Soto et al 2006). Thermal processing such as cooking has caused a significant reduction in resistant and poorly digestible starch and an increase of rapidly digestible starch in peas (Periago et al 1996), chickpeas, and common beans (Marconi et al 2000).

Total NSP in all extruded faba beans and peas was reduced compared to respective raw product values. Extruded chickpeas also had lower total NSP values, but the reduction was smaller and these results are in agreement with those of Alonso et al (2000b) for extruded peas. Rice showed a redistribution of S-NSP and I-NSP after press cooking (Sagum and Arcot 2000) or in cooked chickpeas and common beans (Marconi et al 2000) with increase of S-NSP and decrease of I-NSP (reduction of I/S-NSP ratio) after treatment. This may be comparable to results for extruded chickpeas and peas in the present study, although total NSP were not affected in pressure cooking (Marconi et al 2000). Anguita et al (2006) also noted that extrusion can increase solubilization of pea NSP. However, in the present study, solubilization was less pronounced and NSP contents were higher and this may be attributed to differences in field pea cultivar. Redistribution of S-NSP and I-NSP fractions could be attributed to the partial solubilization or depolymerization of hemicellulose and insoluble pectic substances (Vidal-Valverde et al 1992). When subjected to drying, faba bean flour in the present study showed decreased values of S-NSP, as opposed to that found for peas and chickpeas,

TABLE III
Proximate Composition (dry matter basis) of Raw and Processed Faba Beans (B), Chickpeas (CP), and Field Peas (P), Processing Conditions for Peas, Chickpeas, and Faba Beans in Preconditioner (p) and Dryer (d) at Low (L), Middle (M) or High (H) Temperature

		Proximate Composition[b]								Oligosaccharides[c]			
	Process[a]	Ash	Protein	Fat	Starch	S-NSP	I-NSP	I/S	Total NSP	F-Glucose	Sucrose	RSO	Total
B raw	–	4.3	31.4	1.6	36.9	7.6	16.1	2.1	23.7	0.20	0.9	2.8	3.9
B1	Lp/Ld	4.5	32.1	2.0	38.1	4.9	15.6	3.2	20.5	0.14	0.9	3.4	4.4
B2	Mp/Ld	4.3	31.2	2.0	39.6	5.4	14.4	2.6	19.8	0.14	0.9	2.9	3.9
B3	Mp/Hd	4.2	30.8	1.7	35.0	3.9	14.4	3.7	18.3	0.11	1.2	2.9	4.2
B4	Hp/Hd	4.2	31.7	2.0	39.1	3.6	14.7	4.1	18.3	0.13	1.4	2.4	3.9
B5	Hp/Ld	4.2	30.8	2.0	37.0	3.6	15.6	4.4	19.2	0.11	1.4	2.6	4.1
Bx	Mp/–	4.4	31.2	2.1	34.0	8.6	9.8	1.2	18.4	0.17	1.2	2.7	4.1
SEM[d]		4.3 ± 0.1	31.3 ± 0.5	1.9 ± 0.2	37.1 ± 2.1	5.4 ± 2.0	14.4 ± 2.1	3.0 ± 1.1	19.7 ± 1.9	0.14 ± 0.03	1.1 ± 0.2	2.8 ± 0.3	4.1 ± 0.2
CP raw	–	3.5	27.0	5.5	41.9	2.9	10.9	3.7	13.8	0.04	1.4	3.7	5.1
CP1	Lp/Ld	3.6	27.5	5.1	47.4	3.8	9.8	2.6	13.6	0.05	1.4	3.5	5.0
CP2	Mp/Ld	3.6	26.7	5.3	45.0	4.1	9.4	2.3	13.5	0.02	2.0	3.5	5.5
CP3	Mp/Hd	3.5	27.5	5.6	41.2	3.5	9.4	2.7	12.9	0.01	2.1	3.4	5.5
CP4	Hp/Hd	3.5	27.8	5.6	45.6	3.2	10.2	3.2	13.4	0.02	2.1	3.4	5.5
CP5	Hp/Ld	3.5	27.3	5.5	45.5	3.8	9.4	2.5	13.2	0.03	2.0	3.5	5.5
CPx	Mp/–	3.5	26.5	5.0	44.2	3.9	9.7	2.5	13.6	0.01	1.6	4.0	5.6
SEM		3.5 ± 0.0	27.2 ± 0.5	5.4 ± 0.2	44.4 ± 2.2	3.6 ± 0.4	9.8 ± 0.6	2.8 ± 0.5	13.4 ± 0.3	0.03 ± 0.02	1.8 ± 0.3	3.6 ± 0.2	5.4 ± 0.2
P raw	–	3.4	24.4	1.6	42.2	3.5	12.9	3.7	16.4	0.03	1.3	5.3	6.6
P1	Lp/Ld	3.7	25.6	1.9	43.2	4.6	10.9	2.4	15.5	0.05	1.3	4.2	5.6
P2	Mp/Ld	3.5	25.6	2.0	44.2	4.8	9.8	2.1	14.6	0.05	1.3	4.5	5.9
P3	Mp/Hd	3.4	25.3	1.8	44.9	5.7	8.9	1.6	14.6	0.05	1.4	4.5	6.0
P4	Hp/Hd	3.3	24.4	1.8	45.3	3.7	11.2	3.0	14.9	0.05	1.2	4.9	6.2
P5	Hp/Ld	3.5	25.6	1.9	44.2	4.8	10.5	2.2	15.3	0.06	1.2	5.3	6.6
Px	Mp/–	3.8	26.8	2.7	44.0	4.3	9.7	2.3	14.0	0.07	1.2	5.0	6.3
SEM		3.5 ± 0.2	25.4 ± 0.8	2.0 ± 0.4	44.0 ± 1.0	4.5 ± 0.7	10.6 ± 1.3	2.5 ± 0.7	15.0 ± 0.8	0.05 ± 0.01	1.3 ± 0.1	4.8 ± 0.4	6.2 ± 0.4

[a] Processing treatments with low (L), middle (M), and high (H) preconditioner (p) temperature and low (L) or high (H) dryer (d) temperature.
[b] NSP, soluble nonstarch polysaccharides; I-NSP, insoluble nonstarch polysaccharides; I/S, insoluble/soluble NSP fraction; Total NSP, total nonstarch polysaccharides.
[c] F-glucose, free glucose; RSO, raffinose-series oligosaccharides.
[d] Pooled standard error of the means.

and the results of the aforementioned reports. On the contrary, when faba bean flour was not dried, S-NSP increased. Different behaviors between legumes could be attributed to differences in the synthesis and composition of the NSP fraction. For example, pea uronic acids and mannose show an increasing trend, while xylose does not change under extrusion, and rhamnose and arabinose show a decreasing trend (Alonso et al 2000b). Different trends were reported by Periago et al (1996) between raw and cooked peas for NSP fractions, indicating that differences could be expected in the behavior of NSP fractions of legumes depending on the processing method.

Alonso et al (2000b) found that pea sucrose, raffinose, and verbascose were increased after extrusion, but significant differences were observed only for verbascose values, while stachyose values significantly decreased. In a more recent study, the same authors (Alonso et al 2001) found that pea and kidney bean sucrose, stachyose, and verbascose did not differ before and after extrusion, while raffinose significantly decreased in kidney beans. In addition, autoclaving rapeseed for 1.5 hr resulted in decreased levels of sucrose and stachyose (Mansour et al 1993). In this respect, the effect of extrusion on total oligosaccharides could also be dependent on the fraction composition, and this could be variable among different pulses or seed parts such as hulls, dehulled seeds, or protein concentrates (Knudsen 1997).

Phytic acid values in processed ingredients vary in literature. For instance, Alonso et al (1998, 2000a,b, 2001) found significant reduction in peas (5.9%), faba beans (29%), and kidney beans (4%) after extrusion at 150°C (in outer die). However, according to Abd El-Hady and Habiba (2003), a much lower reduction in phytate was observed in legumes extruded at barrel temperatures of 140 or 180°C. Gualberto et al (1997) showed that extrusion did not affect cereal bran phytate content. In this study, extruded peas, chickpeas, and faba bean phytate values either remained the same or decreased ≤17.5, 17.5, and 22.5%, respectively, compared to the raw legumes. The reduction in phytate was not consistent for the different processing methods, thus further investigation is

TABLE IV
Antinutritional Factors (dry matter basis) of Raw and Processed Faba Beans (B), Chickpeas (CP), and Field Peas (P) and Reduction Percentages

Treatment[a]	Process[b]	Phytic Acid (g/100 g)	Phytic Acid Reduction (%)	Total Tannins (g/100 g)	Total Tannins Reduction (%)	Trypsin Inhibitors (mg/g)	Trypsin Inhibitors Reduction (%)
B raw	–	3.20		1.28		2.20	–
B1	Lp/Ld	2.87	10.3	1.14	10.9	1.24	43.6
B2	Mp/Ld	2.80	12.5	1.21	5.5	1.33	39.3
B3	Mp/Hd	3.21	–	1.25	2.3	1.02	53.7
B4	Hp/Hd	3.17	1	1.25	2.3	1.55	29.7
B5	Hp/Ld	3.32	–3.7	1.31	–2.3	1.38	37.1
Bx	Mp/–	2.48	22.5	1.28	–	2.20	35.7
CP raw	–	2.12		0.49		14.66	–
CP1	Lp/Ld	1.78	16.0	0.49	–	1.63	88.9
CP2	Mp/Ld	2.02	4.7	0.43	12.2	1.66	88.7
CP3	Mp/Hd	1.75	17.5	0.43	12.2	1.81	87.7
CP4	Hp/Hd	1.83	13.7	0.41	16.3	2.09	85.8
CP5	Hp/Ld	2.14	–0.9	0.40	18.4	1.62	89.0
CPx	Mp/–	1.86	12.3	0.46	6.1	1.20	91.8
P raw	–	1.20		0.78		2.74	–
P1	Lp/Ld	1.16	3.3	0.67	11.5	1.26	54.0
P2	Mp/Ld	1.22	–1.7	0.69	9.0	1.17	57.5
P3	Mp/Hd	1.11	7.5	0.71	6.4	1.41	48.5
P4	Hp/Hd	1.13	5.8	0.73	–	1.32	51.8
P5	Hp/Ld	0.99	17.5	0.78	1.3	1.12	58.9
Px	Mp/–	1.87	2.5	0.77	11.5	1.27	53.7

[a] B1–Bx, CP1–CPx, and P1–Px treatments for each legume.
[b] Processing treatments with low (L), middle (M), and high (H) preconditioner (p) temperature and low (L) or high (H) dryer (d) temperature.

TABLE V
Proportion of Total Variation of Faba Beans (B), Chickpeas (CP), and Peas (P) Chemical Compositions Explained by Main Effects of Preconditioner and Dryer Temperature and Interactions[a,b]

Chemical Composition[b]	Preconditioner Temp (p)			Dryer Temp (d)			Preconditioner Temp × Dryer Temp (p × d)		
(% dry matter)	B	CP	P	B	CP	P	B	CP	P
Protein	ns	ns	0.356**	ns	0.431*	0.557***	0.394**	ns	0.058*
Fat	0.674***	0.537**	0.855***	0.337***	0.425**	0.548***	0.077**	ns	ns
Sucrose	0.503**	ns	0.735***	0.190**	ns	0.500***	0.098**	ns	ns
RSO	ns	0.376**	ns	0.065	ns	ns	ns	0.429***	ns
Starch	0.638***	ns	0.750**	0.074*	ns	ns	ns	ns	ns
Soluble NSP	0.072*	ns	ns	0.427***	ns	ns	ns	ns	0.245*
Insoluble NSP	0.751***	0.507*	0.737***	0.528***	ns	ns	0.009*	ns	0.064*
Total NSP	0.599**		0.535*	ns	0.639**	ns		ns	ns
Total tannins	0.510***	0.331***	0.651**	0.229***	0.557***	0.714***	0.147***	ns	ns
Phytic acid	0.417***	0.641***	0.360*	0.194**	0.244***	ns	0.267***	ns	ns
TI	0.572*	0.487*	0.757***	ns	ns	ns	ns	ns	0.003*

[a] *, **, *** Indicate significance at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively; ns, no significance.
[b] RSO, raffinose-series oligosaccharides; NSP, nonstarch polysaccharides; TI, trypsin inhibitor.

imperative. In a review of antinutrients, Francis et al (2001) reported that the effect of thermal treatment on substances such as tannins is still not clear. Total tannins in the current study did not seem to be greatly affected by the levels in processed legumes. For the most part, they were slightly lower than the values for raw materials. Tannins were most reduced in chickpea. In this respect, the results are partially in accordance with those of Abd El-Hady and Habiba (2003), who found a slight decrease in tannins in peas, chickpeas, and faba beans after extrusion at different temperatures. In contrast, Alonso et al (1998, 2000a,b) reported significant reduction, reaching 92%, for both tannins and polyphenols in peas and faba beans extruded at 150°C. Alonso et al (2001) also observed reduction of condensed tannins for peas and kidney beans under the same extrusion conditions. Van der Poel et al (1992), testing various extrusion temperatures of 105–140°C, observed a 30–40% tannin reduction in two pea cultivars as a result of extrusion, irrespective of the extrusion temperature. Differences in tannin reduction could be attributed to higher temperatures or to the duration of processing methods and these are not always clear, especially for the extrusion appliance. It has also been suggested that heat treatment possibly reduces extractability by increasing polymerization of tannins, which would show lower values on subsequent analysis (Van der Poel et al 1991).

Trypsin inhibitors (TI) are heat sensitive (Francis 2001) and they can be reduced or completely destroyed in different plant materials and under different processing conditions (Marquez and Alonso 1999; Frias et al 2000; Romarheim et al 2005). High TI values in raw chickpeas, similar to the present study, have also been reported by others (Abd-El Hady and Habiba 2003). The highest reduction in TI among legumes was noted for chickpeas reaching 92%, while for faba beans it was up to 44% and for peas up to 59%. Similar to these findings, drastic reduction of TI has been reported in the literature for peas (van der Poel et al 1992; Alonso et al 1998, 2000b) and faba beans (Vidal-Valverde et al 1992). While in another study (Abd-El Hady and Habiba 2003), no TI was detected in any of the tested legumes after extrusion processing, irrespective to the initial levels in raw seeds or to the temperature applied.

The existing literature focuses on the effects of extruder temperature on legume composition. However, the present study found that the preconditioning and, to a lesser degree, the drying process, can have an effect on reduction in antinutritional factor level (Tables IV and V). The finding that drying procedure had the least effect on TI may be attributed to the fact that proteinaceous antinutritional factors like TI are very heat-labile and they may have already been inactivated by the preconditioning and main extrusion heat treatments.

CONCLUSIONS

From this study, it can be confirmed that peas, chickpeas, and faba beans are raw materials of high protein, starch, and NSP content. The effects of preconditioning on the nutritional values of the legumes showed that preconditioning temperatures may be valuable tools for partially eliminating antinutritional factors, especially TI, from legumes. Drying temperatures can also contribute to compositional changes, but to a much lesser degree. Total NSP content can be reduced by heat processing in faba beans and peas and to a lesser degree in chickpeas. Redistribution of S-NSP and I-NSP after extrusion and drying seem to be species-related as increase of S-NSP and decrease of I-NSP was found for peas and chickpeas, while the opposite was found for faba beans. Tannins showed resistance to the extrusion processing for all three legumes, while TI proved to be very heat-labile, especially in chickpeas. Wet preconditioning can be used in combination with extrusion to improve the nutritional value of legumes, while drying at 90–150°C does not cause any further reduction of the antinutritional factors.

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