Processing soybeans of different origins

Response of a Chinese and a Western pig breed to dietary inclusion

Guixin Qin

Promotoren: **dr ir M.W.A. Verstegen**
Buitengewoon hoogleraar op het vakgebied van de Veevoeding, in het bijzonder de Voeding van de Eenmagigen

Ma Ning
Professor in animal science, Jilin Agricultural University, Changchun, PR China

Co-promotoren **dr ir A.F.B. van der Poel**
Universitair hoofddocent in de veevoedertechnologie

Chen Peng
Associate professor in animal science, Jilin Agricultural University, Changchun, PR China

Processing soybeans of different origins

Response of a Chinese and a Western pig breed to dietary inclusion

Guixin Qin

Proefschrift

ter verkrijging van de graad van
doctor
op gezag van de rector magnificus,
dr C.M. Karssen,
in het openbaar te verdedigen
op dinsdag 10 september 1996
des namiddags te half twee in de aula
van de Landbouwuniversiteit te Wageningen

CIP DATA KONINKLIJKE BIBLIOTHEEK, DEN HAAG

Qin, Guixin

Processing soybeans of different origins:
response of a Chinese and a Western pig breed
to dietary inclusion.
Guixin Qin
Thesis Landbouwuniversiteit Wageningen. - With ref.- With
summary in English, Dutch and Chinese.
ISBN: 90-5485-589-4
Subject headings: pigs breeds; soybeans, thermal processing

Printed by: Grafisch Service Centrum Van Gils, Wageningen.

Statements

1. The quantification of trypsin inhibitor activity for each batch of soybeans is of practical importance for the optimal use of these soybeans in animal diets. (this thesis)

2. The residual trypsin inhibitor activity in processed soybeans is related to the trypsin inhibitor level in the raw soybeans. (this thesis)

3. Optimal processing condition must be defined separately for soybeans of different origins or different batches. (this thesis)

4. Proper steam-heating can improve the digestion of fat in Chinese soybeans. (this thesis)

5. The digestive system of pigs of different breeds responds differently to soybean antinutritional factors (ANFs). (this thesis)

6. Apparently, sensitivity to dietary antinutritional factors was not taken into account in the selection of modern pig breeds for better performance.

7. Chinese native pig breeds can be important for studying the genetic bases of "resistance" against feed ANFs.

8. Some insects will be very lucky if soybean ANFs are reduced by means of plant breeding.

9. There are lots of soybeans in China.

10. Optimization of the processing and use of soybeans is of great importance for a sustainable agriculture.

11. Time is the essential prerequisite for the existence of everything.

Statements belonging to the thesis: Processing soybeans of different origins: responses of a Chinese and a Western pig breed to dietary inclusion.
by Guixin Qin, Wageningen, The Netherlands, 10 September, 1996.

有些東西實有在尚未得到或已經失去時你才覺察到它們的價值。

Contents

Chapter 1

General introduction

The soybean (*Glycine max*) is one of the oldest crops cultivated by mankind. The cultivation of the soybean in China started as early as 2838 B.C. (McClelland and Cartter, 1937). Soybean cultivation was introduced into Europe in the 17th century and into U.S. in 1804 (Scott and Aldrich, 1983). The large scale production and utilization of soybeans in the Western world, however, only really started from the middle of this century onwards (Leysen, 1991). Nowadays, the soybean, as one of the most important plant protein sources, and plays an important role in feed and food production all over the world. In 1993/94, the total production of soybean in the world was 117.5 million tons, which was mainly produced in the U.S., Brazil, Argentina, Paraguay and China. About 50% of the production originated from the U.S. (Paschal, 1995).

Soybeans are used for feeding animals mainly in the form of soybean meal, which is produced during the process of oil extraction. As soybeans are recognised for their high nutritive value (high oil and protein contents, and better amino acid composition), increased amounts of full-fat soybeans (soybeans prior to oil extraction) are being used in the feed compounding industry (Leysen, 1991; Monari, 1993). The nutritional potential of the full-fat soybeans for non-ruminant and immature ruminant animals, however, is limited by some antinutritional factors (ANFs). These ANFs interfere with the intake, digestion, absorption, metabolism of nutrients, and health status of animals (Liener, 1980; Nitsan and Nir, 1986). Therefore, inactivation of these ANFs is necessary before the soybeans can be used optimally as feed for these animals. In recent years, a lot of research has been conducted on the development of technologies to inactivate these ANFs.

Literature relevant to processing technology for soybean (Monari, 1993) and legume seeds in general (Melcion and Van der Poel, 1993) has been reviewed. Although the ANFs in legume seeds can be inactivated to various extents by chemical (Friedman et al., 1982; Friedman and Gumbmann, 1986; Sessa and Gantous, 1987; Sessa et al., 1990) and biological (Huo et al., 1993; Meijer and Spekking, 1993) means, the most commonly accepted method at present is heat processing (Liener, 1993). This includes cooking (boiling), roasting, expander processing, extrusion, steam heating, micro-wave treatment, etc. These heating technologies, if adequately controlled, can all be used to reduce the contents or the activities of the proteinaceous ANFs in soybean (Melcion and Van der Poel, 1993). Extrusion and pressurized steaming are considered to be the most effective methods for improving the digestibility of the protein of Phaseolus vulgaris beans for pigs (Liener, 1993). Houdijk et al. (1992) made a comparison on the processing cost between different processing technologies. It was found that the cost per unit of processed product with pressurized steaming (toasting) was much lower than that processed with extrusion. In terms of economy, pressurized steaming, could therefore, be a better method than extrusion.

The effectiveness of heat processing on the improvement of the feeding value of soybeans depends on the adequacy of the processing conditions, e.g. the combination of temperature and duration (Melcion and Van der Poel, 1993). Under-processing cannot inactivate ANFs to an accepted or safe level. On the other hand, over-processing may decrease the availability of amino acids and protein for animals, and may increase the energy demand for processing. It is, therefore, necessary to optimize the process technology, in terms of inactivation of antinutritional factors and in terms of the availability of amino acids. An adequate or optimal processing procedure, however, may not be identical for different origins of soybeans because the contents and the natures of ANFs in soybeans may vary among different cultivars (Friedman et al., 1991a and b; Zhao et al., 1991; Fu and Lu, 1992; Mohamed and Rangappa, 1992) or different maturation stages (MacGrain et al., 1992). Thus, soybeans containing different levels of ANFs may need different processing conditions (Friedman et al., 1991a).

The effects of feeding raw or processed soybeans not only depend on the nature of the soybeans themselves, but also on the animals to which these beans are fed. It is well known that different species of animals differ in their response to soybean ANFs (Huisman et al., 1990; Nitsan and Nir, 1986). Antinutritional effects of raw soybeans hardly occur in mature ruminants (Loosli et al., 1961; Perry and Macleod, 1968; Larson and Schultz, 1970) as the ANFs are decomposed in the rumen by microbial enzymes (Baintner, 1981). Non-ruminant species of animals, however, respond to the soybean ANFs in different ways (Nitsan and Nir, 1986). Pigs are considered to be sensitive to soybean ANFs (Combs et al., 1967; Yen et al., 1974). The sensitivity, however, varies with the physiological states of the animals. Herkelman and Cromwell (1990) reviewed the literature on full-fat soybeans fed to pigs. Their review showed that the variation between the physiological stages of pigs in their responses to being fed a raw soybean diet. The growth rate and feed conversion ratio of weanling or young growing pigs fed the diet with raw soybeans as the protein source, were reduced by about 50% and 40% compared with the animals fed a similar diet with soybean meal as the protein source. As age and weight increase, the growth depression is less severe. For adult pregnant sows, no deleterious effect are found after feeding raw soybeans. It is not clear whether there are differences between genotypes of pigs in their sensitivity to soybean ANFs. Significant differences in the morphology of digestive organs (Zhao, 1989; Fevrier et al., 1988; Pond et al., 1981 and 1988; Yen et al., 1990) and digestibilities of dietary nutrients (Fevrier et al., 1988; Qin et al., 1989; Kemp et al., 1991) have been observed between some breeds or genotypes of pigs.

Based on these facts, it is hypothesized that the optimal processing procedure for soybeans varies according to their origin. Soybeans of a specific origin should be processed differently for feeding to different breeds or genotypes of pigs. If this hypothesis is true, the relevant research may have great importance for an adequate utilization of full-fat soybeans in pig production.

The objective of this research is to investigate the possible differences between different origins of soybeans in their ANFs nature and in responses to processing, and the responses of different breeds of pigs to dietary soybean ANFs, by using Argentine and Chinese soybean as materials, and Landrace and Min pigs as target animals.

The literature on ANFs in soybeans and soybean products, and on the use of full-fat soybeans in pig diets are reviewed in Chapter 2 with an emphasis on the variation in ANFs.

A literature review on the variation of digestive capacity among breeds or genotypes of pigs is presented in Chapter 3.

A kinetic study and an ileal digestion trial are described in Chapter 4, in which the processing effects of various steam heating conditions on a batch of Argentine soybeans are presented.

In Chapters 5 and 6, the differences between Argentine and Chinese soybeans in response to heat processing were studied *in vitro* and *in vivo*, respectively, in order to study the interaction between soybean origin and processing condition.

In Chapter 7, the responses of Western and Chinese pig breeds (Landrace and Min) to dietary soybean ANFs are compared in terms of dietary nutrient digestibilities, organ morphology and histological examinations. The results of the literature reviews and the experiments involved in the thesis are discussed in Chapter 8.

References

Baintner, K., 1981. Determination of proteolytic activity of rumen liquor with azacasein. Vet. Med. A. 23: 796.

Combs, G.E., Conness, R.G., Berry, T.H. and Wallace, H.D., 1967. Effect of raw and heated soybeans on gain, nutrient digestibility, plasma amino acids and other blood constituents of growing swine. J. Anim. Sci. 26: 1067.

Fevrier, C., Bourdon, D. and Aumaitre, A., 1988. Digestive capacity of the Chinese pig - effect of dietary fibre on digestibility and intestinal and pancreatic enzymes. Proceedings 4th International Seminar on Digestive Physiology in the Pig 6-10th June 1988, Jablonna, Poland, 172-179.

Friedman, M., Grosjean, O.K. and Zahnley, J.C., 1982. Inactivation of soya bean trypsin inhibitors by thiols. J. Sci. Food Agric. 33: 165-172.

Friedman, M. and Gumbmann, M.R., 1986. Nutritional improvement of soy flour through inactivation of trypsin inhibitors by sodium sulfite. J. Food Sci. 51: 1239-1241.

Friedman, M., Brandon, D.L., Bares, A.H. and Hymowitz, T., 1991a. Effect of heat on the nutritional quality and safety of soybean cultivars. Adv. Exp. Med. Biol. 289: 339-361.

Friedman, M., Brandon, D.L., Bares, A.H. and Hymowitz, T., 1991b. Comparison of a commercial soybean cultivar [Williams 82] and an isoline [L81-4590] lacking the Kunitz trypsin inhibitor: composition, nutritional value, and effects of heating. J. Agric. Food Chem. 39 (2): 327-335.

Fu, C.Z. and Lu, Y.C., 1992, Determination of trypsin inhibitors activity in legumes. Soybean Sci. 11 (3): 169-172.

Herkelman, K.L. and Cromwell, A.G.L., 1990, Utilization of full-fat soybeans by swine reviewed. Feedstuffs. 62 (52): 13-18.

Houdijk, J., Stolp, W. and Van der Poel, A.F.B., 1992, Process cost estimation. Internal Report, Department of Animal Nutrition, Wageningen Agricultural University, Wageningen, The Netherlands.

Huisman, J., Van der Poel, A.F.B., Mouwen, J.M.V.M. and Van Weerden, E.J., 1990. Effect of variable protein contents in diets containing Phaseolus vulgaris beans on performance, organ weights and blood variables in piglets, rats and chickens. Br. J. Nutr. 64: 755-764.

Huo, G.C., Fowler, V.R., Inborr, J. and Bedford, M., 1993. The use of enzymes to denature antinutritive factors in soybean. In: A.F.B. van der Poel, J. Huisman an H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proc. 2nd International Workshop on Antinutritional Factors (ANFs) in Legume

Seeds. Wageningen, 1-3 December 1993, pp. 517-522.

Kemp, B., Den Hartog, L.A., Klok, J.J. and Zandstra, T,. 1991. The digestibility of nutrients, energy and nitrogen in the Meishan and Dutch Landrace pig. J. Anim. Phys. Anim. Nutr. 65: 263-266.

Larson, A. and Schultz, L.H., 1970. Effects of soybeans compared to soybean oil and meal in the ration of dairy cows. J. Dairy Sci. 53: 1233-1240.

Leysen, R., 1991. Soybean derived food ingredients. Paper presented at the new products seminar during Food Ingredients Europe, Paris-France, October 1991.

Liener, I.E., 1993. Summary of the presentations and recommendations for the future. In: A.F.B. van der Poel, J. Huisman an H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proc. 2nd International Workshop on Antinutritional Factors (ANFs) in Legume Seeds. Wageningen, 1-3 December 1993, pp. 537-547.

Liener, I.E., 1980. Toxic Constituents of Plant Feedstuffs, 2nd Edition. Academic Press, New York, pp. 503.

Loosli, J.K., Warner, A.A. and Hintz, H.F., 1961. Value of corn distillers, dried grains, soybean oil meal, heated soybeans and soybean oil meal plus starch for milk production. J. Dairy Sci. 44: 1910-1914.

McClelland, C.K. and Cartter, J.L., 1937. Improvement in soybeans. In: USDA Yearbook. pp. 1154-1189.

McGrain, A.K., Chen, J.C., Wilson, K.A. and Tan-Wilson, A.L., 1992. Proteases catalysing processing and degradation of Kunitz soybean trypsin inhibitor during seed maturation. Phytochem. 31 (2): 421-426.

Meijer, M.M.T. and Spekking, W.T.J., 1993. Enzymatic inactivation of proteinaceous protease inhibitors. In: A.F.B. van der poel, J. Huisman an H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proc. 2nd International Workshop on Antinutritional Factors (ANFs) in Legume Seeds. Wageningen, 1-3 December 1993, pp. 529-533.

Melcion, J.P. and Van der Poel, A.F.B., 1993. Process technology and antinutritional factors: principles, adequacy and process optimization. In: A.F.B. van der Poel, J. Huisman an H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proc. 2nd International Workshop on Antinutritional Factors (ANFs) in Legume Seeds. Wageningen, 1-3 December 1993, pp. 419-434.

Mohamed, A.I. and Rangappa, M., 1992. Screening soybean (grain and vegetable) genotypes for nutrition and anti-nutritional factors. Plant Foods for Hum. Nutr. 42 (1): 87-96.

Monari, S., 1993. Fullfat Soya Handbook, 2nd Edition. American Soybean Association, Brussels, pp. 1-28.

Nitsan, Z. and Nir, I., 1986. Accentuated response to soybean inhibitors by meal-feeding in various species. Adv. Exp. Med. Boil. 199: 199-223.

Paschal, R., 1995. World 1994/95 soybean production. World Agricultural Production. 1995 (3): 54-59.

Perry, F.G. and Macleod, G.K., 1968. Effects of feeding raw soybeans on rumen metabolism and milk composition in dairy cows. J. Dairy Sci. 51: 1233-1238.

Pond, W.G., Jung, H.C. and Varel, V.H., 1988. Effect of dietary fibre on young adult genetically lean, obese and contemporary pigs, body weight, carcass measurements organ weights and digest content. J. Anim. Sci. 66: 699-706.

Pond, W.G., Yen, J.T., Lindvall, K.N. and Dale Hill, 1981. Dietary alfalfa meal, for genetically obese and lean growing pigs. Effect on body weight gain and on carcass and gastrointestinal tract measurement and blood metabolites. J. Anim. Sci. 51 (2): 367-373.

Qin, G., Chen, P. and Gao, Z., 1989. Influence of pig breeds and diet type on digestibility of nutrients. Swine Production. 3: 6-8.

Scott, W.O. and Aldrich, S.R., 1983. Modern Soybean Production (2nd Ed.) S&A Publications, Inc., Champaign, III. pp. 209.

Sessa, D.J. and Gantous, P.E., 1987. Chemical inactivation of soybean trypsin inhibitors. J. Am. Oil Chem. Soc. 64: 1682-1687.

Sessa, D.J., Haney, J.K. and Nelsen, T.C., 1990. Inactivation of trypsin inhibitors with ascorbic acid plus copper. J. Agric. Food Chem. 38: 1469-1474.

Yen, J.T., Hymowitz, T. and Jensen, A.H., 1974. Effects of soybeans of different trypsin inhibitor activities on performance of growing swine. J. Anim. Sci., 38: 304-309.

Yen, J.T., Mersmann, H.J., Hill, A.D. and Pond, W.G., 1990. Effect of ractopamine on genetically obese and lean pigs. J. Anim. Sci. 68: 3705-3712.

Zhao, G., 1989. Research on Min Pigs. Heilongjang Science and Technology Press.: 145-185.

Zhao, S.W., Zhou, S.H., Hu, M.X., Meng, X.X., Li, A.P. and Wang, S.M., 1991, The frequencies of Ti and SP1 alleles in soybeans (G. max) from three provinces of northeast China. Soybean Sci. 10 (1): 77-81.

Chapter 2

Soybean antinutritional factors: the variation of activities and responses of pigs to full-fat soybeans.

G. Qin and P. Chen

Department of Animal Science, Jilin Agricultural University, Changchun 130118. P.R. of China.

1. Introduction

Soybeans (*Glycine max.*) contain high levels of fat and protein. They have been used as a food and feed ingredient for a long time. Like other legume seeds, soybeans contain many antinutritional factors (ANFs) such as trypsin inhibitors, lectins, saponins, goitrogenic factors, rachitogenic factors, allergenic factors and metal-chelating factors. These ANFs influence the digestion of nutrients and the health of animals and human beings. Therefore, the soybeans have to be processed prior to their direct use as human food or animal feed. The most popularly used soybean product in animal feed is soybean meal which has generally undergone a heat treatment during oil pressing or extraction. This heating procedure inactivates the ANFs in raw materials to a considerable extent. Therefore, soybean meal can be safely used in livestock diets.

In recognition of the high nutritive value of soybeans, the utilization of full-fat soybeans in animal feed has increased rapidly in recent years (Monari, 1993). As a result, much research has been conducted in order to understand the characteristics of soybean ANFs, their variation patterns and the inactivation technology. The results of the research are of great importance for the optimal utilization of soybeans and soybean products in animal production systems.

2. Antinutritional effects of ANFs in soybeans

2.1. Trypsin inhibitors

There are two important types of trypsin inhibitor in soybeans: the Kunitz and the Bowman-

Birk. The Kunitz inhibitor is a peptide consisting of 181 amino acids and containing two disulfide bridges. Its molecular weight is about 21000 daltons (Birk, 1989). It strongly inhibits the activity of trypsin and weakly inhibits chymotrypsin. Heat and gastric juices may inactivate it. The Bowman-Birk inhibitor is also a peptide which consists of 71 amino acids, and contains 7 disulfide bridges. Its molecular weight is about 8000 daltons. This inhibitor has 2 inhibitory sites which can independently bind trypsin and chymotrypsin. It is quite resistant to gastric juices and some proteolytic enzymes, such as pepsin and pronase (Birk, 1989; Huisman, 1990). It is also resistant to heat, alkali and acid (Monari, 1993). On average, the contents of the Kunitz and Bowman-Birk inhibitor in raw soybeans are in the order of 1.4 and 0.6%, respectively.

The main antinutritional function of protease inhibitors is that they bind to trypsin and chymotrypsin to inhibit their activities and reduce digestive efficiency. Consequently, the pancreas secretes more enzymes, which results in pancreatic hypertrophy. Additionally, a loss of endogenous sulphur amino acids may result as these enzymes contain a high proportion of sulphur amino acids.

2.2. Lectins (Haemagglutinins)

Lectins are proteinaceous compounds. Most of them are in the form of glycoproteins (Jaffe, 1980). Soybean lectins are tetrameric molecules consisting of equal amounts of two slightly different subunits (Goldstein and Poretz, 1986). There are specific sites in each of the subunits of lectins, which can bind with the membrane receptors of epithelial cells of intestines, and interfere with the digestive and absorptive processes (Huisman, 1990).

2.3. Saponins

Saponins are glycosides. The level of saponins in soybeans is about 0.5%. They are associated with a bitter taste and have a haemolytic effect on red blood cells. They cause minor antinutritional effects.

2.4. Goitrogenic factors

These factors are also glycosides which belong to the isoflavinic group. Some of these compounds can cause enlargement of the thyroid gland and reduce the activity of thyroxine.

2.5. Rachitogenic factors

These factors can interfere with the calcium metabolism of bone tissue, and influence calcification. Raw soybeans contain only about 0.10% of these compounds.

2.6. Allergenic factors

Allergenic factors are known to be somewhat more thermostable. They can cause an allergenic response in humans. Whether they also have the same effect on animals remains to be verified (Monari, 1993).

2.7. Metal chelating factors

These are protein-phytic acid complexes. These substances have a strong affinity to some metal ions such as manganese, zinc, copper and iron. These metal chelating factors in soybean or soybean products may reduce the availability of some trace mineral elements.

Among the ANFs mentioned above, trypsin inhibitors and lectins are the most important ones. Others are present in low levels in soybeans or soybean products, and have minor influence on animal health and production.

3. Variation of soybean ANFs activity

The activity of the ANFs in soybeans or soybean products may vary according to the origin of the raw materials, to the methods or conditions of processing, and to the animals species. These items are discussed separately.

3.1. *Origins of soybeans*

Soybeans of different genotypes, geographical regions or years, may differ in the type, level or activity of the ANFs they contain. This has been well documented. For example, trypsin inhibitor activity (TIA) in raw soybeans of different origins varied from the maximum of above 30 mg/g to the minimum of less than 10 mg/g (Table 1). Even for the same variety, the results were evidently different between literature. The TIA of the soybeans "Williams 82" reported by Herkelman et al. (1989), Fu et al. (1992) and Susmel et al. (1995)were 22.4, 20.4 and 24.55 mg/g, respectively. This may have been due not only to the error of laboratory measurement, but also to the differences in the geographical region or the time (year) that the soybeans were grown.

The genetic patterns of trypsin inhibitors (TI) in soybeans has been revealed two decades ago. Hymowitz et al. (1972) demonstrated that there are about four alleles involved in trypsin inhibitor inheritance. They are Ti^a, Ti^b, Ti^c and ti. Ti^a, Ti^b and Ti^c are dominant each other. Ti^b is lowest in TIA. Gene ti is recessive and has no TIA. In 1970s, USDA determined the genotype of trypsin inhibitor for 4000 cultivars, and found that only 2 of

Table 1. TIA in raw soybeans of different origins.

Literature	TIA		Origin of soybeans[1]
	units/g	mg/g	
Hove et al. (1979)		26.2	NI
Slump et al. (1979)		20.1	produced in Brazil
		24.4	produced in USA
Valdebouze et al. (1980)		32.6	NI
Doell et al. (1981)		18.7	NI
Cook et al. (1988)		5 ppm[2]	Williams
		0.5 ppm[2]	improved Williams
Hanock et al. (1989)		24.1	Williams
		13.3	Low Kunitz TI line
Herkelman et al. (1989)		22.4	Williams 82
		11.6	Low TI Variety
Herkelman et al. (1990)		24.0	NI
Xian and Farrell. (1991)		28.1	NI
Fu et al. (1992)	22.7		Clark 63
	20.0		L81-4871
	21.1		Amsoy 71
	16.5		L83-4387
	20.3		Williams 82
	17.6		L81-4590
	15.6		P.I. 196168
	22.8		Joghm
	25.8		Miller 67
	17.4		Lu 4XL83-4387
	17.4		Zhong 19XL83-4387
	20.8		Lu 4XL83
	21.2		Zhong 19XL83
	21.2		Ludou 4
	21.6		Zhongdou 19
	23.9		Yianhuang 3
	26.3		Gaolihuang
	25.5		Zhanbian 1
	25.1		Datuhuang
Herkelman et al. (1992)		20.9	Williams 82
		9.9	Low TI Variety
Zollitsch et al. (1993)	26.3		Produced in Austria
Susmel et al. (1995)		16.03	L81-4590
		24.55	Williams 82
		18.28	L83-4387
		23.02	Amsoy 71

[1] NI: not indicated

[2] Kunitz TI

these cultivars had no TIA. In 1980s, Chinese workers also started studying the genetic behavior of trypsin inhibitors in soybeans. Hu et al. (1984) determined the genotype of 82 Chinese cultivars and found that all of the 82 cultivars had the Ti^a allele. Zhao et al. (1991) made a determination for 2277 cultivars growing in the north-east of China. They found the frequency of Ti^a, Ti^b and Ti^c were 99.56%, 0.35% and 0.09%, respectively. The frequency of the genotypes (allele) differed between provinces (Table 2).

Based on the results reported in relevant research, it was demonstrated that the TIA of soybeans is controlled by gene, and different genotypes of soybeans may have different TIA. The TIA may also have been influenced by the geographical region where the soybean was grown because the geographical distribution of soybean genotypes followed certain patterns.

Table 2. Ti genotype and distribution frequency of 2277 soybean cultivars from North-east China (Zhao et al., 1991).

		Ti^a		Ti^b		Ti^c		ti	
Province	No determined	No.	%	No.	%	No.	%	No.	%
Heilongjiang	719	712	99.0	6	0.83	1	0.14	0	0
Jilin	814	812	99.8	2	0.25	0	0	0	0
Liaoning	714	743	99.9	0	0	1	0.13	0	0
Total (average %)	2277	2267	99.6	8	0.35	2	0.09	0	0

Liu et al. (1993) reported the results of the determination on Ti allele of 14067 soybean cultivars and 5049 wild varieties from 24 provinces of China. It was found that among the cultivars, Ti^a had an evident dominance. Its frequency was 100% in 17 of the 24 provinces. In Jiangshu and Anhui provinces, 4 double zone genotypes were observed. Among the wild varieties, however, the genotype was more complicated than that among cultivars. The frequencies of Ti^b and Ti^c appeared more frequently, and more double zone types were found (Table 3). The regularity of the geographical distribution of the Ti genotype was also observed. Ti^b was more frequently distributed to the north of Changjiang river, especially in the Huanghuaihai region. Ti^c was only observed in wild varieties, and mainly grow in the south-east spring-summer-autumn soybean growing area, especially in Fujian province (Table 4). No ti gene was found among the Chinese soybean cultivars and wild varieties

Table 3. Frequency of Ti genotype of soybean cultivars and wild varieties from different provinces of China (Liu et al., 1993).

Province	No determined	Ti^a		Ti^b		Ti^c		double zone	
		No.	%	No.	%	No.	%	No.	%
Cultivars:									
Beijing	650	650	100						
Inamongolia	190	190	100						
Hebei	749	749	100						
Ningxia	99	99	100						
Gansu	250	225	90	25	10				
Xinjiang	20	20	100						
Shanxi	1927	1927	100						
Shandong	769	765	99.5	4	0.5				
Henan	526	525	99.8	1	0.2				
Shannxi	950	950	100						
Jiangsu	1298	1292	99.5	4	0.3			2	0.2
Anhui	676	672	99.4	2	0.3			2	0.3
Shanghai	41	41	100						
Hubei	1223	1223	100						
Sichuan	870	870	100						
Zhejiang	610	610	100						
Fujian	240	239	99.6	1	0.4				
Jiangxi	329	329	100						
Hunan	337	337	100						
Guizhou	1318	1318	100						
Yunnan	300	299	99.7	1	0.3				
Guangxi	453	453	100						
Guangdong	231	231	100						
Tibet	11	11	100						

Continue Table 3.

Province	No determined	Ti^a		Ti^b		Ti^c		double zone	
		No.	%	No.	%	No.	%	No.	%
Wild varieties:									
Heilongjiang	739	727	98.4	12	1.6				
Jilin	878	778	88.6	99	11.3	1	0.1		
Liaoning	1100	1099	99.9	1	0.1				
Beijing	5	5	100						
Hebei	43	34	79.1	3	7.0			6	13.9
Ningxia	24	24	100						
Shanxi	422	372	88.2	28	6.6			22	5.2
Shandong	70	59	84.3	6	8.6			5	7.1
Gansu	90	90	100						
Henan	298	289	97.0	6	2.0	3	1.0		
Shannxi	400	360	90.0	37	9.2			3	0.8
Jiangsu	110	108	98.2			2	1.8		
Anhui	117	110	94.0	7	6.0				
Sichuan	35	35	100						
Hubei	70	69	98.6	1	1.4				
Zhejiang	142	138	97.2	3	2.1	1	0.7		
Tibet	8	8	100						
Hunan	54	52	96.3	2	3.7				
Guizhou	57	40	70.2	5	8.8			12	21.0
Fujian	370	335	90.5	7	1.9	28	7.6		
Yunnan	2	2	100						
Guangdong	15	14	93.3			1	6.7		

Table 4. Frequency of Ti genotype in different cultivation regions. (Liu et al., 1993)

Region	Cult./wild	Number Determined	Ti^a		Ti^b		Ti^c	
			No.	%	No.	%	No.	%
North spring soybean cultivation region	Cult.	1708	1708	100				
	Wild	2789	2667	95.9	115	4.1	1	0.04
Huanghuai summer soybean cultivation region	Cult.	4422	4392	99.3	30	0.7		
	Wild	1280	1180	92.2	80	6.2	3	0.2
Changjiang basin spring-summer soybean cultivation region	Cult.	5050	5043	99.9	5	0.1		
	Wild	274	254	92.7	6	2.2		
Southeast spring-summer-autumn soybean cultivation region	Cult.	1516	1515	99.9	1	0.1		
	Wild	566	525	92.8	12	2.1	29	5.1
South year round soybean cultivation region	Cult.	684	684	100				
	Wild	15	14	93				

which were determined. The TIA level of soybeans can be reduced by means of plant breeding. Since Singh et al. (1969) first found a low TIA soybean cultivar, attention has been paid to the hereditary feature relevant to TIA. In 1986, Hymowitz successfully developed a new low TIA soybean variety. The productivity of this variety was similar to conventional variety (cultivar). Its TIA, however, was 50% of the conventional one.

3.2. Influence of processing

The trypsin inhibitors in soybeans can be effectively inactivated by various treatments. With the increase of interest in yhe utilization of full-fat soybeans in animal diets, several processing technologies have been developed. These technologies can be grouped into 3 categories: physical technology (mainly heating), chemical technology and biological technology.

3.2.1. Physical technology

This category of technology is referred to as heat processing and is categorized as follows in this paper.

Cooking This involves soaking the soybeans in water (with salt or alkali) and boiling for some time. Then the beans are dried and fed in whole or ground form. This method is primary and simple, but it is costly and not suitable for large scale production. Therefore, it is not popularly used (Melcion and Van der Poel, 1993)

Steam heating The steam can be atmospheric pressure or high pressure. At atmospheric pressure, the temperature cannot be above 100 °C. TIA can be reduced by 90% without evident damage to lysine availability when beans are heated with steam for 30 minutes (Janssen & Friedrich, 1985). High pressure steam processing needs a special container. Generally, the pressure is adjustable, and the temperature inside the container can reach 133-136 °C (Zmudzinski, 1989). The heating duration varies dependent on the temperature and pressure of the steam inside the container. When the beans were steam-heated at 120 °C for 7.5 min., their TIA was reduced from 20.6 mg/g to 3.3 mg/g (Qin et al., 1996).

Microwave treatment This treatment is conducted in an electromagnetic field. The vibrating of the water molecules present in soybeans turns the electromagnetic energy into heat. Thus, the ANFs are inactivated. The effectiveness of micro-wave treatment is associated with the moisture content of raw material and the duration of the treatment. The lower the moisture level of the raw material, the higher the residual TIA in the products (Chen et al., 1986). Generally, treating for 15 min. may reduce TIA by 90%.

Roasting treatment This method is used to treat raw materials by dry heating. Heat is transferred to raw materials by metal surfaces or other carriers, such as sand, salt, ceramic tiles or air, to denature ANFs. In this method, lectins can be completely destroyed by roasting for 10-60 sec. at 190 °C, and TIA can be reduced to a safe level by roasting for 90 sec. at 800 °C (Schmidt, 1987).

Table 5. The effect of processing on TIA inactivation by various treatment conditions.

References	Treatment conditions	Reduction of TIA (%)
Mustakes et al., 1970	Extrusion, 135 °C, moisture 15%	12
	Extrusion, 121 °C, moisture 20%	43
	Extrusion, 135 °C, moisture 25%	62
	Extrusion, 135 °C, moisture 20%	89
	Extrusion, 148 °C, moisture 20%	98
Balloun, 1980	Raw soybeans	0
	Steaming, 0.3 kg/m^2, 5 min	73
	Roasting, 127 °C, 10 min	43
	Roasting, 175 °C, 5 min	43
	Steaming, 0.3 kg/m^2, 15 min	87
	Steaming, 0.7 kg/m^2, 10 min	94
	Steaming, 1.05 kg/m^2, 15 min	98
	Roasting, 204 °C, 12 min	93
	Roasting, 232 °C, 8 min	96
Lorenz et al., 1980	Extrusion, 121 °C	0
	Extrusion, 132 °C	30
	Extrusion, 138 °C	27
	Extrusion, 143 °C	57
	Extrusion, 149 °C	74

Extrusion cooking Extrusion is carried out in a special machine: the extruder. In this procedure, raw materials are forced through a die, and meanwhile, a high temperature is formed through friction, which may inactivate ANFs.

Thermal processing methods discussed above are commonly used in processing soybeans. Any of these methods can effectively reduce the activity of ANFs (Table 5). However, extrusion is generally considered as a better one because it not only heats but also shears the raw material. The shearing effects rupture the oil cells and make the oil more available (Carew et al., 1962; Featherston and Rogler, 1966).

In terms of economic aspects, pressurized steam treatment is more favorable than extrusion. The latter costs 1.7-3.2 times as much as the former per unit product (Melcion and Van der Poel, 1993).

3.2.2. Chemical technology

Evidence from some experiments indicated that some ANFs (such as trypsin inhibitors and lectins) can be inactivated by chemical means (Friedman et al., 1982; Friedman and Gumbmann, 1986; Sessa et al., 1987, 1990). In principle, the inactivation of ANFs using this category of method is achieved by cleaving the disulfide bridges of their molecules, subsequently change their molecular structure, thus inactivating the inhibitors.

Chemical agents that have been used for this include sodium sulphate (Friedman and Gumbmann, 1986), copper sulphate (Sessa et al., 1990), ferrous sulphate and some thiols (Friedman et al., 1982). Adequate temperature and time are also needed in chemical treatment. Sessa and Gantous (1987) reported that suitable temperature and time for inactivating Kunitz trypsin inhibitor is 65 °C and 30 min. when the soya trypsin inhibitors were inactivated with sodium metabisulfite. In the experiment conducted by Sessa et al. (1990), at the temperature of 27 °C and 65 °C, the Kunitz TIA decreased by 40% and 90%, respectively, when 10 mM ascorbic acid and 0.8 mM $CuSO_4$ were used as the inactivation agents.

3.2.3. Biological technology

ANFs in raw soybeans can also be inactivated by biological means. Enzyme treatment and germination treatment are examples in this category.

Enzyme treatment Meijer and Spekking (1993) isolated a fungal strain at a pH of 3.0 and 37 °C, similar condition to those in stomach. The activity of the protease produced by the strain to inactivate trypsin inhibitors was 20 mg/l/h. In their second isolation, they isolated a strain of bacteria under condition of pH 7.0 and 37 °C. The protease produced by this strain could inactivate Kunitz trypsin inhibitor as quickly as 200 mg/l/h.

Huo et al. (1993) examined the capacity of five proteases to inactivate trypsin inhibitors and lectins in soybeans. Their results showed that some enzymes were highly effective. They could reduce TIA from 36.6 mg/g to 13.3 mg/g at the enzyme dosage of 1% (w/w) within one hour. If the duration incubation was prolonged for another 11 hours, TIA was reduced to 1.2 mg/g products. They found found that the activity of lectins could not be inactivated by these enzymes as efficiently as TIA were.

Germination treatment In biological systems, ANFs in legume seed can protect the seed against the attacks of molds, bacteria, insects and birds. After the seeds have started to germination, this protection is less necessary (Classen et al., 1993). Therefore, they are decomposed by some endogenous enzymes. Thus, germination may be an alternative way to reduce ANFs in soybeans. Some experiments have presented evidence for this.

Tan-Wilson et al. (1982) reported that the activity of Bowman-Birk trypsin inhibitor was reduced to zero in seed cotyledon on the 13th day of germination, but Kunitz inhibitor was not. Wilson et al. (1988) found that Kunitz trypsin inhibitor was attacked by at least 3 proteases (K_1, K_2 and K_3) during germination. The active peak of K_1 appeared on the fourth day of germination, the peak of K_2 and K_3 occurred on the eighth and tenth to fourteenth day, respectively. Lectin activity was reduced more quickly during germination. By the fourth day, its activity was reduced by 90% (Chen et al., 1977).

4. Variation of animal response to ANFs

4.1. Among species

There are considerable differences in the morphology of digestive organs and in the physiology of digestion among animal species. The results of relevant research show that different animal species responses to ANFs vary greatly. The differences between the mature ruminant animal and the non-ruminant animal are the most obvious. Raw soybeans have little or no antinutritional effect in mature ruminant animals (Loosli et al., 1961; Perry et al., 1968; Larson et al., 1970), because ANFs are decomposed in the rumen by the enzymes originating from microorganisms before they arrive in the small intestine (Baintner, 1981). Thus, the majority of ANFs cannot interfere with digestion and absorption in mature ruminants.

Non-ruminant animals generally respond sensitively to ANFs of soybeans or other legume seeds. Feeding the diets containing certain level of these ingredients to these animals may result in a decrease in feed intake, growth rate and digestibility of nutrients, and an increase in pancreas size, secretion of digestive enzymes, weight of intestines and digesta in gut. Differences in responses to feeding a diet containing the ANFs have also been observed between non-ruminant animals species. Nitsan and Nir (1986) compared rats, chickens, gosling and calf. It was demonstrated that gosling was more sensitive to intaking raw soybean than others. Xian and Farrell (1991) reported that the rabbit was not as sensitive as rat and chicken to raw soybeans. Huisman et al. (1990a, 1990b) studied the differences between rats, piglets and chickens in responses to dietary peas, and found that piglets were more sensitive than rats and chickens regarding growth rate, feed conversion ratio and the digestibility of nutrients, The pancreas weight of piglets did not change as much as that of rats and chickens. Van der Poel et al. (1990) observed a similar result for common beans among animal species to that of Huisman et al. (1990a, 1990b). Struthers and MacDonald (1983) determined the inhibitory activity of soybean trypsin inhibitors to the trypsin originating from rat, monkey, human, bovine, porcine and mink. Different inhibitory activities were observed when soybean trypsin inhibitor was low in concentration.

Pancreatic enlargement resulting from feeding raw soybeans is associated with the trypsin inhibitors contained in the beans (Liener, 1979). When the trypsin in digesta becomes bound to its inhibitor, the amount of free trypsin decreases, which makes the endocrine cells in the small intestinal mucosa produce cholecystokinin-pancreomycin (CCK-PZ). This hormone stimulates the acinar cells of the pancreas to produce more digestive enzymes. Subsequently, the pancreas enlarges (Huisman, 1990). This feed-back mechanism may vary among animal species. The observation of Liener and Kakade (1980) indicated that pancreatic hypertrophy due to soybean trypsin inhibitors was associated with the relative weight of the pancreas. For the species whose relative pancreatic weight exceeded 0.3% of their body weight, the pancreas may be hypertrophic. For those species whose relative weight of pancreas is below this value, their pancreas cannot be hypertrophic. Mice, rat, chicken and gosling belong to the former; and pig, dog, calf and human belong to the latter. Hypertrophy of the pancreas may be an adaptation mechanism because the animals which become pancreatic hypertrophic (rat and chicken) can overcome the detrimental influences. The growth rate (Liener et al., 1985) and digestive enzymes (Nitsan and Alumot, 1964) in the gut of these animals were nearly the same as in normal animals. However, the guinea-pig (Nasdai, 1980) and calf (Kakade et al., 1975) could not overcome the detrimental effects. Their growth remained depressed until the feeding of raw soybeans stopped (Nitsan et al., 1971).

According to the literature, piglet, calf and gosling are the most sensitive animals to soybean ANFs; chicken, mice and rat are second; and rabbit and mature ruminant are not sensitive.

4.2. Among physiological stages

It is well known that there are obvious differences in the responses to the ANFs in legume seed between immature and mature ruminant animals. Within a same species of non-ruminant animals, differences may exist between the ages. The pig is one of such species. Young pigs are extremely sensitive, while adult pigs have high toleration to raw soybeans. There was no detrimental effect on performance when raw soybeans were used as the only protein source in sows' diet (Yen et al., 1991). Heat treatments influenced the nitrogen digestibility of full-fat soybeans for weaner pigs but did not for grower or finisher pigs (Marty and Chavez, 1993).

4.3. Among feeding patterns

The deleterious effects of soybean ANFs may be different between different feeding patterns. Nitsan and Nir (1986) compared ad libitum feeding and meal feeding of a raw soybean diet in several species of animals (rats, chicks and geese). They found that the detrimental influence of a raw soybean diet was significantly less severe in the animals fed ad libitum than in those meal-fed. The explanation for these results is that animals can develop a defence mechanism against dietary toxins. When fed ad libitum, they may reduce the size of the meal and increase the number of meals, to keep the total ANFs in the gut within a tolerable level. For meal feeding however, the sensation of hunger interferes with this defence mechanism. Animals may consume excessive amounts of toxins within a short period, which may exceed the tolerable level, and cause a serious response or may be even lethal (Nitsan and Nir, 1986).

Overall, the deleterious effects of soybean ANFs are influenced by many factors which include the origin of soybeans, processing technologies, animal species and age of the animal. These factors have to be considered, when soybeans or soybean products are going to be used in animal diets.

5. Effects of feeding full fat soybeans in pigs

Relevant research on feeding pigs with full fat soybeans started in the 1960s. Literature relating to the utilization of soybeans in pig diets has accumulated, and increasing amounts of full fat soybeans are being used in pig production (Wiseman, 1987). The nutritional value and feeding effect of full fat soybeans, however, varies greatly among the differently processed products and among the different physiological stages of animals.

5.1. Nutritional values of processed soybeans for pigs

Influenced by origin or processing technology, the nutritional data for full-fat soybeans for pigs vary greatly among literature. Long and Ewan (1982) (quoted by Monari, 1993) reported that gross energy (GE), digestible energy (DE), metabolizable energy (ME) and net energy (NE) of extruded soybeans were 21.87, 18.76, 18.26 and 13.36 MJ/kg dry

Table 6. Energy, digestible protein and amino acid levels (Waaijenberg, 1985)

	Roasted full fat soybeans	Roasted and flaked full fat soybeans
DE (MJ/kg)	17.51	17.87
ME (MJ/kg)	16.40	16.76
Digestible protein (g/kg)	320	320
Digestible lysine (g/kg)	20.7	20.7
Digestible methionine (g/kg)	4.3	4.3
Digestible cystine (g/kg)	4.9	4.9

Table 7. Average contents of digestible protein and amino acids in full fat soybeans (g/kg) (AEC, 1987)

	Extruded soybeans	Roasted soybeans
Protein	336.0	302.0
Lysine	21.4	18.9
Methionine	4.7	4.2
Cystine	4.1	3.9
Threonine	12.8	11.8
Arginine	25.0	22.5
Glycine	13.0	12.0
Serine	17.4	15.9
Histidine	8.7	8.2
Isoleucine	16.2	13.8
Leucine	25.9	22.5
Phenylalanine	17.0	14.8
Tyrosine	12.3	11.9
Valine	16.2	13.8

matter. The NRC values (1988) for DE and ME of heat processed soybeans were 16.88 and 15.16 MJ/kg, which were much lower than the corresponding data measured by Long and Ewan (1982) (quoted by Monari, 1993), and the ratio of ME/DE was very different from theirs. The DE and ME value of heat-treated soybeans reported by INRA (France) (1984) were 17.57 and 16.51 MJ/kg. The corresponding data from AEC (1987) were 17.74 and 16.61, respectively. Some data of treated soybeans reported by Waaijenberg (1985) and AEC (1987) are listed in Tables 6 and 7, respectively.

5.2. Effects of feeding full-fat soybeans in piglets

Full-fat soybeans, with high levels of energy and protein, are an ideal ingredient for young pigs in intensive pig production. Generally, the full-fat soybeans are considered to have the following advantages: high protein content with a good amino acid balance; a large proportion of oil, of which over half is the polyunsaturated essential fatty acids; an ability to mix rapidly and uniformly with other dietary ingredients (Monari, 1993). These virtues, however, can only be realized after adequate processing of the soybeans. Young pigs are very sensitive to the processing effects of soybeans. In a literature review (Herkelman and Cromwell, 1990), it was stated that, compared to soybean meal, feeding raw soybeans to piglets or young grower pigs reduced their growth rate and feed efficiency by 50% and 40%, respectively. Variations in feeding effects were also observed between differently processed soybeans (Aumaitre, 1985; Noland et al., 1976; Faber and Zimmermann, 1973; Li et al., 1990; Hanock et al., 1988, 1990; Adams and Jensen, 1985). Adequately processed full-fat soybeans can be used to replace milk powder, fish meal or soybean meal in piglets diets without deleterious effect (Aumaitre, 1985; Jurgens and Helgren, 1982; Myer and Froseth, 1983; Papadopoulos, 1986; Aumaitre, 1985). In Britain, USA and France, diets for weaning piglets usually contain up to approximately 30% of full-fat soybeans. These feeds generally yield feed conversion ratio's ranging from 1.0 to 1.5:1 during the period from 4 to 12 kg body weight (Haythornthwaite, 1984, quoted by Monari, 1993).

5.3. Effects of feeding full fat soybean in fattening pigs

Compared with piglets, the growing and fattening pigs have a greater resistance to ANFs in soybeans, but are still sensitive to them. The daily gain and feed conversion efficiency were 20% and 19% lower, respectively, for the fattening pigs fed a raw soybean diet than for the animals fed a soybean meal diet (Herkelman and Cromwell, 1990), indicating that the soybeans also need to be processed when fed to fattening pigs.

It has been demonstrated by a number of researchers, that replacing soybean meal with adequately processed full-fat soybeans could improve the performance (daily gain and feed conversion ratio) of growing and finishing pigs (Table 8). The inclusion proportion of

Table 8. The performance of growing and finishing pigs fed processed full fat soybean (SB) or soybean meal (SBM).*

Reference	Pig body weight (kg)	Soybean processing technology	Daily gain (kg)		Feed/gain	
			SBM	SB	SBM	SB
Jimenez et al., 1963	20-95	extrusion	0.74	0.75	3.41	3.16
Combs et al., 1969	53-82	steam	0.80	0.90	3.82	3.57
Noland et al., 1969	16-50	extrusion	0.67	0.71	2.64	2.43
Noland et al., 1970	28-91	IR irradiation	0.81	0.78	3.20	3.10
Noland et al., 1985	36-91	IR irradiation	0.84	0.93	3.58	3.16
Noland et al., 1986	17-51	extrusion	0.67	0.71	2.64	2.43
Villegas et al., 1970	50-100	IR irradiation	0.93	0.98	3.58	3.39
Zimmermann, 1970	18-93	IR irradiation	0.69	0.72	3.56	3.25
Ruffin et al., 1971	29-95	roasting	0.67	0.70	3.71	3.35
Wahlstrom et al., 1971	30-93	roasting	0.84	0.85	3.36	3.15
Danielson, 1972	29-95	not specified	0.73	0.77	3.78	3.37
Hanke et al., 1972	26-57	roast/extrusion	0.79	0.77	2.70	2.53
Hanke et al., 1972	57-95	roast/extrusion	0.79	0.83	3.39	3.29
Young, 1972	22-57	moisture heating	0.68	0.69	2.22	2.20
Olson et al., 1973	20-118	roasting	0.71	0.73	3.48	3.10
Carlisle et al., 1973	45-98	roast/extrusion	0.79	0.78	3.26	2.99
Seerley et al., 1974	29-95	roasting	0.67	0.67	3.75	3.82
Seerley et al., 1974	26-95	French cooker	0.74	0.69	3.13	3.20
McConell et al., 1975	21-102	roasting	0.74	0.77	3.57	3.45
Hitchcock et al., 1979	27-100	extrusion	0.79	0.82	3.33	3.23
Myer and Froseth,1983	22-91	extrusion	0.68	0.71	3.01	3.28
Campbell et al., 1984	71-104	roasting	0.70	0.66	3.92	3.91
Crenshaw et al., 1984	32-102	roasting	0.80	0.81	3.41	3.31
Campbell et al., 1985	40-111	roasting	0.77	0.73	3.53	3.78
Jurgens, 1985	27-95	extrusion	0.61	0.67	3.41	3.08
Papadopoulos, 1986	20-55	extrusion			2.75	2.52
Wahlstrom et al., 1986	40-100	extrusion	0.75	0.79	3.44	3.25
Danieison, 1987	21-105	roasting	0.84	0.84	3.10	2.91
Walker et al., 1987	18-105	roasting	0.85	0.83	3.05	3.03
Danieison, 1988	22-100	roasting	0.91	0.89	3.02	2.85
Cromwell et al., 1990	29-99	roasting	0.89	0.89	3.16	3.10

* Data partially adapted from Herkelman and Cromwell, 1990.

Table 9. Comparison of slaughtering parameters of pigs fed full fat soybean diets with those of pigs fed soybean meal diets.*

Reference	Killing out percentage (%)	Backfat change (%)	Firmness of carcass fat
Becker et al., 1961		+3.4	softer
Jimenez et al., 1963	+0.1	+1.3	softer
Wyson et al., 1964		+9.4	softer
Noland et al., 1970		+10.2	
Villegas et al., 1970		+5.8	softer
Jensen et al., 1970		0.0	softer
Jensen et al., 1970		-1.8	
Hanson et al., 1970		+4.2	softer
Zimmermann et al., 1970	+0.8	+4.6	softer
Wahlstrom et al., 1971	+2.0	+2.2	softer
Ruffin et al., 1971		+2.9	
Bergkamp, 1972	+1.6	+4.5	
Carlisle et al., 1973		-3.2	higher iodine number
Olson et al., 1973		+9.3	
Villegas et al., 1973		+3.3	softer
Seerly et al., 1974	+0.3	+4.2	highly unsaturated
McConnell et al., 1975		+3.7	softer
Noland et al., 1976	+0.9	+5.6	softer
Jurgens, 1985		+1.8	
Wahlstrom et al., 1986		+4.7	
Danielson, 1988		+4.9	
Cromwell et al., 1990		-2.1	

* "+" and "-" means increase or decrease of the animal fed full fat soybean diet compared with those fed soybean meal diet.

soybeans in whole diet is usually 10-15%. But it was also reported that inclusion of 27% did not result in an adverse influence on the performance of growing-finishing pigs, with the exception of producing soft carcass fat. The literature also shows that inclusion of full fat soybeans in the diet for fattening pigs can not only improve the growth rate and feed conversion ratio, but can also increase the killing-out percentage (Table 9). Fatty carcasses and soft fat caused by the high level of polyunsaturated fatty acids are the only problems of using full-fat soybeans in fattening pig diets. Therefore, the proportion of the soybeans in the diet should not be too high.

Table 10. Effects of soybean meal and raw soybean diets on reproductive performance of sows.*

Reference	Litters	Diet protein source	Litter size	Body weight at weaning) (kg)	Survival at weaning (%)	Change of sow body weight (kg) during lactation
Jensen et al.,	40	soybean meal	9.8	7.0	92.9	-14.4
1971		raw soybeans	10.1	6.8	85.7	-15.4
Allee et al.,	98	soybean meal	9.3	5.4	93.9	-6.5
1985		raw soybeans	9.4	5.2	95.7	-10.4
Crenshaw and	176	soybean meal	10.1	5.4	82.5	-7.0
Danielson,1985b		raw soybeans	10.5	5.4	82.6	-7.0
Golz and Crenshaw,	50	soybean meal	7.9	5.6	87.3	+0.3
1986		raw soybeans	8.1	5.0	90.1	-3.4
Newman et al.,	87	soybean meal	10.1	5.7	90.1	-30.0
1987		raw soybeans	10.3	5.0	85.4	-35.0
Herkelman et al.,	56	soybean meal	9.8	8.5	78.8	+5.0
1990	64	raw soybeans	9.8	7.7	75.8	-5.0

* Partially adapted from Herkelman and Cromwell, 1990.

5.4. Effects of feeding full-fat soybeans in sows

Addition of fat to the diets for sows in late gestation and early lactation can increase the number and weight of weaned piglets (Moser and Lewis, 1981; Pettigrew, 1981; Nelsen and Austin, 1984), which has led to increasing interest in the use of full-fat soybeans as a means of adding oil to the diets of sows. Adult pigs might be able to tolerate the ANFs in raw soybeans (Combs et al., 1967). Therefore, a number of researches on feeding raw soybeans to sows were conducted. The results reported by Crenshaw and Danieson (1985), Herkelman and Cromwell (1990) and Yen et al. (1991) indicated that there was no adverse effect on reproductive performance of sows when raw soybeans, as the only protein source, were incorporated in the diet for pregnant sows. To some extent, the birth weight of piglets increased when raw soybeans were fed to the sows during pregnancy, due to the increase in oil intake (Herkelman and Cromwell, 1990).

Lactating sows respond differently to raw soybean diets compared with pregnant sows (Table 10). During lactation, sows require large amounts of energy and protein for milk production. Inclusion of raw soybeans in their diet may reduce feed intake because the raw soybeans are unpalatable. The reduction in feed intake, subsequently, causes a decrease in body weight and milk production of the sow, and the body weight and survival rate of the piglets at weaning (Herkelman and Cromwell, 1990). Therefore, raw soybeans should not be used in large proportions in the diet of lactating sows.

6. Summary

Based on the literature reviewed in the present paper, it can be concluded that the content and the activity of ANFs present in soybeans or soybean products vary greatly according to the soybean origins (from different cultivars, varieties, geographical regions or produced in different years).

The activities of ANFs in any specific batch of soybeans can change greatly after processing with various processing technologies. Different species of animals respond differently to the soybean ANFs. The age and physiological status of animals obviously influence the deleterious effects caused by intake of soybean ANFs, which is more evident in pigs. These phenomena indicate that an optimal utilization of full-fat soybeans in animal feeding system is extremely complicated. When processing a specific batch of soybeans for a specific animal herd, a specific processing technology or processing condition may be needed.

References.

Adams, K.K. and Jensen, A.H. (1985) Anim. Feed Sci. Technol. 12: 267-274.

A.E.C., Tables A.E.C. (1987) Recommandations pour la Nutrition Animale, 3d Edition, A.E.C. Commentry, France.

Allee, G.L. et al. (1985) Report of Progress, Agric.Exp. Sta., Kansas State Univ. N0. 486. p. 58

Aumaitre, A. (1985) In: "Proceedings of Onidol-Cis symposium" III Congres sur le soja. Paris France.

Baintner, K. (1981) Vet. Med. A 23: 796.

Balloun, S.L. (1980) A Technical Report for American Soybean Association, St. Louis, MO. USA. (quoted by Monari, 1993).

Becker et al. (1961) Quoted by Monari,S. (1993) Fullfat Soya Handbook (Second Edition) 20-22, Brussels, Belgium.

Bergkamp, J.V. (1972) MSc thesis. Iowa State Univ. USA.

Birk,Y (1989) In: J. Huisman, A.F.B. van der Poel and I.E. Liener (Eds) Recent advances of research in antinutritional factors in legume seeds. PUDOC, Wageningen, The Netherlands, 83-94.

Campbell, D.R. et al. (1984) Florida Agric. Exp. Sta., Dept. of Anim. Sci. Res. Rep. AL-1984-6.

Campbell, D.R. et al. (1985) Florida Agric. Exp. Sta., Dept. of Anim. Sci. Res. Rep. AL-1985-4.

Carlisle, G.R. et al. (1973) Quoted by Monari,S. (1993) Fullfat Soya Handbook (Second Edition) 20-22, Brussels, Belgium.

Carew, L.B. et al. (1962) Poult. Sci. 41: 61.

Chen, K.C. et al. (1977) J. Food. Sci. 42: 1666-1668.

Chen, X.J. et al. (1986) Sci. Aliments. 6: 257-272.

Classon, H.L. et al. (1993) In: Recent advances of research in antinutritional factors in legume seeds (editor: Van der Poel, A.F.B., Huisman, J. and Saini, H.S.). Wageningen, The Netherlands, 1-3 December, pp: 501-516.

Combs, G.E. et al. (1967) J. Anim. Sci. 26: 1067-1071.

Combs, G.E. and Wallace, H.D. (1969) Report of 14th Annual Swine Field Day, Univ. of Florida. No. AN 70-2.

Cook, D.A. et al. (1988) J .Anim. Sci: 1686-1691.

Crenshaw, M.A. and Danielson, D.M. (1985)a J. Anim. Sci. 60: 163.

Crenshaw, M.A. and Danielson, D.M. (1985)b Nebraska Swine Report, Ne, USA.

Cromwell, G.L. et al. (1990) J. Anim. Sci. 68 (Supp.l): 8.

Danieison, M. (1988) J. Anim. Sci. 66 (Suppl.I) 129.

Danielson, D.M. (1972) Nebraska Swine Report.

Doell, B.H. et al. (1981) Foods Human Nutrition 31: 319.

Faber, J.L. and Zimmermann, D.R. (1973) J. Anim. Sci. 36: 902-907.

Featherston, W.R. and Rogler,J.C. (1966) Poult. Sci 45: 330.

Friedman, M. et al. (1982) J. Sci. Food Agric. 33: 165-172.

Friedman, M. and Gumbmann,M.R. (1986) J. Food Sci. 51: 1239-1241.

Fu, C.Z. et al. (1992) Soybean Sci. 11 vol 3: 269-272.

Goldstein, I.J. and Poretz, R.D. (1986) In: I.E. Liener et al (Eds) The lectins, properties and applications in biology and medicine. Academic Press. New York, US. 35-247.

Golz, D.I. and Crenshaw, T.D. (1986) Univ. of Wisconsin-Madison Swine Rep. P. 22.

Hanke, H.E. (1972) J. Anim. Sci. 35: 958.

Hanock, J.D. et al. (1989) J. Anim. Sci. 67 (Suppl. 2): 128.

Hanock, J.D. et al. (1990) J. Anim. Sci. 68 (Suppl.1) 101.

Hanson, L.E. et al. (1970) Quoted by Monari,S. (1993) Fullfat Soya Handbook (Second Edition) 20-22 Brussels, Belgium.

Hasdai, A. (1980) Ph.D Thesis. The Hebrew University of Jerusalem, Israel. (quoted by Nitsan and Nir, 1986).

Herkelman, K.L. et al. (1990) J. Anim. Sci., 68 (Supp. 1): 1.

Herkelman, K.L. et al. (1989) KY Swine Res.Rep.-Progress Rep. 321: 33-36.

Herkelman, K.L. et al. (1992) J. Anim. Sci. (1992): 818-826.

Herkelman, K.L. and Cromwell, G.L. (1990) Feedstuffs 62 (52): 13-22.

Hitchcock, J.P. et al. (1979) J. Anim. Sci. 49 (Suppl): 8.

Hove, E.L. et al. (1979) New Zealand J. Agric. Res 22: 41.

Hu, Z.A. et al. (1984) J. Plant. 26 vol 3: 328-332.

Huisman, J. (1990) PhD Thesis. Wageningen Agric. Univ. The Netherlands.

Huisman, J. et al. (1990a) British Journal of Nutrition 64: 743-753.

Huisman J. et al. (1990b) Journal of Nutrition 64: 755-764.

Hymowitz, T. (1972) Crop Sci. 12: 197-198.

Hymowitz, T. (1986) Nutritional and toxicological significance of enzyme inhibitors in food. M. Friedman (Ed) Plenum publ. Co. New York.

Huo, G.C. et al. (1993) Personal communication.

I.N.R.A. (1984) Feeding of non-ruminant livestock. Butterworths, London, UK.

Jaffe, (1980) Hemagglutinins (lectins) In: I.E. Liener (Ed) Toxic constituents of plant foodstuffs. Academic Press. New York, US 73-102.

Jensen, A.H. et al. (1970) J. Anim. Sci. 31: 1021-1030.

Jensen, A.H. et al. (1971) Illinois Pork. Ind. Day Rep. p. 6.

Jimenez, A.A. et al. (1963) J. Anim. Sci. 22: 471-475.

Jurgens, M.N. and Helgren, H.H. (1982) Iowa State University Swine Report AS-535-E.

Kakade, M.L. et al. (1875) J. Dairy Sci. 59: 1484-1489.

Kratzer, F.H. et al. (1990) Anim. Feed. Sci. Technl. 31:247-259.

Larson, A. et al. (1970) J. Dairy Sci. 53: 1233-1240.

Li, D.F. et al. (1990) J. Anim. Sci. 68 (Suppl.1): 115.

Liener, I.E. and Kakade, M.L. (1980) In: I.E. Liener (Ed) Toxic constituents of plant foodstuffs. Academic Press. New York, US 7-71.

Liu, X.Y. et al. (1993) Jilin Agri. Sci. 1: 6-9.

Loosli, J.K. et al. (1961) J. Dairy Sci. 44: 1910-1914.

Marty, B.J. and Chavez, E.R. (1993) Can. J. Anim. Sci. 73: 411-419.

McConnell, J.C. et al. (1975) J. Anim. Sci. 41: 1021-1030.

Meijer, M.M.T. and Spekking,W.T.J. (1993) In: Recent advances of research in antinutritional factors in legume seeds (editor: Van der Poel, A.F.B., Huisman, J. and Saini, H.S.) Wageningen, The Netherlands, 1-3 December, pp: 529-533.

Melcion, J.P., Van der Poel, A.F.B. (1993) In: Recent advances of research in antinutritional factors in legume seeds (editor: Van der Poel, A.F.B., Huisman, J. and Saini, H.S.) Wageningen, The Netherlands, 1-3 December, pp: 419-434.

Monari, S. (1993) Fullfat Soya Handbook (Second Edition) 20-22, Brussels, Belgium.

Moser, B.D. and Lewis, A.J. (1981) Pig news and information 2 vol 3: 265-269.

Mustakas, G.C. et al. (1970) Food Technol. 24: 1290.

Myer, K.O. and Froseth, J.A. (1983) J. Anim. Sci. 57-296.

National Research Council (NRC). (1988) Nutrient Requirements of Swine, Ninth Revised Edition, National Academic Press, Washington, DC, USA.

Nelson, J.L. and Austin, J.L. (1984) In: Nebraska Swine Research Report, Ne. USA

Newman, C.W. et al. (1987) Nutri. Rep. Int. 36: 319.

Nitsan, Z. and Alumot, E. (1964) J. Nutri. 87: 179-184.

Nitsan, Z. and Nir, I. (1986). Adv. Exp. Med. Biol. 199: 199-223.

Nitsan, Z. et al. (1971) J. Dairy Sci. 54: 1294-1299.

Noland, P.R. et al. (1969) Arkansas Farm Res. XVIII, N0. 4 pp. 6.

Noland, P.R. et al. (1970) Arkansas Farm Res. XIX, N0. 6 pp. 8.

Noland, P.R. et al. (1976) J. Anim. Sci. 43: 763-769.

Noland, P.R. (1985) Publication of ASA. St. Louis, Mo. USA.

Noland, P.R. et al. (1986) (quoted by Monari, 1993).

Olson, D.G. et al. (1973) J. Anim. Sci. 37: 49.

Papadopoulos, G. (1986) Publication of ASA Brussels, Belgium.

Perry, F.G. et al. (1968) J. Dairy Sci. 51: 1233-1238.

Pettigrew, J.E. Jr. (1981) J. Anim. Sci. 53:107.

Qin, G. et al. (1996) Anim. Feed Sci. Technol. In Press.

Ruffin, B.G. (1971) J. Anim. Sci. 32: 391.

Schmidt, F. (1987) Die Muhle. 124: 179-181.

Seerly, R.W. et al (1974) J. Anim. Sci. 39: 1082-1091.

Sessa, D.J. and Gantous, P.E. (1987) J. Am. Oil Chem. Soc. 64(12): 1682-1687.

Sessa, D.J. et al. (1990) J. Agri. Food Chem. 38(7): 1469-1474.

Singh, L. et al. (1969) Crop Sci. 9: 489.

Slump, P. et al. (1979) TNO-report 6022.

Struthers, B.J. et al. (1983) J. Nutri. 103 (4): 800-804.
Susmel, P. et al. (1995) J. Sci. Food Agri. 67: 441-445.
Tan-Wilsin, A.L. et al. (1982) Plant Physiol. 70: 493-497.
Valdebouze, P. et al. (1980) Can. J. Plant Sci. 60: 695-701.
Van der Poel, A.F.B. et al. (1990) Livestock Production Science 25: 137-150.
Villegas, F.J. et al. (1970) J. Anim. Sci. 37: 443-449.
Villegas, F.J. et al. (1973) J. Anim. Sci. 31: 213.
Waaijenberg, A. (1985) Report on Soyax, Schouten/Giessen, The Netherlands.
Wahlstrom, R.C. et al. (1971) J. Anim. Sci. 32: 891-894.
Walker, G.L. et al. (1987) J. Anim. Sci. 65 (Suppl I) 314.
Wilson, K.A. et al. (1988) Plant Physiol. 88: 355-360.
Wiseman, J. (1987) Publication of American Soybean Association, Madrid, Spain.
Wyson et al. (1964) (quoted by Monari,S. 1993).
Xian, J. and Farrell, D.J. (1991) Anim. Feed Sci. Technol. 34: 127-139.
Yen, J.T. et al. (1991) J. Anim. Sci. 61: 656-663.
Young, L.G. (1972) Can. J. Anim. Sci. 52: 425.
Zhao, S.W. et al. (1991) Soybean Sci. 10, vol 1: 77-80.
Zimmerman, D.R. et al. (1970) Iowa Farm Sci. 25: 36-38.
Zollitsch, W. et al. (1993) Anim. Feed Sci. Technol. 41: 237-246.
Zmudzinski (1989) Proc. VICTAM Conf, Utrecht, The Netherlands, May 23-26st 81p.

Chapter 3

Variation of digestive capacity between genetically different pig populations: a review

G.X. Qin[1,2], M.W.A. Verstegen[1] and M.W. Bosch[1]

[1] Dept. Animal Nutrition, Agricultural University Wageningen, Wageningen, The Netherlands
[2] Dept. Animal Science, Jilin Agricultural University, Changchun China

1 Introduction

Production attained by pigs is more closely related to the consumption of digestible nutrients rather than that of gross nutrients (Green, 1989). Formulating diets for pigs is, therefore, generally based on the digestible nurients (e.g energy, protein and amino acids). The contents of the digestible nutrients in a specific feed depend, however, not only on the properties of the feed itself, but also on the properties of the animals that consume the feed. Pigs of different ages, physiological status, health conditions or genetic background may differ in feed-intake pattern (De Haer and De Vries, 1992), in nutrient digestion (Qin and Cui, 1983; Xiu, 1984; Wenk and Morel, 1985; Fevrier et al., 1988; Varel et al., 1988; Qin et al., 1989; Kemp et al., 1991) and in utilization of nutrients (Chadd et al., 1993; Friesen et al., 1994). So, animals may receive different amounts of digestible nutrients, even though they consume the same amount of the same feed. In practice, the amount of the digestible nutrients that pigs obtain from their intake can vary considerably from the calculated diet values (Bakker et al., 1994).

Digestive capacity of pigs (the ability of pigs to ingest feed and to digest and absorb nutrients at certain rate) is an important characteristic associated with their performance. Understanding the quantitative relationship between the nutrient requirement of an animal and the nutrient supply from a feed more accurately is of great importance for optimizing feed utilization and maximizing animals' production. In recent decades, various investigations have been conducted to study the influence of animal factors on the digestion of feeds. The influences of most animal factors, such as age and physiological status, have already been shown. With regard to the influence of the pigs' genetic background (breed or genotype) on the digestive ability, no common conclusion can be obtained from the literature (Xiu, 1986), since the results obtained in different studies have not been consistent. It is therefore important to understand the general patterns in digestive capacity of genetically different pigs.

2. The relevant results of previous literature

2.1. Morphology of gastro-intestinal tract

After ingestion, nutrients are processed, digested and absorbed during passage through the gastro-intestinal tract. The structure and function of the gastro-intestinal tract may, therefore, reflect the digestive ability of animals. In different studies, the weight, length and volume of the gastro-intestinal tract of pigs with different genetic backgrounds have been measured and compared. Hovorka (1957) observed that the intestine of pure domestic pigs was longer than that of crossbreeds of wild X domestic pigs. Zhao et al. (1989) reported that Min pigs (a native breed in Northeast China) have a larger stomach and a longer, as well as heavier, small and large intestine than Landrace pigs. The number (77) of large-intestine haustrae of Min pigs was nine more than that of Landrace pigs (68). Fan (1981) and Duan (1984) described the morphological differences in the gastro-intestinal tract between Harbin White and Min pigs. Their results showed that these two breeds are significantly different in the length and surface area of their large and small intestines, in the weight of large intestines, and in the height of their jejunum villus. Fevrier et al. (1988) found that the small intestine and colon of Meishan pigs were heavier than that of Large White. The small intestine of Large White was, however, longer. There were no significant differences in the weight of the stomach between the two breeds. In the experiments conducted by Pond et al. (1981, 1988) and Yen et al. (1990), the weight and length of the gastro-intestinal tract of genetically lean, obese or contemporary pigs fed on different dietary conditions were measured . It was found that obese pigs had the shortest small intestine and the lowest weight in all gastro-intestinal-tract segments. The volume and weight of the digesta in colon were lower for the obese pigs than for the lean and contemporary pigs.

The dietary factors may, to a certain extent, influence the weight and/or volume of different segments of the gastro-intestinal tract (Pond et al., 1988; Yen et al., 1990; Pekas, 1993). However, no significant interaction between diet and genotype was found for any of the morphological criteria of the gastro-intestinal tract.

Among the results (Table 1) in the literature quoted, the colon weight (or whole large

Table 1 Weight of Gastrointestinal tract of the Pigs with Different Genetic Background

	Body Weight	Stomach	Small Intestine	Caecum	Colon
Zhao et al. (1989, kg)					
Min Pigs	(adult)	1.71	2.31	-----	4.78[1]
Landrace	(adult)	1.38	0.88	-----	2.45[1]
Significance		ns	*		*
Fevier et al. (1988, g/100 kg empty body weight)					
Control diet:					
Meishan	71.8	678	1793	178	2159
Large White	92.5	591	1821	167	1424
Fibrous diet:					
Meishan	72.4	746	2176	229	2542
Large White	95.9	608	1833	171	1411
Significance	ns	*	ns	**	
Pond et al. (1981, g/100 kg empty body weight)					
no alfalfa meal:					
Lean type pig	96.5	517.0	1018.4	176.3	1197.6
Contemporary pig	95.7	534.3	1077.7	144.9	1118.4
Obese pig	96.5	501.8	699.5	134.3	983.9
alfalfa meal:					
Lean type pig	94.7	555.2	1018.7	172.6	1238.2
Contemporary pig	95.6	526.7	1144.3	183.4	1305.3
Obese type pig	96.9	439.3	847.7	138.3	1035.1
Significance		**	**	**	**

continue Table 1.

	Body Weight	Stomach	Small Intestine	Caecum	Colon
Pond et al. (1988; % of BW)					
1% alfalfa meal:					
Lean type pig	110.3	0.520	0.637	0.094	1.064
Contemporary pig	119.6	0.433	0.627	0.141	1.074
Obese type pig	100.0	0.403	0.466	0.127	0.695
80% alfalfa meal:					
Lean type pig	92.7	0.634	0.803	0.172	1.320
Contemporary pig	97.5	0.643	0.690	0.167	1.261
Obese type pig	83.4	0.528	0.553	0.158	1.061
Significance		**	**	ns	**
Yen et al. (1990; % of slaughter weight)					
Basal diet:					
Lean type pig	100.7	0.48	0.99	0.14	1.13
Obese type pig	93.3	0.42	0.90	0.11	0.99
+20ppm Ractopamine:					
Lean type pig	101.6	0.43	1.00	0.14	1.03
Obese type pig	93.7	0.40	0.88	0.11	0.89
Significance		*	*	*	*

*p<0.05
**p<0.01
ns=non-significant
[1]Colon+caecum+rectum

intestine) was more frequently found to be significantly different between breeds or lines than any other segment. It seems that the digestion in the colon probably plays an important role in the variation of digestive ability between different breeds or genotypes of pigs.

2.2. Transit time of digesta in the gastro-intestinal tract

The transit rate of digesta in the gastro-intestinal tract determines the length of contact between feed and enzymes. It also influences the development time of micro-organisms in the gut, and regulates the time of contact between digestion products and absorptive surfaces (Rerat and Corring, 1991). Transit time of digesta is positively related to the digestibility of dry matter, organic matter and nitrogen (Metz and Dekker, 1985). There is evidence of the existence of differences in digesta transit rate between genetically different populations of pigs. Hu (1987) reported that the residence time of digesta in the digestive tract of Min sows was 20 and 3.13 hours longer than that of Landrace and Harbin White sows, respectively. Varel et al. (1988) and Pond et al. (1988) found that the passage rate of digesta in genetically obese pigs is faster than in genetically lean or contemporary pigs, which is associated with the findings that obese pigs have shorter small intestines and lower colon weights than the other two genotypes (Pond et al., 1988). Zhao et al., (1989) reported that the time delay between dosing and first appearance of the marker in the faeces for Min and Landrace pigs was 45.93 and 33.70 h, and the mean residence time of the marker was 53.37 and 45.87 h, respectively.

2.2. Digestive enzymes

Ekstrom et al. (1975, 1976) reported that Chester White had a higher specific-lactase activity than Hampshire pigs during the first 4 weeks of life. After 6 weeks of age, however, there was a small difference between the two breeds. Duan (1984) observed that there were significant differences in the liver and pancreas weights, and the height of intestinal glands between Harbin White and Min pigs. Fevrier et al. (1988) reported that there were differences in the specific activities of pancreatic and intestinal enzymes between Meishan and Large White pigs, but that they were not statistically significant.

2.4. Digestibility of nutrients

During the last two decades, a number of studies have been published on the variation of digestibility of nutrients between genetically different pigs. The data from some of the literature, in which the digestibility of nutrients was compared between pigs with different genetical background, are listed in Tables 2 and 3. It was found that there are some inconsistencies among the results of the published works. Fevrier et al. (1988), Wenk and Morel (1985), Xiu,(1984), Varel et al. (1988), Qin and Cui (1983), Qin et al. (1989), and

Table 2. Comparison of digestibility between genetically different pigs: traditional and improved breeds. Dry matter (DM), organic matter (OM), gross energy (GE), crude protein (CP), crude fibre (CF), N-free extract, neutral detergent fibre (NDF) and acid detergent fibre (ADF)

		DM	OM	GE	CP	CF	EE	NFE
Meishan (M) vs. Dutch Landrace (DL), Kemp et al.(1991)								
Standard diet:	M	90.2	88.7	87.7	47.8	65.3	93.5	
	DL	88.8	87.2	85.8	36.4	60.6	92.8	
P value<		0.11	0.10	0.26	0.03	0.03	0.16	
Fibrous diet:	M	72.7	71.1	76.4	22.0	70.3	80.0	
	DL	71.3	69.7	76.0	18.1	67.2	79.3	
P value <		0.13	0.11	0.75	0.10	0.14	0.18	
Jiaxing (J) vs. Duroc x J (DJ)vs Hampshire x J (HJ) vs. Landrace x J (LJ) vs. Yorkshire x J (YJ), Zhang et al. (1990)								
16% CP:	J	79.9	81.4	79.1	83.8	26.6	78.7	84.5
	DJ	78.3	79.6	77.1	80.3	23.8	72.1	83.6
	HJ	79.5	81.0	78.9	82.7	28.7	67.3	84.9
	LJ	79.5	86.9	78.5	84.0	24.9	73.0	84.1
	YJ	80.4	81.7	79.5	85.5	28.4	74.3	84.6
14% CP:	J	78.8	80.0	77.4	81.8	18.9	58.7	84.9
	DJ	78.8	80.2	77.4	79.0	27.9	61.1	85.1
	HJ	79.8	81.1	79.1	80.8	28.4	62.4	85.8
	LJ	81.5	82.8	80.6	83.7	31.5	69.7	86.8
	YJ	81.6	82.9	80.7	85.3	30.3	71.3	86.5
Meishan (M) vs Large White (LW), Frevrier et al. (1988)						NDF	ADF	
Control diet:	M	90.3	92.3	91.1	93.2	40.7	48.3	41.1
	LW	88.9	91.2	89.7	91.6	33.9	42.8	35.9
Fibrious diet:	M	79.8	82.0	80.1	87.1	32.2	44.1	35.0
	LW	76.4	78.8	76.4	82.4	22.3	36.4	26.9
P value <		0.01	0.01	0.01	0.01	0.01	0.01	0.01

continue Table 2.

		DM	OM	GE	CP	CF	EE	NFE
Min (MI) vs. Landrace (L) vs Kermmiroff (K), Han et al. (1983)								
High CP:	MI	80.2			75.5	55.1		
	L	80.5			75.8	45.2		
	K	81.4			78.5	40.1		
High fibre:	MI	70.6			63.2	31.6		
	L	67.7			63.0	28.9		
	K	68.8			60.8	28.7		
Low fibre diet:	MI	82.8			75.6	46.6		
	L	81.3			74.7	44.6		
	K	79.8			70.0	46.6		
P value >:		0.05			0.05	0.05		
Harbin White (HW) vs. Duroc x Harbin White (DH) vs Duroc, Chen (1988)								
60 kg BW:	HW	89.4	91.2	88.7	83.1	75.8		
	DH	88.8	90.5	88.1	82.5	71.6		
	D	87.4	88.8	85.9	79.1	67.4		
80 kg BW:	HW	89.5	91.1	88.5	83.2	72.6		
	DH	89.2	90.5	88.4	82.2	73.9		
	D	90.8	92.7	90.5	85.4	65.2		
P value >:		0.05	0.05	0.05	0.05	0.05		

continue Table 2.

	DM	OM	GE	CP	CF	EE	NFE
Qin et al. (1989):							
Control diet:							
Dongliao black (DL)	89.4		90.3	86.7			
Landrace x DL	84.7		86.2	79.1			
Hampshire x DL	84.5		85.0	80.1			
High protein low fibre diet:							
DL	82.8		83.2	84.1			
Landrace x DL	82.0		82.3	78.5			
Hampshire x DL	85.7		85.2	82.3			
High protein high fibre diet:							
DL	82.3		82.1	74.8			
Landrace x DL	79.9		79.2	68.9			
Hampshire x DL	76.7		76.6	66.6			
Low protein high fibre diet:							
DL	81.1		81.9	86.8			
Landrace x DL	79.0		79.3	82.7			
Hampshire x DL	79.7		80.3	84.1			
P value <:	0.01		0.01	0.01			

Table 3. Comparison of digestibility between geneticaly different pigs: contemporary breeds. Dry matter (DM), gross energy (GE), crude protein (CP), cellulose, hemicellulose (HC) and cell wall

	DM	GE	CP	Cellulose	HC	Cell Wall
Varel et al. (1988)						
High fibre diet[1] :						
Obese type pig	45.9	41.9	53.1	14.0	34.1	17.0
Lean type pig	53.4	51.7	59.5	29.5	43.8	29.4
Contemporary pig	50.8	47.7	58.3	23.1	39.2	24.4
Low fibre diet:						
Obese type pig	84.5	84.7	76.4	64.0	65.1	62.3
Lean type pig	88.2	88.5	82.8	78.2	83.9	80.8
Contemporary pig	87.1	87.1	80.8	71.0	82.6	78.5
Pvalue <:	0.05	0.05	0.05	0.05	0.05	0.05
McConell et al. (1971)						
High CP diet at 41 kg BW[2]:						
Fat type pig	87.8	86.9	86.3			
Lean type pig	87.7	86.8	87.4			
Low CP diet at 41 kg BW:						
Fat type pig	87.3	86.2	83.8			
Lean type pig	87.0	86.0	80.9			
High Cp diet at 70 kg BW:						
Fat type pig	88.4	88.2	88.0			
Lean type pig	88.7	88.1	87.9			
Low CP diet at 70 kg BW:						
Fat type pig	88.9	88.5	86.0			
Lean type pig	87.9	87.2	82.9			
High CP diet at 95 kg BW:						
Fat type pig	89.0	88.3	87.9			
Lean type pig	88.7	88.1	86.7			
Low CP diet at 95 kg BW:						
Fat type pig	88.7	88.0	83.4			
Lean type pig	89.4	88.7	86.4			
P value >	0.05	0.05	0.05			
Qin et al. (1983)						
Landrace pig	81.7	82.5	78.9			
Kermmiroff pig	80.4	81.2	75.4			
Landrace x Kermmiroff	82.1	83.1	79.5			
P value	>0.05	>0.05	<0.05			
Wenk and Morel (1985)						
Restricted feeding, 30 kg BW:						
Thick backfat line		78.7				
Thin backfat line		79.3				
Restricted feeding, 70 kg BW:						
Thick backfat line		81.1				
Thin backfat line		81.4				
Ad libitum feeding at 30 kg BW:						
Thick backfat line		78.8				
Thin backfat line		79.7				

Kemp et al. (1991) have reported that there are significant differences in nutrient digestibility between different breeds or between different genotypes of pigs. However, the differences were not significant in the experiments conducted by McConnell et al. (1971), Zhang et al. (1990), Han et al. (1983), Chen et al. (1988), and You (1982). It should be noted that, in studies in which no difference was found, the diets had a lower fibre content. The extent of digestive differences between breeds may depend on the contrast of breeds, dietary composition or the kind of nutrients compared. For instance, the variation in the digestibility of crude fibre (or its ingredients, e.g. cellulose, hemicellulose, cell-walls) is commonly larger than that in other nutrients.

Significant interactions between breed and diet type were also reported by Fevrier et al. (1988) and Qin et al. (1989). In their experiments, larger differences in digestibility between breeds were found when pigs were fed high-fibre diets. Age had no obvious effect on the variation in digestibility between genotypes, although digestibility of nutrients generally increased with age in a given period of life (Chen, 1988; Wenk and Morel, 1985; McConnell et al., 1971).

3. General discussion

3.1. Variation in digestive ability

Objectively, differences in digestive ability exist between genetically different populations of pigs according to the results on the measurements of nutrient digestibility, weight and size of gastrointestinal tracts, transit rate of digesta in gut, and other aspects from the relevant literature, although the differences reported in some studies are not statistically significant. However, this does not mean that there are significant differences between any two different breeds or genotypes. The difference in digestive ability between two breeds or genotypes may depend on the extent of their genetic differences and of their raising environments, especially in terms of feeding condition. The larger the differences are in their genetical background or in environmental conditions during their evolution, the more obvious the differences may be in digestive ability between them. For example, the difference in the digestibility of gross energy between the genetically lean and obese pigs derived from the crossing of Yorkshire and Duroc pigs, which were selected over 18 generations for low and high backfat (Varel et al., 1988),was much larger than that between positive-line and negative-line pigs selected over seven and eight generations for low and high backfat (Wenk and Morel, 1985). This has also been demonstrated by comparisons of Chinese breeds with American and European breeds (Zhao, 1989; Fevirer et al., 1988; Qin et al., 1989; Kemp et al., 1991), and of the pure domestic pig with the crossbreed of domestic X wild pig (Hovorka, 1957). As a result of geographical isolation and the differences in the raising and feeding conditions in which the animals were selected, large genetic differences in digestive-capacity traits could have occurred between the different types of pig breeds.

In terms of experimental data, if the genetic differences are not large enough to be dominant over errors and variance derived from other factors, or if experimental errors are too large, the genetical variation will probably be concealed.

3.2. Relations between gut structure and digestive ability

The digestive ability of pigs depends on many factors, such as the structure of the gastrointestinal tracts (e.g. weight, length, volume), digesta transit rate, digestive-enzyme activities, and microflora in the gut. Among these factors, the gastro-intestinal-tract structure and digesta transit rate are more closely related to the digestive ability than the other traits according to the data (Tables 1, 2) of some relevant literature. The pigs with heavier, longer and larger gastro-intestinal tracts (relative to their body weight) usually have longer residence time of digesta and higher digestive ability (Fevrier et al., 1988; Pond et al., 1988; Varel et al., 1988; Zhao et al., 1989). The residence time of digesta correlates positively with the digestibility of nutrients (Warner, 1981; Metz and Dekker, 1985; Varel et al., 1988). One explanation for these findings is that the longer gastro-intestinal tract and longer transit time may increase the time of contact between digesta and digestive enzymes, and of contact between digestion products and absorptive surfaces. Another explanation is that a longer residence time may be advantageous to the microbial degradation of fibre in the gut (Warner, 1981; Van Soest, 1982), especially in the hindgut where main digestion of fibre occurs (Cranwell, 1968; Keys et al., 1974; Den Hartog et al., 1987) and degraded products are rapidly absorbed (Argenzio and Southworth, 1974). The breeds or genotypes of pigs with an increased caecum and colon should therefore, have a higher ability to digest fibre. This is in agreement with the results obtained by Fevrier et al., (1988), Pond et al., (1988) and Varel et al., (1988). It can be shown from their findings that the variation in digestion in large intestines between breeds or genotypes is greater than that in small intestines, although there are some significant differences in the weight and/or length of the small intestines between genetically different pigs reported in some literature.
Fibre is an important component of the organic matter of the diet. It affects the dietary gross energy. The microbial degradation of fibre determines the digestion of the fibre, and thus, also influences the digestibility of dry and organic matter, and gross energy. In addition, the degradation of crude protein and other carbohydrates are also involved in microbial fermentation.

The variation of pigs' digestive ability is found to be most associated with their large-intestine structure (Fevrier et al., 1988; Pond et al., 1988; Varel et al., 1988; Zhao et al., 1989). Mason and Just (1976) reported that the energy flow through the rectum was significantly different between litters, but not for that through the ileum. Thus, digestive ability might differ between genetically different pigs, mainly as a result of the differences in their microbial digestion in the hind gut.

Between different genotypes, differences have also been found in digestive glands (liver, pancreas and intestinal glands; Xiu, 1984) and in digestive enzymes (Ekstrom et al., 1975, 1976). This indicates the possible genetic differences in small intestinal digestion, moreover, the variation in digestive glands may indicate the genetic differences in response to anti-nutritional factors.

3.3. Interaction between animal and diet

The existence of an interaction between breeds (or genotypes) and diet characteristics (Han et al., 1983; Fevrier et al., 1988; Qin et al., 1989) indicates that, when different breeds are compared with each other, their relative digestive ability may change with the diet condition. In one diet, a breed may show a higher digestive ability than other breeds, but not in another diet, and may even be in the opposite order. This is probably one of the explanations for the inconsistencies in the results found in the literature.
The interaction between animal genotypes and diet characteristics in utilization of feed nutrients is of great importance for effectively using feed resources and accurately formulating diets. A specific feedstuff may have a higher digestible value for a specific breed or genotype than for others. Consequently, the nutritional value of feedstuffs can differ between breeds or genotypes (Bakker et al., 1994).

The calculated digestible values of a diet may differ from the real value for a genetically specific population of pigs. The value can be re-corrected in accordance with the digestive characteristics of the pigs, the property of diet and the interaction between them, so that the error, the difference between the calculated and the real digested value, can be minimized.

4. Conclusion

Genetic differences in digestive ability of pigs do exist between different breeds or lines. However, this is not to say that there are significant differences in digestibility between any two breeds or lines, or in any digestion aspect. The significant digestion differences are more generally found between the breeds with larger differences in their genetic background, and the differences are more pronounced in their large-intestinal structure and fibre digestibility. However, whether there are breed or genotype differences in response to feed antinutritional factors remains to be studied.

These differences may be an important factor influencing the utilization of feed nutrients. Genetically different pigs may favour a specific type of diets in terms of digestibility. Therefore, the digestion specificities have to be considered when a diet is being formulated for a genetically specific pig herd.

Summary

Literature relevant to digestive capacity variation between breeds or genotypes of pigs is reviewed in this paper. The general pattern found in the literature is that significant differences in digestion more commonly exist between breeds with large differences in their genetic background, and the differences are most pronounced in their large-intestinal structure and fibre digestibility. Based on the results of the literature review, it is concluded that genetically different pigs favour a specific type of diet in terms of digestibility.

Zusammenfassung

Variationen in der Verdauungskapazitat von genetisch schweinepopulationen: eine Ubersicht

In der Literaturubersicht werden Unterschiede in der Verdauungskapazitat von verschiedenen Rassen und Genotypen bei Schweinen aufgezeigt. Danach finden sich signifikante Unterschiede zwischen Schweinerassen mit grosseren genetischen Unterschieden und zwar verursacht durch Verschiedenheiten der Morphologie der Dickdarms und damit der Rohfaserverdaulichkeit. Das sollte bei der Formulierung von Diaten fur unterschiedliche Schweinerassen berucksichtigt werden.

References

Argenzio, R.A. and Southworth, M (1974) Sites of organic acid production and absorption in gastrointestinal tract of the pig. American Journal of Physiology 228 (2): 454.

Bakker, G.C.M., R. Jongbloed, M.W.A. Verstegen, A.W. Jongbloed and M.W. Bosch (1994) Nutrient digestibility and the performance of growing fattening pigs as affected by incremental additions of fat to starch or non-starch poly saccharides. Animal Production. (in press).

Chadd, S.A., D.J.A. Cole and J.R. Walters. 1993. The food intake, performance and carcass characteristics of two pig genotypes grown to 120 kg live weight. Anim. Prod. 57: 473-481

Chen, J.H. (1988) A study on digestibility of feed nutrients in growing-finishing pig of different breeds. Heilong Veterinary and Animal Husbandry. 1988(1):4.

Cranwell, P.D. (1968) Microbial fermentation in the Alimentary tract of the pig. Nutrition Abstract and Review (series B) 38 (3): 721-730.

Duan, Y.C. (1984) Morphological differences in gastrointestinal tract between Harbin White and Min pigs. Journal of North-east Agricultural college. (suppl.): 12-18

Ekstrom, K.E., Benevenga, N.J. and Crummer, R.H. (1975) Changes in the intestinal lactase activities in the small intestine of two breeds of swine from birth to 6 weeks of age. Journal Nutrition 105: 1032-1038.

Ekstrom, K.E., Grummer, K.N. and Benevenga, V.J. (1976) Effects of a diet containing 40% dried hey on the performance and lactose activities in the small intestine end caecum of Hampshire and Chester white pigs. Journal of Animal Science 42: 106-113.

Fan, Z.F. (1981) Comparison of gastrointestinal tract between Harbin White and min pigs. Journal of North-east Agricultural College. (2): 83-87

Fevrier, C., Bourdon, D. and Aumaitre, A. (1988) Digestive capacity of the Chinese pig-effect of dietary fibre on digestibility and intestinal and pancreatic enzymes. Proceedings 4th International Seminar on digestive physiology in the pig 6-10th June 1988, Jablonna, Poland, 172-179.

Fevrier, C., Bourdon, D. and Aumaitre, A. (1990) Effects of level and source of dietary fibre on digestive utilization of the diet and growth performance in large white and meishan pig. Chinese Pig Symposium 5-6th July 1990, Toulouse, France, 233-234.

Friesen, K.G., J.L. Nelssen, J.A. Unruh, R.D.Goodband, and M.D. Tokach. 1994. Effects of the interrelationship between genotype, sex and dietary lysine on growth performance and carcass composition in finishing pigs fed to either 104 or 127 kilograms. J. Anim. Sci. 72: 946-954

Green, S. (1989) A note on the digestibility of Nitrogen and Amino acids in meat, skimmed-milk and fish meal in young pigs. Animal Production 48: 237-280.

De Haer, L.C.M., and A.G. De Vries. 1992. Genetic aspects of the feed intake pattern of group housed growing pigs. Ph.D Thesis, Wageningen Agricultural University, The Netherlands. pp: 99-116

Den Hartog, L.A., Huisman, J, Verstegen, M.W.A. and Van Weerden, E.J. (1987) The digestibility of nutrients in the large intestine of the pig. 38th Annual Meeting of European Association for Animal Production, Lisbon, Portugal 28th September to 1st October.

Han, W.Z., Xiao Z.D., Cui B.H. and Gao M.Q. (1983) A study on adversity-resistance of Min Pig. Chinese journal of Animal Science. 1983(30): 15-17.

Hovorka, F. (1957) Growth and digestive processes in crossbred wild and in improved white pigs. Animal Breeding Abstracts 27 (1): 79.

Hu, D.J. (1987) The pass rate of digesta through the digestive tract of different breed sows. Journal of Heilongjiang Animal Husbandry and Veterinary Medicine. 1987(5): 1-3

Kemp, B., Den Hartog, L.A., Klok, J.J. and Zandstra, T. (1991) The digestibility of nutrients, energy and nitrogen in the Meishan and Dutch Landrace pig. Journal Animal Physiology and Animal Nutrition 65: 263-266.

Keys, J.E. and DeBarthe, I.V. (1974) Cellulose and hemicellulose digestibility in the stomach, small intestine and large intestine of swine. Journal of Animal Science 39 (1): 53-56.

Mason, V.C. and Just, A (1976) Bacterial activity in hid-gut of pigs. It's influence on the apparent digestibility of dietary energy and fat. Z.Tierphysiology, Tierernährung und Futtermitelkunde 36: 301-310.

McConnell, J.C., Barth, K.M. and Griffin, S.A. (1971) Nutrient digestibility and nitrogen metabolism studies at different stages of growth with fat and lean type swine fed two levels of protein. Journal of Animal Science 32 (4): 654-657.

Metz, S.H.M. and Dekker, R.A. (1985) Effects of housing on gastrointestinal transit time and digestibility of feeds in growing pigs. Proc. of the 3rd International Seminar on digestive physiology in the pig 16-18th May 1985, Copenhagen, Denmark: 396-399.

Pekas, J.C. (1993) Maintenance feeding of 100 kg pigs: effect on carcass lean and fat yeild and on gastrointestinal organ size. Animal Production 57: 455-464

Pond, W.G., Jung, H.C. and Varel, V.H. (1988) Effect of dietary fibre on young adult genetically lean, obese and contemporary pigs, body weight, carcass measurements organ weights and digest content. Journal of Animal Science 66: 699-706.

Pond, W.G., Yen, J.T., Lindvall, K.N. and Hill D.A. (1981) Dietary alfalfa meal, for genetically obese and lean growing pigs, effect on body weight gain and on carcass and gastrointestinal tract measurement and blood metabolites. Journal of Animal Science 51 (2): 367-373.

Qin, G.X., Chen P. and Gao Z.Q. (1989) Influence of pig breeds and diet type on digestibility of nutrients. Swine Production.1989(3): 6-8.

Qin, G.X. and Cui B.H. (1983) Determination of the digestive capacity of different pig breeds and their crossbreeds. Chinese Journal of Animal Science.1983(6): 9-10.

Rerat, A. and Corring, T. (1991) Animal factors affecting protein digestion and absorption. Proceedings of the 5th International Symposium on digestive physiology in pigs: 24-26th April, 1991. Wageningen,(Doorwerth) Netherlands: 1-30.

Van Soest, P.J. (1982) Nutritional Ecology of the Ruminant. O & M, Inc., Corvallis

Varel, V.H., Jung, H.G. and Pond, W.G. (1988) Effect of dietary fibre of young adult genetically lean, obese and contemporary pigs, rate of passage digestibility and microbiological data. Journal of Animal Science 66: 707-712.

Warner, A.C.I. (1981) Rate of Passage of digesta through the gut of animals and birds. Nutrition Abstracts and Reviews (seris B) 51 (12): 789-820.

Wenk, C. and Morel, P. (1985) Genetic variation of the digestibility of energy in growing pigs. Proceedings of the 3rd International Seminar on digestive physiology in the pig, 16th -18th May, 1985 Copenhagen, Denmark: 396-399.

Xiu, X.Y. (1984) Digestibility of Harbin White and Min pigs. Journal of North-east Agricultural College. 1984(suppl.): 81-88

Xiu, X.Y. (1986) Factors influencing the digestibility of feeds. in: Proceedings in animal nutrition. Heilongjang Science and Technology Press.: 6-10.

Yen, J.T., Mersmann, H.J., Hill, A.D. and Pond, W.G. (1990) Effect of ractopamine on genetically obese and lean pigs. Journal of Animal Science 68: 3705-3712.

You, G.X. (1982) Factors influencing digestibility of pigs' feed: differences between breeds. Abstract of Animal Science.1982(6): 18.

Zhang, G.H., Ma, Q.Z. and Wang, J. (1990) Study on feeding characteristics of chinese native pig. Chinese pig Symposium 5-6th July 1990, Toulouse, France 189-198.

Zhao, G. (1989) Research on Min Pigs. Heilongjang Science and Technology Press.: 145-185.

Chapter 4

Thermal processing of whole soybeans: studies on the inactivation of antinutritional factors and effects on ileal digestibility in piglets

G. Qin[1,2], E.R. ter Elst[2], M.W. Bosch[2] and A.F.B. van der Poel[2]

[1]Department of Animal Science, Jilin Agricultural University, Changchun 130118. P.R. of China.
[2]Department of Animal Nutrition, Wageningen Agricultural University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

Abstract

Two experiments were conducted to investigate the effects of steam processing on the nutritional improvement of full-fat soybeans.

In a kinetic study, soybeans were toasted at 102°C, 120°C and 134°C for various durations (19 temperature-time combinations, [T,t]). The raw and processed soybeans were measured for their functional lectins, trypsin inhibitor activity (TIA), urease activity (UA) and protein dispersibility index (PDI). The raw soybeans contained 7,638 $\mu g\ g^{-1}$ functional lectins, 23.44 mg g^{-1} TIA, 2.22 UA (ΔpH) and 85.7% PDI, respectively. These criteria all decreased as the heating time increased. Of all criteria measured, the level of functional lectins was found to be most effectively inactivated by high temperature.

In the second experiment, 35 piglets of approximately 30 kg liveweight were used. The animals were fitted with a post-valvular T-caecum (PVTC) cannulae and divided into 7 groups, which were fed a control diet and 6 experimental diets. The diets consisted of 80% control diet and 20% processed soybeans which were treated under the following conditions: 102°C/10 min, 102°/20 min, 102°C/40 min, 120°C/2 min, 120°C/7.5 min and 134°C/1.5 min. The apparent ileal digestibilities of the soybeans processed at the above described [T/t] conditions were 37.0, 49.1, 61.3, 48.2, 57.0 and 56.8% for dry matter (DM); 51.1, 68.3, 81.2, 70.3, 82.0 and 82.2% for nitrogen (N); 82.2, 84.1, 89.2, 89.6, 93.0 and 91.8% for ether extract, respectively. The apparent digestibilities of DM and N increased as the level of antinutritional factors decreased. It appears that a certain amount of energy is required to achieve the inactivation of antinutritional factors, either by treatment at a high temperature for a short time (e.g. 134°C/1.5 min) or for a longer time at a lower

temperature (e.g. 102°C/40 min). It was noticed that the residual TIA content of the processed soybeans was correlated to the variation in digestibility among the animals, which indicates that there are considerable differences between individual animals in their responses to the soyabean antinutritional factors.

Key words: Piglets, soybeans, antinutritional factors, thermal processing, ileal digestibility

1. Introduction

Soybeans (*Glycine* spp.), either raw or inadequately processed, are known to negatively influence feeding value when consumed by humans or nonruminant animals, due to the presence of various antinutritional factors, which have a negative effect on digestion and utilization of nutrients by animals (Liener, 1980). The activity of trypsin inhibitors, the most deleterious soybean antinutritional factor, is relatively higher in soybeans than in other legume seeds (Leterme et al., 1988). Therefore, it is necessary to process raw soybeans properly before feeding to animals.

The effects of processing a given product, may vary considerably with different processing procedures or conditions. An ideal thermal treatment procedure should sufficiently inactivate antinutritional factors while simultaneously maintaining the bio-availability of essential amino acids in the product (van Barneveld, 1993). The optimization of an efficient thermal processing depends on the combination of temperature, time (duration), moisture content and particle size (Melcion and van der Poel, 1993). However, the optimal processing conditions may vary also with the different origin or cultivar of soybean being processed.

In this study, in vitro and in vivo evaluation for full fat soybeans treated under various combinations of temperature and time, were conducted to examine the effect of processing conditions on the inactivation of antinutritional factors and protein dispersibility index (PDI).

PDI measures dispersibility of proteins in water and is generally used as a quality parameter of protein denaturation upon thermal processing of soybeans. In addition, the effect on the apparent ileal digestibility of nutrients from treated soybeans was examined in piglets.

2. Materials and methods

2.1 Soybeans and processing

Soybeans (*Glycine max* L., cull grade), grown in Argentina, were purchased from a commercial supplier. The crude protein, crude fat, crude fibre, ash and nitrogen free extract, were 384, 207, 43, 51 and 315 g kg^{-1}, respectively on dry matter basis. For experiment 1, whole soybeans (without prior crushing) were processed at the WageningenFeed Processing Centre with a laboratory-scale pressurized steam toaster which has been described in detail previously (van der Poel et al., 1990). Several temperature-time combinations were used (see Table 3), and were conducted in randomized order. Since with high temperature the inactivation rate for antinutritional factors is increasing, not all antinutritional factors were analysed at all processing times because the accuracy of analysis is less in detecting very low levels. After steam processing, single samples of processed soybeans were immediately air-dried in a forced-draught oven at 35°C for 24 h, then milled to pass a 1 mm screen and stored at 4°C prior to laboratory analyses.

The steam processing of soybeans for experiment 2 was carried out following the same procedure as for experiment 1.

2.2 Ileal digestion trial

Six soybean samples from different treatments were evaluated in an ileal digestion trial with pigs (experiment 2).

The apparent ileal digestibility of dry matter (DM), nitrogen (N) and crude fat (CFAT) was measured in castrated crossbred male piglets which had been fitted with a post-valvular T-caecum (PVTC) cannula at a liveweight of about 10 kg. Cannula design and surgical procedure were as described by Van Leeuwen et al. (1988). After being cannulated, the piglets were housed individually in appropriate cages (900 x 800 x 600 mm) at an ambient temperature of 22°C. The trial started when the piglets had recovered from surgery and had an average weight of 30 kg. Six experimental diets and one control diet were used in the trial. Each diet was fed to five animals.

The formulation of the control diet is shown in Table 1. The six experimental diets consisted of 80% of the control diet and 20% soybeans. The soybeans were treated under the following conditions: 102°C/10 min, 102°C/20 min, 102°C/40 min, 120°C/2 min, 120°C/7.5 min and 134°C/1.5 min. Chromium oxide (Cr_2O_3) was added as an indigestible marker to each diet (10 g kg^{-1}) to determine the recovery of ileal digesta. All diets were pelleted without steam addition (pellet diameter: 3 mm). The composition of the control and experimental diets are given in Table 2.

Feed was administered with water at the ratio of 1:1. Water was supplied ad libitum from a nipple. The cannulated animals were fed equal amounts of feed at 2.6 times the maintenance requirement of ME (420 KJ ME $kg^{-0.75}$ body weight), twice daily, at 8.00 and 16.00 h during the adaptation and the digesta collection period. For the first two days of the adaptation period, all animals were fed the control diet. For the experimental groups, the control diets were gradually replaced by 25, 50, 75 and 100% of their experimental diets during the following four days. Thereafter, the animals were adapted to their experimental diets for seven days.

Table 1 Formulation of the control diet (g kg^{-1}) for the ileal digestion trial with piglets

Maize starch	573	$CaCO_3$	19
Wheat middlings	50	$CaHPO_4.2H_2O$	286
Casein	131	NaCl	30
Herring meal	50	Dl-methionine	11
Cellulose	21	L-threonine	06
Sunflower oil	10	L-tryptophan	02
Dextrose	60	$NaHCO_3$	122
Cane molasses	40	$KHCO_3$	64
Vitamin premix[a]	10	Marker Cr_2O_3	10

[a]Vitamin, trace mineral premix (mg kg^{-1} unless otherwise mentioned) supplied by 1 kg of diet, including: MgO, 2000; $CuSO_4.5H_2O$, 150; $ZnSO_4.H_2O$, 150; MgO, 150; $FeSO_4.7H_2O$,200; $CoSO_4.7H_2O$, 0.5; $Na_2SeO_3.5H_2O$, 0.3; $Na_2MoO_4.2H_2O$, 3; H_3BO_3, 3; KI, 5. Vit. A, 9,000 IU; Vit. D, 1,800 IU, Vit. E, 30; $Na_2MoO_4.2H_2O$, 5; thiamin HCl, 8; riboflavin, 8; Ca-d-panthotenate, 15; pyridoxine HCL, 4; choline chloride, 2000; folic acid, 2; cyanocobalamin, 0.02; biotin, 0.3; L-ascorbic acid, 50; inositol, 100; *p*-aminobenzoic acid, 2.5; ethoxyquin, 125. The remainder was made up of maize starch.

Ileal digesta were collected with plastic pouches for 12 h a day, for 5 days following the adaptation period. In order to avoid decomposition of the components, 1 ml of Merthiolaat (bacteriostatic; 30 mg ml^{-1}) was added to the collected digesta. After collection, all ileal digesta were weighed individually, and stored at -20°C pending analysis.

The apparent ileal digestibilities of DM, N and CFAT of the control and experimental diets, were calculated using Chromium as a marker. The ileal digestibilities of these nutrients in processed soybeans were calculated according to the mean of control diet digestibilities and the individual observations of nutrient digestibilities in the experimental diets as described by van der Poel et al. (1992).

The data obtained were analyzed for variance and linear correlation procedures (SAS, 1988).

Table 2 Proximate analyses (g kg^{-1} DM) of the control and experimental diets[a] (Experiment 2) and levels of TIA (mg g^{-1}), urease (Δ pH), lectins (μg g^{-1}) and protein dispersibility index (%) of processed soybeans[b]

Temperature (°C)/ Duration (min)	Control	Experimental diets					
		102/10	102/20	102/40	120/2	120/7.5	140/15
Diets							
Dry matter	894	899	894	891	899	894	890
Crude protein	189	239	238	236	241	239	239
Crude fat	25	58	64	65	58	62	60
Crude fibre	20	28	27	29	27	29	26
N-free extract	596	512	504	500	512	502	502
Ash	64	62	62	62	62	62	62
Soybean							
TIA	23.4	5.8	2.9	1.9	6.0	2.4	2.4
UA	2.2	1.9	0.2	0.0	0.1	0.0	0.0
Lectins	7638	1005	105	11-16	<0.5	<0.5	<0.5
PDI	85.7	39.5	27.0	20.4	28.1	12.4	10.4

[a] After pelleting; means (n=2).
[b] Control column refers to unprocessed beans.

2.3 Laboratory analytical methods

All chemical and physical analyses were carried out in duplicate in air-dried samples. The effect of heating on protein quality was estimated by determining the protein dispersibility index (PDI; AOCS, 1979). Trypsin inhibitory activity (TIA; mg g^{-1} product) was measured in re-milled samples (0.08 mm sieve) according to the method described by van Oort et al. (1989). Urease activity (UA, difference between sample pH and blanco pH referred to as pH) was determined according to AOCS Official Method Ba 9-58 (AOAC, 1979). Functional lectins in samples were analyzed with an immuno-assay (FLIA-BBM) using pig brush border membrane (BBM) as substrate as reported by Hendriks et al. (1987).

Fresh samples of digesta were analysed in duplicate for moisture and nitrogen (Kjeldahl N) according to standard methods (Weende analysis). Diet samples and freeze-dried digesta samples were ground and analysed for dry matter (DM; drying at 103°C during 4 h), crude fat (CFAT; petroleum ether (40-60) extract; 6 hours extraction), and chromium (Cr). Cr was measured by atomic absorption spectroscopy (Perkin Elmer 300).

3. Results

3.1 Kinetic study

With the prolongation of heating time at different temperatures, TIA, UA, lectins and PDI were all decreased following a logarithmic pattern. All parameters measured, however, decreased to a different extent (Tables 3 and 4). At the temperature of 102 °C, TIA sharply decreased with the prolongation of heating time up to 7.5 min, after which the reduction became more gradual. At 120°C and 134°C, TIA was reduced to very low levels within 1.5 min. The residual TIA were approximately equal to the values for beans heated for 20-40 min at 102°C.

Table 3 Effect of steam temperature and time on trypsin inhibitor activity (TIA; mg g^{-1}), lectins (μg g^{-1}), urease activity (UA; Δ pH) and protein dispersibility index (PDI; %) in steam processed soybeans

	TIA			Lectins			UA			PDI		
Temp.°C	102	120	134	102	120	134	102	120	134	102	120	134
Time, min												
0	23.44	23.44	23.44	7638	7638	7638	2.22	2.22	2.22	85.7	85.7	85.7
1.5	-	6.76	2.44	-	-	-	-	0.11	0.02	-	33.3	10.4
2	-	5.98	1.83	-	<0.5	-	-	0.11	0.02	-	28.1	10.5
2.5	16.25	6.09	-	-	-	-	2.12	0.06	-	57.4	24.9	-
4	-	-	-	-	-	-	-	0.06	-	-	19.3	-
5	10.19	2.76	-	-	-	-	1.86	0.03	-	45.2	15.9	-
7.5	6.20	2.23	-	-	<0.5	-	1.59	0.00	-	41.0	12.4	-
10	5.76	1.70	-	1005	-	-	1.24	0.03	-	39.5	10.5	-
20	2.89	-	-	105	-	-	0.17	-	-	27.0	-	-
40	1.89	-	-	14	-	-	0.04	-	-	20.4	-	-
80	0.80	-	-	-	-	-	0.04	-	-	11.6	-	-

-, not determined.

Although the UA and PDI showed similar inactivation patterns as TIA, UA was more sensitive to high temperature than TIA. For the heat treatment 120°C/2.5 min, the TIA residual value only decreased to 37.5% of the activity of that in 102°C/2.5 min. The UA residual, however, decreased to 2.8% of the corresponding value. At 102 and 120°C, PDI decreased with the prolongation of heating time at a lower rate than TIA and UA, which indicated that, with regard to the length of heating time, PDI was not as sensitive as TIA and UA.

Table 4 Regression models for the change of trypsin inhibitor activity (TIA), urease activity (UA) and protein dispersibility index (PDI) with heating duration at 102°C and 120°C for steam processed whole soybeans

102°C		120°C	
Model	R	Model	R
TIA=16.91-4.15 ln X	0.93	TIA=8.08-2.89 ln X	0.98
UA=2.83-0.71 ln X	0.95	UA=0.12-0.05 ln X	0.90
PDI=67.53-12.9 ln X	0.99	PDI=36.62-12.0 ln X	0.99

Variables in the models: TIA (mg g^{-1}), UA (Δ pH), PDI (%).
X: heating duration in minutes.
Ln: natural logarithm ~ ^{2}log

Table 5 Correlation coefficients between trypsin inhibitor activity (TIA; mg g^{-1}), urease activity (UA; ΔpH), lectins (μg g^{-1}) and protein dispersibility index (PDI; %) in steam processed whole soybeans

	Correlation	P
TIA vs UA	0.8439	<0.01
TIA vs lectins	0.9841	<0.01
TIA vs PDI	0.9590	<0.01
UA vs lectins	0.9179	<0.05
UA vs PDI	0.8950	<0.01
PDI vs lectins	0.9534	<0.01

Compared with other criteria, lectins were much more sensitive to high temperatures. At 102°C heated for 20 min, only 1.4% of the original functional lectin level (FLIA-BBM) remained in the product. When the temperature was raised to 120°C however, a heating time of only 1.5 min decreased the lectin level to almost zero. For the latter treatment, TIA and UA retained considerable activities in the products.

All the above mentioned criteria had a similar tendency in response to the treatment. For whole processed soybeans, there were very high correlations between each of these criteria, as shown in Table 5.

Table 6 Apparent ileal digestibility coefficients[1,2] (%) of dry matter, nitrogen and crude fat of the piglet diets and of soybeans, steam processed under different temperature-time conditions

	Dry matter		Nitrogen		Crude fat	
	Mean	SD	Mean	SD	Mean	SD
Control diet	86.9[a]	0.9	85.3[a]	1.4	84.3[ab]	2.0
Experimental diets						
102°C/10 min	76.9[c]	3.1	72.3[c]	4.4	83.3[b]	6.3
102°C/20 min	78.9[bc]	1.1	78.3[b]	1.1	84.5[ab]	2.6
102°C/40 min	81.5[b]	1.3	83.2[ab]	2.7	88.1[ab]	2.6
120°C/2 min	79.5[bc]	2.3	79.3[ab]	3.0	88.1[ab]	3.2
120°C/7.5 min	81.2[b]	0.8	83.5[ab]	0.2	90.4[a]	0.8
134°C/1.5 min	81.2[b]	1.2	82.8[ab]	1.0	89.5[ab]	0.5
Soybeans						
102°C/10 min	37.0[b]	15.7	51.1[b]	12.3	82.2[a]	9.5
102°C/20 min	49.1[ab]	5.3	68.3[ab]	2.9	84.1[a]	4.0
102°C/40 min	61.3[a]	6.3	81.2[a]	7.4	89.2[a]	3.7
120°C/2 min	48.2[ab]	11.9	70.3[a]	8.3	89.6[a]	4.9
120°C/7.5 min	57.0[ab]	4.4	82.0[a]	0.6	93.0[a]	1.2
134°C/1.5 min	56.8[ab]	6.2	80.2[a]	2.9	91.8[a]	0.7

[1] Means and standard deviation;

[2] Data with different superscripts in a column per subtitle are significantly different

3.2 Ileal digestion trial

The ileal digestibility data from all the diets and soybeans are shown in Table 6. They indicate that the digestibilities of some nutrients of soybeans and the diets containing the soybeans were largely influenced by the treatments. There were differences between individual piglets in their response to antinutritional factors in soybeans (or treatments). The differences between data for soybean DM, N and CFAT digestibility were 24.3, 30.9 and 10.8 percentage units, respectively.

($P<0.05$);Soybeans treated under the conditions of 102°C/40 min, 120°C/7.5 min and 134°C/1.5 min displayed similar results for DM, N and CFAT ileal digestibility. Their DM and N digestibilities were significantly higher than those treated at 102°C/10 min ($P<0.05$).

The digestibility responses to treatments were different between the nutrients. For N, the magnitude for improvement upon heat processing proved to be larger than for CFAT or DM. The digestibility of N in the properly treated (134°C/1.5 min) soybeans was 30.9 percentage units higher than that in the under-processed (102°C/10 min) soybeans ($P<0.01$). In contrast with N, there was no significant difference in CFAT digestibility of soybeans between treatments ($P>0.05$) although it showed some responses to treatment to a certain extent.

The correlation analysis showed that the means of nutrient digestibility were inversely correlated to their standard deviations. The correlation coefficients for DM, N and CFAT were -0.84 ($P<0.05$), -0.74 ($P<0.01$) and -0.63 ($P<0.20$) of the soybean data, respectively. It was also found that there were high positive correlations between the digestibilities of nutrients (DM, N and CFAT) in soybeans. The correlation coefficients of DM to N, DM to CFAT, and N to CFAT were 0.98 ($P<0.01$), 0.86 ($P<0.05$) and 0.88 ($P<0.05$), respectively.

4. Discussion

4.1 Kinetic study

TIA and UA of the raw Argentina soybeans used in the present experiment had similar activities to soybeans of American origin (Slump and Dukel, 1979; Herkelman et al., 1990; 1992), and of Brazilian origin (Slump and Dukel, 1979) and of Austria origin (Zollitsch et al., 1993). However, the TIA was lower than that of the soybeans measured by Xian and Farrell (1983) although the UA was similar.

The rate of TIA decrease caused by heat processing, was different for different range of heating time. For instance, heated under 102°C, TIA decreased rapidly within 7.5 min, after which the inactivation rate was more gradual. This had also been found in previous studies using soybeans (Collins and Beaty, 1980; Liener and Thomlinson, 1981) or dry beans (*Phaseolus vulgaris* L.) (van der Poel et al., 1990). The extent of inactivation of TIA was not in complete agreement with some previous results observed in other procedures with similar treatment temperature and duration. The residual TIA in the soybeans roasted at 120°C for 5 min (Zollitsch et al., 1993) or autoclaved at 121°C for 10 min (Herkelman et al., 1990) was 7.2% and 47.5% of those in the raw soybeans, respectively. In the present experiment, the residual TIA of the soybeans treated for 120°C/5 min and 120°C/10 min was 11.8% and 7.3% of those of the raw soybeans, respectively. The treatment effects not only depend on temperature and heating duration, but also on many other factors. For example, the origin of the raw soybeans may be one of the factors which led to the differences between the results of present and previous experiments. According to the results of Chang et al. (1984) and Monari (1993), the TIA of adequately processed soybeans should not exceed 4 mg g^{-1} product. Referring to this standard, the soybeans treated at 102°C for 20 min 120°C for 5-7.5 min and 134°C for 1.5 min were expected to be the adequately treated ones. However, for PDI, the treatment conditions of 120°C/7.5 min and 134°C/1.5 min were too severe, the PDI (12.4% and 10.4% respectively) being somewhat below the acceptable value range (15-28%) as recommended by Monari (1993).

The residual value of TIA (1.83 mg g^{-1}) in the soybeans treated at high temperature, short time (134°C/2 min) was similar (1.89 mg g^{-1}) to that treated at low temperature, long time (102°C/40 min). However, the PDI (10.5 %) of the former treatment was only half of that (20.4 %) of the latter treatment. These data indicated that although HTST treatment and LTLT treatment had a similar effect in inactivation of TIA, the former denatured the proteins much more severely than did the latter.

Lectins were found to be highly sensitive to temperature. At 120°C and 134°C heated for 1.5 min they were almost completely inactivated. Therefore, it can be assumed that HTST treatment is more effective for the raw materials in which lectins are the main antinutritional factors.

4.2 Ileal digestibility

The significant differences in N and DM ileal digestibilities between differently treated soybeans, showed the effectiveness of heat treatment on the improvement of the nutritional value of soybeans. This is well supported by previous studies (Rudolph et al., 1983; Herkelman et al., 1989a,b; 1992; Healy et al., 1990; Vandergrift et al., 1983). In the present experiment, the digestibilities of the measured nutrients in the soybeans treated at 102°C/10 min was evidently lower, indicating that they were underprocessed. The soybeans treated at 102°C/40 min, 120°C/7.5 min and 134°C/1.5 min seem processed more adequately with regarding to their ileal digestibilities of nutrients than those treated at other conditions.

Similar results for ileal digestibility were observed in the soybeans treated at LTLT, intermediate temperature, intermediate time, and HTST. This similarity indicates that the inactivation of protease inhibitors in the soybeans may need a fixed amount of energy. An adequate processing of soybeans based on N-ileal digestibility can then be achieved by adjusting heating temperature and/or heating time.

The N ileal digestibility is more sensitive to processing, compared to DM and CFAT. This suggests that the protease inhibitors are the main antinutritional factors influencing nitrogen digestion in soybeans, and heat processing effects mainly resulted from the inactivation of protease inhibitors. The respons of N digestibility to the processing was paralleled by DM digestibility, and was an indirect result of the inactivation of the antinutritional factors, in that a large part of the digestible DM consisted of digestible protein.

The improvement of oil digestion for soybeans is mostly associated with the physical damage to cell structure: the more severe the rupture of the cells, the greater the improvement in utilisation of the oil (Carew et al., 1961, 1962; Featherston and Rogler, 1966; Adams and Jensen, 1985). The toasting technology used in this experiment, with less or no mechanical damage to the cells, may be somewhat less effective in improving fat digestibility. Perhaps, this is the main explanation for the relatively small responses of ileal CFAT digestibility to the toasting treatments in the present experiment.

The high correlations between data of TIA, UA, lectins, PDI and digestibilities of nutrients (N, DM and CFAT), indicate that the processing effects of soybeans can be estimated to a considerable extent by the analytical criteria (see Table 7). The digestibilities of N and DM were more closely correlated to TIA, UA and lectins than to the digestibility of CFAT. It seems that the improvement of ileal N and DM digestibilities can be estimated more accurately by these criteria than for CFAT. The digestibility of CFAT was more correlated to PDI than to other analytical criteria, which indicates that protein denaturation may be, to certain extent, associated with the mechanical damage of soybean cell structure. Among the analytical criteria, PDI had the highest negative correlation coefficients to either N or DM or CFAT digestibility, indicating that PDI may be an important indicator for adequate processing of soybeans, with regarding to the improvement of nutrient digestibility. Visser and Tolman (1993), reported that the protein digestibility coefficient for calves could be largely explained by laboratory analytical variables. They found that TIA, lectins and aggregated proteins, but not PDI, were the most important variables to explain the variation in protein digestibility. Perhaps, the highly negative correlation between PDI and protein digestibility can only occur under conditions in which the products are under- or adequately processed, since the nutrient digestibility may decrease with the reduction of PDI in over-heated conditions (De Wet, 1982).

Table 7 Coefficients of correlation between analytical data and ileal digestibility coefficients (ID) of nutrients from steam processed whole soybeans

	TIA	PDI	UA	FLIA
ID-Nitrogen	-0.7804	-0.9314	-0.9242	-0.8978
ID-Dry matter	-0.8457	-0.8765	-0.8720	-0.8403
ID-Crude fat	-0.4859	-0.8886	-0.7798	-0.7636

The variation of nutrient digestibility coefficients between individual piglets was found to be associated with the means of digestibility coefficients and the inactivation of antinutritional factors. The lower the ANFs (TIA/UA), the higher the nutrient digestibility, and the smaller the variation in digestibility. The standard deviation of DM, N and CFAT digestibility of the soybeans with the higher TIA and UA (treated at 102°C/10 min) were approximately as large as 4, 20 and 9 times of that with lower TIA and UA (treated at 120°C/7.5 min). The correlation coefficients between the means and standard deviations of digestibility for each of the nutrients measured in this experiment are shown in Table 7. Vandergrift et al. (1983) reported that variation in amino acid and N digestibilities were one to two fold greater among pigs fed raw soyflakes than pigs fed heated soyflakes. They suggested that differences exist between pigs in their ability to tolerate the high level of trypsin inhibitors or other antinutritional factors present in soya products. Goihl (1990) and Qin et al. (1994) stated that some pigs utilize raw soybeans more efficiently than others. Based on observations in the present experiment and previous reports, it can be stated that there is a considerable variation between individual animals in their respons to antinutritional factors of soybeans.

In conclusion, steam toasting can effectively inactivate TIA and lectins in soybeans, with a concomitant reduction of the UA and PDI. At temperatures of 102°C and 120°C, TIA, UA, lectins and PDI decreased with the prolongation of heating time in a logarithmic pattern. These analytical parameters were highly correlated with each other.

DM and N digestibility of the soybeans can be significantly improved by steam toasting. The soybeans treated at 102°C/40 min, 120°C/7.5 min and 134°C/1.5 min showed similar and satisfactory results in terms of their nutrient digestibility. There were considerable differences between individual animals in respons to antinutritional factors in soya. The animal factors which lead to such differences are still unknown. In addition, the utilization of nitrogen and amnino acids remain to be studied.

Acknowledgements

The financial support from the NOVEM for sample analyses is thankfully acknowledged. The authors thank Dr Yonggang Liu and Mw Dr B. Williams for their valuable contribution during the preparation of this article.

References

Adams, K.L. and Jensen, A.H., 1985. Effect of processing on the utilization by young pigs of the fat in soya beans and sunflower seeds. Anim. Feed Sci. Technol., 12:267-274.

American Oil Chemists' Society, 1979. Protein dispersibility index (PDI). AOCS Official Method Ba 10-65, revised 1978, corrected 1979.

American Oil Chemists' Society, 1979. Urease activity. AOCS Official Method Cd 8-53.

Carew, L.B., Hill, R.W. Jr. and Nesheim, M.C., 1961. The comparative value of heated ground unextracted soybeans and heated dehulled soybean flakes as a source of soybean oil and energy for the chicks. J Am. Oil Chemists' Soc., 38: 249-253.

Carew, L.B., Hill, R.W. Jr. and Nesheim, M.C., 1962. The effect of pelleting on the nutritional value of ground soybeans for the chick. Poultry Sci., 41:61.

Chang, C.L., Tanskley, T.D., Jr., Knabe, D.A., Zebrowska, T. and Gregg, E.J., 1984. Effect of different heat treatments during processing on nutrient digestibilities of soybean meal by growing swine. J. Anim. Sci., 59 (suppl. 1): 268-269.

Collins, J.L. and Beaty, B.F., 1980. Heat inactivation of trypsin inhibitor in fresh green soybeans and physiological responses of rats fed the beans. J. Food Sci., 45:542-546.

Featherston, W.R., and Rogler, J.C., 1966. A comparison to processing conditions of unextracted soybeans for utilization by the chick. Poultry Sci., 45:330.

Goihl, J.H., 1990. Amino acid supplementation of soybean diets examined. Feedstuffs. 62 (42):16-18.

Healy, B.J., Giesemenn, M.A., Hancock, J.D., Lewis, A.J., Jones D.B. and Koch, K.B., 1990. Heat treatment and dietary lysine concentration affect the nutritional value of low inhibitor soybeans in finishing pigs. J. Anim. Sci., 68 (suppl. 1): 399.

Hendriks, H.G.C.J.M., Koninkx, J.F.J.G., Draaier, J., van Dijk, J.E., Raaijmakers, J.A.M. and Mouwen, J.M.V.M., 1987. Quantitative determination of the lectin binding capacity of small intestinal brush border membrane. An Enzyme Linked Lectin Sorbent Assay (ELLSA). Biochem. Biophysiol. Acta. 905:371-375.

Herkelman, K.L., Cromwell, G.L., Stakly, T.S. and Pfeiffer, T.W., 1989a. Utilization of low trypsin inhibitor soybeans by pigs and chicks. KY. Swine Res, Rep-Progress Rep. (321):33-36.

Herkelman, K.L., Cromwell, G.L., Stakly T.S. and Pfeiffer, T.W., 1989b. Effects of feeding soybeans having low Kunitz trypsin inhibitor on performance and pancreas weights of chicks. J. Anim. Sci. 67 (suppl. 2):41.

Herkelman, K.L., Cromwell, G.L. and Stakly, T.S., 1990. Effect of heating time on the nutritional value of full-fat soybeans for chicks. J. Anim. Sci. 68 (suppl.1):1.

Herkelman, K.L., Cromwell, G.L., Stakly T.S., Pfeiffer T.W. and Knabe, D.A., 1992. Apparent digestibility of amino acids in raw and heated conventional and low-trypsin-inhibitor soybeans for pigs. J. Anim. Sci., 70:818-826.

Leterme, P., Beckers, Y. and Thewis, A., 1988. Inter- and intravarietal variability of the trypsin inhibitors content of peas and his influence on apparent digestibility of crude proteins by growing pigs. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds (J. Huisman, A.F.B. van der Poel and I.E. Liener, Editors), Wageningen, Netherlands. 23-25 Nov. 1988, 121-124.

Liener, I.E., 1980. Toxic constituents of plant foodstuffs. 2nd ed., Academic press, New York, 503 pp.

Liener, I.E. and Thomlinson, S., 1981. Heat inactivation of protease inhibition of a soybean line lacking the Kunitz trypsin inhibitor. J. Food Sci., 46: 1354-1356.

Melcion, J.P. and van der Poel, A.F.B., 1993. Process technology and antinutritional factors: principles, adequacy and process optimization. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of the Second International Workshop on 'Antinutritional Factors (ANFs) in Legume Seeds' (A.F.B. van der Poel, J. Huisman and H. S. Saini, Editors), Wageningen, The Netherlands, 1-3 December 1993, 419-434.

Monari, S., 1993. Fullfat soya handbook (Second edition). American Soybean Association, 20-22 Rue du Commerce-1040 Brussels, 6-9.

Qin, G., Chen, P. and Gao, Z., 1989. Influence of pig breed and diet type on digestibility of nutrients. Swine Production. 3:6-8.

Qin, G., Verstegen, M.W.A. and Bosch, M.W., 1994. Variation of digestive capacity between genetically different populations of pig: a review. **Tijdschrift** Submitted for publication.

Rudolph, B.C., Boggs, L.S., Knabe, D.A., Tanksley, T.D. Jr. and Anderson, S.A., 1983. Digestibility of nitrogen and amino acids in soybean products for pigs. J. Anim. Sci. 57: 373-386

SAS, 1988. Statistical Analysis System, SAS/STAT User's Guide, Version 6.2. SAS Institute Inc. Cary, NC.

Slump, P. and Dukel, F., 1979. Amino acid levels and other parameters of soybean meal and soybeans of different origins. CIVO-TNO Institute, Report nr. 6022.

Van Barneveld, R.Y., 1993. Effect of heating protein on the digestibility, availability and utilization of lysine by growing pigs. Ph.D. thesis, Dept. of Agriculture, University of Queensland, Australia. 221 pp.

Vandergrift, W.L., Knabe, D.A., Tanksley, T.D. Jr. and Anderson, S.A., 1983. Digestibility of nutrients in raw and heated soyflakes for pigs. J. Anim. Sci., 57:1215-1224.

Van der Poel, A.F.B., Blonk, J., Van Zuilichem, D. J. and van Oort, M.G., 1990. Thermal inactivation of lectins and trypsin inhibitor activity during steam processing of dry beans (*Phaseolus vulgaris* L.) and effects on protein quality. J. Sci. Food Agric., 53:215-228.

Van der Poel, A.F.B., Dellaert, L.M.W., van Norel, A. and Helsper, J.P.F.G., 1992. The digestibility in piglets of faba bean (*Vicia faba* L.) as affected by breeding towards the absence of condensed tannins. Br. J. Nutr., 68, 793-800.

Van Leeuwen, P., Huisman, J., Verstegen, M.W.A., Baak, M.J., Van Kleef, D.J., Van Weerden, E.J. and Den Hartog, L.A., 1988. A new techique for collection of ileal chyme in pigs. Proceedings of the 4th International Seminar on Digestive Physiology in the Pig. Polish Academy of Sciences, Jablonna, Poland, 289-296.

Van Oort, M.G., Hamer, R.J. and Slager, E.A., 1989. The trypsin inhibitor assay: improvement of an existing method. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds. J. Huisman, A.F.B. van der Poel, I.E. Liener (Editors), PUDOC, Wageningen, 110-113.

Visser, A. and Tolman. G.H., 1993. The influence of various processing conditions on the level of antinutritional factors in soya protein products and their nutritional value for young calves. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of the Second International Workshop on 'Antinutritional Factors (ANFs) in Legume Seeds' (A.F.B. van der Poel, J. Huisman and H.S. Saini, Editors), Wageningen, The Netherlands, 1-3 December, 1993, 447-453.

Wet, P.J. de, 1982. Effect of processing on nutritive value of feeds: proteins. In: Handbook of Nutritive Value of Processed Food. M. Rechcigl Jr. (Editor), Vol. II, CRC Press, Inc., Florida, pp. 321-341.

Xian, J. and Farrell, D.J., 1990. The nutritive value of microwave-processed raw soya beans determined with chickens, rats and rabbits. Anim. Feed Sci. Technol., 34:127-139.

Zollitsch, W., Wetscherek, W. and Lettner, F., 1993. Use of differently processed full-fat soybeans in a diet for pig fattening. Anim. Feed Sci. Technol., 41:237-246.

Chapter 5

Effect of temperature and time during steam treatment on the protein quality of full-fat soybeans from different origins

G.X. Qin[1], M.W.A. Verstegen[2] and A.F.B. van der Poel[2]

[1] Department of Animal Science, Jilin Agricultural University, Changchun 130118, P.R.China
[2] Department of Animal Nutrition, Wageningen Agricultural University, P.O. Box. 338, 6700 AH Wageningen, The Netherlands

Abstract

Soybeans (*Glycin max.*) of Argentine and Chinese origin were steam-toasted at 102°C, 118°C and 136°C for various times with a laboratory-scale steam toaster. All the samples of raw and processed soybeans of the two origins were analyzed for dry matter (DM), crude protein (CP), trypsin inhibitor activity (TIA), protein dispersibility index (PDI) and fluorodinitrobenzene (FDNB) reactive lysine. Chinese raw soybeans showed higher levels of CP, TIA and PDI, and lower level of FDNB reactive lysine than Argentine raw soybeans (366 vs 357 g/kg, 20.6 vs 15.2 mg/g, 87.6 vs 85.6% and 17.4 vs 19.4 g/kg, respectively). The TIA and PDI of the two soybean origins decreased following a logarithmic pattern with the prolongation of heating time when beans were steam-heated at various temperatures. The reduction rate of TIA and PDI, however, was different between the two origins of soybeans. Chinese soybeans seemed to require a longer time or higher temperature to reduce their TIA to a safe level in comparison with the Argentine soybeans. In the case of beans heated at 136°C, the difference in PDI between Chinese and Argentine soybeans diminished.

It is concluded that the two soybeans origins need different processing conditions in terms of improving their protein properties.

1. Introduction

Raw soybeans have to be processed when they are to be used as an ingredient in diets for monogastric and immature ruminant animals, due to the presence of certain antinutritional factors (ANFs) (Monari, 1993). The contents of trypsin inhibitors (TI) (Sangle et al., 1993) and/or the chemical composition (Zarkadas et al., 1994) of soybeans are influenced by genotype (Herkelman et al.,1990 and 1992; 1995; Qin and Chen, 1995), geographical region of their growth (Fu and Lu, 1992; Zhao et al., 1991) and their maturity (McGrain et al., 1992). It was found that the soybeans of different origins respond differently to a given processing technology or to treatment conditions (Friedman et al., 1991). A proper processing procedure needs to inactivate ANFs to an acceptable level without reducing the availability of nutrients (Voragen et al., 1995; Van der Poel et al., 1995). The responses to a treatment, however, may vary among the origins of soybeans with regard to both the inactivation of ANFs and the change in the availability of nutrients. Thus, each batch of soybeans requires its own optimum treatment procedure in terms of an improvement in nutritional value.

In the present experiment, trypsin inhibitor activity (TIA), fluorodinitrobenzene reactive lysine (FDNB) and protein dispersibility index (PDI) were determined for raw and steam toasted Argentine and Chinese soybeans, to evaluate the effects of different steam-heating temperatures and durations on the protein quality of the two soybean origins.

2. Materials and Methods

2.1. Soybean origins

Commercial soybeans (*Glycin max.*) of Argentine and Chinese origin were purchased from Schouten Industries (Giessen, The Netherlands) and Food & Oil Import & Export Company (Jilin Province, China) respectively. The dry matter contents of the Argentine and Chinese soybeans were 896 g/kg and 924 g/kg, and their crude protein contents were 357 g/kg and 366 g/kg, respectively.

2.2. Treatment of the soybeans

Soybeans of both origins were steam-toasted at different combinations of temperature and duration (Table 1). The beans were not crushed before the thermal processing.

A laboratory-scale steam toaster as described by Van der Poel et al. (1990) was used for the processing of whole soybeans in this experiment. After heating the empty toaster to the designed temperature, batches of 2 kg soybeans were fed through the inlet sluice. A feed rate was chosen to provide a single layer of beans on the belt conveyor. The speed of the belt conveyor was adjusted for each batch to give the required residence time. Temperature tolerances were within 0.3°C. Immediately after steam processing, the soybeans were put into screen bottom trays and spread in one layer for cooling down for half an hour. After cooling, they were air-dried in a thermo-controlled drying chamber (36 h. at 40 °C). The dried soybeans were then milled to pass through a 1 mm screen (for proximate and PDI analysis) or through a 0.5 mm screen (for TIA and FDNB reactive lysine analysis), and stored in a cool room (4 °C) until analysis.

2.3. Analytical methods

Dry matter (DM) content of the samples was measured by standard method (103°C for 4h). Nitrogen was determined by the Kjeldahl method (ISO, 1979), and the crude protein content (CP) was calculated by N*6.25. The protein quality of raw and processed soybeans was estimated by analyzing the trypsin inhibitor activity (TIA), protein dispersibility index (PDI) and fluorodinitrobenzene (FDNB) reactive lysine. TIA was determined according to the modified procedure of Kakade et al. (1974) as described by Van Oort et al. (1989). PDI was determined with the standard procedure issued by AOCS (1964). The FDNB reactive lysine was measured according to the method reported by Carpenter (1960) as modified by Booth et al. (1971). All parameters were analyzed in duplicate.

2.4. Data processing

Curve fitting were conducted in a logarithmic model for the data of TIA and PDI at various treatment conditions with Slide Write Version 6.0. The model was:

$$Y=a_0+a_1*\ln(X)$$

where Y is TIA (mg/g) or PDI (%) and X is heating duration (min.). A linear correlation analysis was carried out between relevant parameters with the software of SAS (1989).

3. Results

The results of TIA, PDI, FDNB reactive lysine, CP and DM of the samples of the soybeans treated at various conditions are presented in Table 1.

Table 1. Effects of steam toasting on trypsin inhibitor activity (TIA), protein dispersibility (PDI) and fluorodinitrobenzene reactive lysine (FDNB) of Argentine and Chinese commercial soybeans

	TIA(mg/g)	PDI(%)	FDNB(g/kg)	DM(g/kg)
Treatment (°C/min.)				
Argentine soybeans:				
raw	15.2	85.6	19.3	895.7
100/5.0	7.3	55.4	18.4	947.7
100/10.0	4.8	48.3	16.4	948.5
100/20.0	2.5	37.5	18.6	947.0
100/40.0	1.6	25.0	18.9	946.2
118/2.5	3.7	23.9	18.3	942.8
118/5.0	2.0	15.8	18.9	934.8
118/10.0	1.2	12.0	17.8	934.0
118/20.0	0.4	9.8	18.0	931.9
136/1.5	1.0	9.7	17.5	938.8
136/2.5	0.8	9.5	18.0	936.7
136/5.0	0.3	9.5	16.7	930.6
136/10.0	0.0	10.4	16.2	920.0
Chinese soybeans:				
raw	20.6	87.6	17.4	923.5
100/5.0	13.1	64.8	18.6	949.8
100/10.0	7.4	52.3	18.8	947.3
100/20.0	4.3	42.5	17.6	946.3
100/40.0	2.4	29.9	17.8	943.6
118/2.5	8.9	47.1	18.4	945.7
118/5.0	4.4	29.5	17.7	947.4
118/10.0	2.2	17.2	15.5	940.9
118/20.0	0.7	9.9	18.3	930.8
136/1.5	2.6	13.0	17.9	929.8
136/2.5	1.9	11.3	17.7	937.9
136/5.0	0.5	9.4	16.9	920.7
136/10.0	0.0	9.7	16.2	918.8

The results indicated that TIA, PDI, FDNB reactive Lysine and CP in raw soybeans differed between the two origins. The level of TIA, PDI and CP of Chinese raw soybeans were 5.4 mg/g, 1.9 % unit and 9 g/kg higher than that of Argentine raw soybeans, respectively. The FDNB reactive lysine in Argentine raw soybeans was 2 g/kg higher than in Chinese raw soybeans.

When heated at various temperatures, the TIA and PDI in both Argentine and Chinese soybeans evidently decreased with an increase in heating duration. These parameters, however, showed different patterns for the two origins of soybeans. The residual TIA in the Chinese soybeans appeared to be higher compared to TIA in Argentine soybeans, especially for samples heated for short time at various temperatures. The differences in the relative reduction of TIA between the soybean origins, however, diminished with the prolongation of heating (see Figures 1 and 2).

The differences between the soybean origins in response to steam-heating were more pronounced for the PDI value than for any other parameters. With regard to PDI, the Chinese soybeans were found to be less sensitive to the higher temperature, though not to duration of heating than the

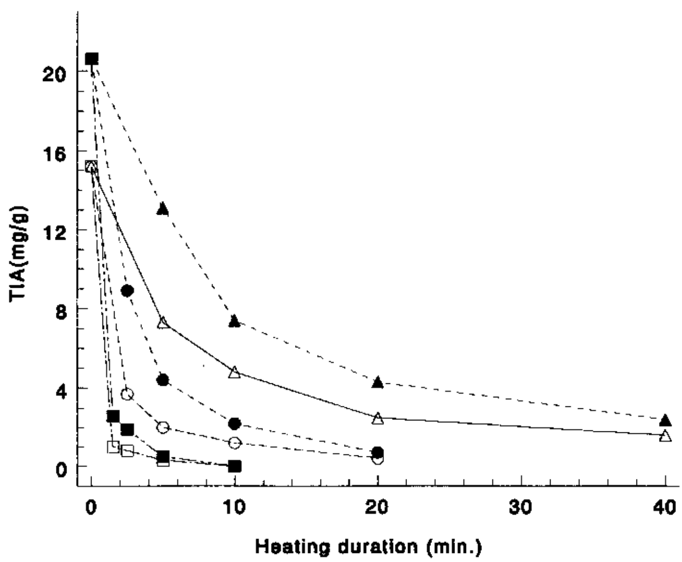

Figure 1. TIA variation of Argentine (Ar) and Chinese (Ch) soybeans heated at different temperatures (△: Ar 100°C; ▲:Ch 100°C; O: Ar 118°C; ●: Ch 118°C; □: Ar 136°C; ■: Ch 136°C)

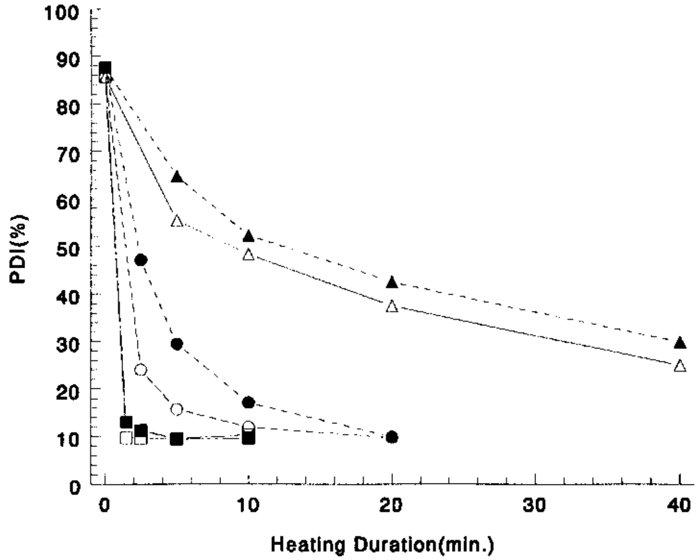

Figure 2. PDI variation of Argentine (Ar) and Chinese (Ch) soybeans heated at different temperatures (△: Ar 100°C; ▲:Ch 100°C; O: Ar 118°C; ●: Ch 118°C; □: Ar 136°C; ■: Ch 136°C)

Argentine soybeans. For example, the PDI values of Chinese soybeans heated at 118°C for 2.5, 5.0 and 10 min., and at 136°C for 1.5 min., were 1.97, 1.87, 1.43 and 1.34 times as high as the corresponding values of Argentine soybeans. When the soybeans were heated at the same temperature for a longer time(e.g. 118 °C for 20 min. and 136°C 10 min.), the difference in the PDI value between the two soybean origins disappeared (see Figures 1 and 2). As the PDI was reduced to the level of about 10%, it remained unchanged, even though more severe heating treatment was subjected.

The curve fitting equations for TIA and PDI are given in Table 2. The TIA as well as the PDI variations of the two origins of soybeans after different treatments were well described by the curve fitting equations (Table 2).

The variation of the FDNB reactive lysine was not quite regular at the heating temperatures of 100°C and 118°C for both soybean origins. However, it was observed that reactive lysine of these two origins of soybeans decreased with the prolongation of heating time when soybeans were heated at 136°C.

A correlation analysis, based on the pooled data of the two soybean origins, showed that there was a highly significant correlation between TIA and PDI (R=0.9421, p<0.01). FDNB active lysine was also correlated to TIA and PDI (R=0.3301, p<0.10; R=0.3707, p<0.10, respectively), but the correlations were not as high as that between TIA and PDI.

The parameters and determination coefficients of the curve fitting equations for the data of TIA and PDI of the soybeans treated at 100°C, 118°C and 136°C are presented in Table 2.

Table 2. The values of a_0 and a_1 in fitting equation[a] for TIA and PDI and the determination coefficients (R^2) of the equations.

	a_0	a_1	R^2
TIA:			
100°C: Argentine soybeans	11.47	-2.80	0.9816
Chinese soybeans	20.25	-5.08	0.9714
118°C: Argentine soybeans	4.85	-1.54	0.9794
Chinese soybeans	11.61	-3.87	0.9685
136°C: Argentine soybeans	1.25	-0.55	0.9936
Chinese soybeans	3.13	-1.44	0.9835
PDI:			
100°C: Argentine soybeans	80.55	-14.73	0.9926
Chinese soybeans	91.09	-16.51	0.9989
118°C: Argentine soybeans	28.43	-6.69	0.9592
Chinese soybeans	60.83	-17.86	0.9830
136°C: Argentine soybeans	9.36	0.33	0.6794
Chinese soybeans	13.21	-1.82	0.8999

[a] ($Y= a_0+a_1*\ln(x)$)

4. Discussion

The TIA levels in the two soybean origins as determined in the present experiment were within the normal range compared with the literature reviewed by Qin and Chen (1995). The TIA level of the raw Argentine soybeans, however, was only 65% of that of the Argentine soybeans measured in a previous investigation (Qin et al., 1996). Differences also existed between the soybeans treated under similar conditions in present and previous experiments. The PDI values of raw soybeans and the soybeans treated at 118°C and 136°C were similar to that in similarly treated soybeans before (Qin et al., 1996), though the soybeans treated at 100°C were not. These inconsistencies between present and previous data of Argentine soybeans may have been caused by the origin difference between batches.

The TIA values, for both Argentine and Chinese soybeans, decreased in nonlinear patterns with the prolongation of heating irrespective of the heating temperature. This supported earlier observations in soybean heat processing reported by Collins and Beaty (1980), Liener and Thomlinson (1981), Qin et al. (1996) and Monari (1993).

The results of the TIA determination in the present study indicated that there were substantial differences between Argentine and Chinese soybeans in responses to steam toasting. Heated at a low temperature and/or during a short time, the Argentine soybeans were more sensitive in their reduction of TIA, but, with the increase of heating temperature and/or heating duration, this sensitivity was decreased. At the most severe heating condition (at 136°C during 10 min.), the TIA level in soybeans of both origins decreased below the detection limit. The differences in TIA between the two soybean origins varied with the treatment conditions. The more severe the heating treatment was employed, the smaller the difference was between them.

For adequate processing, the heating conditions should not be too severe. Chang et al. (1984) and Monari (1993) suggested that the accepted TIA level of an adequately processed soya product should be below 4 mg/g product. Based on this standard, proper heating durations could be calculated with the fitted equations for different heating temperatures (Table 3). Apparently, heating time is 10 and 5 min. longer for Chinese soybeans than for Argentine soybeans to inactivate TI to the safe level at temperatures of 100°C and 118°C, respectively. The soybeans containing a lower level of TIA needed less severe heating. Friedman et al. (1991) also found that low trypsin inhibitor soybeans needed a shorter time than conventional soybeans to reduce their TIA to a safe level when heated at similar temperatures.

The PDI for any origin of the soybeans decreased non-linearly with the prolongation of heating and the increase of heating temperature. After reduced to the level of about 10%, the PDI kept unchangeable. At the most severe heating condition, the PDI even increased a little. This phenomenon was also observed in previous study (Qin et al., 1996). A possible explanation is the hydrolysis of protein being initiated at only the highest temperature (Van der Poel et al., 1990).

Table 3. Adequate duration at different heat temperatures as calculated with the fitted equations based on a residual TIA level of 4 mg/g products.

Temperature	soybean origin	adequate heat duration(min.)	TIA (mg/g) (%)	PDI
100 °C	Argentine	15	4	40
	Chinese	25	4	38
118 °C	Argentine	2	4	23
	Chinese	7	4	26
136 °C	Argentine	0.01	4	8
	Chinese	0.5	4	14

For a well-processed soybean product, the PDI has to be kept to a certain level. Monari (1993) suggested that the acceptable PDI level is in the range from 15 to 28. According to this standard, when the two soybean origins heated at 100°C and 118°C for an adequate duration to reduce TIA to the safe level (4 mg/g) for each of them separately, their PDI values calculated with the fitted equations were still kept high enough to be acceptable (see Table 3). However, when heated at 136°C to inactivate TIA to the safe level, the PDI value may be decreased to a much lower level than acceptable. It seems that the high temperature (136°C) denatures protein more severely than it inactivates TIA, which is in accordance with the statement of Labuza (1973). He converted the data of Hackler et al. (1965) into approximate kinetic parameters, and found that doubling the rate of trypsin inhibitor destruction by increasing process temperature would increase the destruction of many nutrients four- to five-fold.

The high correlation between TIA and PDI as found in the present study indicates that the inactivation of TIA, to a certain extent, is accompanied by the denaturation of proteins in the soybeans. Qin et al. (1996) also observed a high correlation between TIA and PDI soybeans steam toasted at various conditions. But, Tromp et al. (1995) reported, for the roasted whole soybeans, the soluble protein level was not directly correlated to the trypsin inhibitor content. It seems that the treatment effect on the correlation is different between steam heating and roasting.

The reactive lysine content, as measured by FDNB, was not clearly influenced by steam toasting when the soybeans were heated at 100 °C and 118°C. At 136°C, however, the FDNB active lysine content reduced as the heating time was prolonged, and the changes in the FDNB reactive lysine were not paralleled with those in TIA and PDI. The correlation analysis results showed that FDNB active lysine was not significantly correlated to TIA and PDI ($P>0.05$). These results indicate that it is possible to optimize the processing procedure so that the antinutritional factors can be inactivated while simultaneously maintaining the availability of essential amino acids.

In conclusion, the TIA in the soybeans could be reduced to an acceptable level by different heating conditions (combinations of heating time and temperature). Both TIA and PDI decreased non-linearly with increase of heating temperature and duration. These parameters, however, changed in different patterns for different origins of soybeans. It seems that Argentine soybeans need less severe processing conditions than Chinese soybeans as evaluated with TIA and PDI. Safe levels of TIA, however, need to be validated by animal trials.

References

AOCS, 1964. American Oil Chemist' Society. Protein dispersibility index (PDI), AACC-method 46-24, 2.1-2.2

Booth, V.H., 1971. Problems in the determination of FDNB-available lysine. J. Sci. Food Agric. 22, 658-666

Carpenter, K.J., 1960. The estimation of available lysine in animal protein foods. Biochem. J. 77, 604-610

Collins, J.L. and Beaty B F., 1980. Heat inactivation of trypsin inhibitor in fresh green soybeans and physiological responses of rats fed the beans. J. Food Sci. 45, 124-126

Chang, C.L., Tanskley T D., Jr, Knabe D A., Zebrowska T. and Gregg E J., 1984. Effect of different heat treatments during processing on nutrient digestibilities of soybean meal by growing swine. J. Anim.Sci. 59 (suppl. 1), 268-269

Friedman, M., Brandon, D.L., Bates, A.H., Hymowitz, T. and Friedman, M., 1991. Effect of heat on the nutritional quality and safety of soybean cultivars. Adv. Exp. Med. and Bio. 289, 339-361

Fu, C.Z. and Lu, Y.C., 1992. Determination of trypsin inhibitor activity in legumes. Soybean Science. 11(3), 269-272

Hackler, L.R., Van Buren, J.P., Steinkraus, K.H., El Rawi, I. and Hand, D.B., 1965. Effect of heat treatment on nutritive value of soymilk protein fed to weanling rats. J. Food Sci. 30, 723-728

Herkelman, K.L., Cromwell, G.L. and Stakly, T.S., 1990, Effect of heating time on the nutritional value of full-fat soybeans for chicks. J. Anim. Sci., 68 (Suppl. 1): 1.

Herkelman, K.L., Cromwell, G.L., Stakly, T.S., Pfeiffer, T.W. and Knabe, D.A., 1992, Apparent digestibility of amino acids in raw and heated conventional and low-trypsin-inhibitor soybeans for pigs. J. Anim. Sci., 70: 818-826.

ISO, 1979. International Standard 5983. Animal feeding stuffs-Determination of nitrogen content and calculation of crude protein content.

Kakade, M.L., Rackis, J.J., McGhee, J.E. and Puskai, G., 1974. Determination of trypsin inhibitor activity of soy products: a collaborative analysis of an improved procedure. Cereal Chem. 51, 376-382

Labuza, T.P., 1973. Effects of dehydration and storage. Food Technol. 27, 20-25,27,51

Liener, I. and Thomlinson, S., 1981. Heat inactivation of protease inhibition of a soybean line lacking the Kunitz trypsin inhibitor J. Food Sci., 46, 1354-1356

McGrain, A.K., Chen, J.C., Wilson, K.A., Tan-Wilson, A.L., 1992. Proteases catalysing processing and degradation of Kunitz soybean trypsin inhibitor during seed maturation. Phytochemistry. 31(2), 421-426

Monari, S., 1993. Fullfat Soya Handbook. American Soybean Association, 20-22 Rue du Commerce-1040, Brussels. pp. 6-9

Qin, G. and Chen, P., 1995. Antinutritional factors in soybeans and the responses of pig to them. In: fourth symposium of Northeast pig production research congress, Changchun, P.R. China, Nov. 20-22, 1995

Qin, G., Ter Elst, E.R., Bosch, M.W. and Van der Poel, A.F.B., 1996. Thermal processing of whole soya beans: Studies on the inactivation of antinutritional factors and effects on ileal digestibility in piglets. Anim. Feed Sci. Technol. 57, 313-324

Sangle, M., Devi, R., Pawar, V.D., 1993. Proximate composition and anti-nutritional factors of soybeans. J. Maharashtra Agri. Univ., 18(3), 391-393

SAS, 1988, Statistical Analysis Systems. SAS/STAT User's Guide, Version 6.2. Statistical Analysis Systems Institute Inc., Cary, NC.

Tromp, C.T., Aghavan, G.S.V. and Alikhani, Z., 1995. Nutritive quality of whole soybeans heat-treated in a continuous flow processor. J. Agric. Engineering Research. 61, 49-56

Van Oort, M.G., Hamer, R.J. and Slager, E.A., 1989. The trypsin inhibitor assay: improvement of an existing method. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds. J.Huisman, A.F.B. van der Poel, I.E.Liener (Editors). PUDOC, Wageningen, 110-113

Van der Poel, A.F.B., Blonk, J., Van Zuilichem, D.J. and Van Oort, M.G., 1990, Thermal inactivation of lectins and trypsin inhibitor activity during steam processing of dry beans (Phaseolus vulgaris L.) and effects on protein quality. J. Sci. Food Agric., 53: 215-228.

Van der Poel, A.F.B., Verstegen, M.W.A. and Tamminga, S., 1995. Chemical, physical and nutritional effects of feed processing technology. In: Proceedings of the 16th Western Nutrition Conference. September 13 and 14, 1995, Saskatoon, Saskatchewan, Canada. pp. 70-86

Voragen, A.G.J., Gruppen, H., Marsman, G.J.P. and Mul, A.J., 1995. Effect of some manufacturing technologies on chemical, physical and nutritional properties of feed. In: Recent Advances in Animal Nutrition. (V editors), 93-126

Zarkadas, C.G., Yu, Z.R., Hope, H.J., Mineroamador, A. and Rochemont, J.A., 1994. Comparison of protein-bound and free amino acid contents of two Northern adapted soybeans cultivars. J. Agric. Food Chem. 42(1), 21-33

Zhao, S.W., Zhou, S.H., Hu, M.X., Meng, X.X., Li, A.P. and Wang, S.M., 1991. Ti and SP[1] locus genotype frequency and distribution of cultivars of soybean from three provinces of Northeast. Soybean Sci. 10(1), 77-80

Chapter 6

Effects of steam toasting on the digestibility and nitrogen utilization of Argentine and Chinese soybeans in piglets.

G.X. Qin[1,2], M.W.A. Verstegen[2], M.W. Bosch[2] and A.F.B. van der Poel[2]

[1] Department of Animal Science, Jilin Agricultural University, Changchun 130118, P.R. China.
[2] Department of Animal Nutrition, Wageningen Institute of Animal Sciences (WIAS), Wageningen Agricultural University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands

Abstract

Argentine and Chinese soybeans were steam-heated at 100 °C for 40 min., 118 °C for 5 min. or 136 °C for 1.5 min.. The effect of heating on the protein quality of the soybeans was evaluated by both *in vitro* and *in vivo* experiments. In the *in vitro* evaluation, trypsin inhibitor activity (TIA), protein dispersibility index (PDI) and fluorodinitrobenzene (FDNB) reactive lysine were analyzed. Digestion and nitrogen (N) balance trials were conducted with 32 castrated male piglets (Dutch Landrace X Dutch Yorkshire). The results showed that the highest residual TIA for both Argentine and Chinese soybeans was observed in the beans heated at 118 °C for 5 min. The soybeans heated at 100 °C for 40 min. had the highest PDI. The lowest PDI was found in the soybeans heated at 136 °C for 1.5 min. The Chinese soybeans had a higher TIA than the Argentine soybeans heated under corresponding conditions. The FDNB reactive lysine changed irregularly. The net protein utilization (NPU) of the soybeans heated at 118 °C/5 min. was significantly ($P<0.05$) lower than those heated under other conditions. The N digestibility of the soybeans heated at 118 °C/5 min. was also lower than others, but the difference was not significant. A significant ($P<0.05$) interaction between soybean origin and heating condition was observed in fat digestibility of soybeans. The fat digestibility of Chinese soybeans was improved more by heating at high temperature/short time (136 °C/1.5 min.). It was concluded that Argentine and Chinese soybeans differ in their response to steam heating. Heating at 118 °C for 5

min. was not as effective as heating at 100 °C for 40 min. and at 136 °C for 1.5 min. in terms of an improvement in the nutritional value of the soybeans.

1. Introduction

Heat processing, by denaturating the proteinaceous antinutritional factors (ANFs) and changing the structure of proteins, can effectively improve the digestibility and availability of nutrients from soybeans (*Glycine max*)(Noland et al., 1976; Vandergrift et al., 1983; Li et al., 1993; Qin et al., 1996a). The effects of heat processing, however, vary greatly among different processing technologies and processing conditions (Melcion and Van der Poel, 1993). The responses to heating treatments are also different between soybeans of different origins (different genotypes, growing in different geographical regions or produced in different years or of different maturaty) (Friedman et al., 1991a and b; Qin et al., 1996b), because there may be differences in their activity and content of ANFs and/or chemical composition (Friedman et al., 1991a; Mohamed and Rangappa, 1992; Sangle et al., 1993; Yu and Kiang, 1993; Liu et al., 1994; Zhao et al., 1995). An optimal processing procedure for a batch of soybeans, therefore, may not be the optimum for another batch of soybeans. In the present study, piglets were used in a digestion and nitrogen-balance trial to evaluate the nutritional improvement of Argentine and Chinese soybeans that were steam-toasted under different conditions.

2. Materials and Methods

2.1. Soybeans processing and diet formulation

Argentine (A) and Chinese (C) soybeans were purchased from different commercial suppliers. Both origins of soybeans were steam-toasted at 100°C/40min. (1), 118°C/5min. (2) or 136°C/1.5min. (3) at the WageningenFeed Processing Centre with a laboratory-scale pressurized steam toaster. The structure of the toaster and toasting procedure of the soybeans were as described by Van der Poel et al. (1990c). The processed soybeans were cooled down to room temperature immediately after toasting, and air-dried in a forced-draught oven at 35°C for 48 h. Then, the soybeans were milled to pass a 3 mm screen, and used for the experiment. Samples of the soybeans treated under various conditions were taken and milled to pass a 1 mm screen for proximate and PDI analysis, or a 0.5 mm screen for TIA and fluorodinitrobenzene (FDNB) reactive lysine analysis.

In order to minimize the experimental error caused by the difference in dietary protein level between the control diet and the experimental diets, two control diets were formulated for this experiment. The control-1 diet was lower in protein level, and the control-2 diet had a similar protein level to the experimental diets, which consisted of 80% control-1 and 20% variously heat-treated soybeans of different origins. In the experimental diets, the soybean treatments are further referred to according to their origin and treatment condition as A1, A2, A3, C1, C2 and C3, respectively. The ingredient and nutrient composition of all diets are presented in Tables 1 and 2.

Table 1. Diet composition and nutrient contents

Ingredients (g/kg)	Control-1	Control-2	Experimental diets
Maize starch	749.7	695.1	599.7
HP soybeans*	-	-	200.0
Dextrose	60.0	60.0	48.0
Caseine	55.0	110.0	44.0
Soybean oil	10.0	10.0	8.0
Cellulose	21.0	21.0	16.8
Cane molasses	40.0	40.0	32.0
$CaCO_3$	1.9	1.9	1.5
$CaHPO_4$	28.6	28.6	22.9
NaCl	3.0	3.0	2.4
$KHCO_3$	6.4	6.4	5.1
$NaHCO_3$	12.2	12.2	9.8
Dl-methionine	1.8	1.2	1.4
L-threonine	0.5	0.6	0.4
Premix	10.0	10.0	8.0

* Argentine soybeans or Chinese soybeans steam heated at 100°C for 40 min., 118°C for 5 min. and 136°C for 1.5 min., respectively.

Table 2. Nutrient contents of the control and experimental diets*

Nutrients (g/kg)	Control-1	Control-2	A1	A2	A3	C1	C2	C3
Analysed:								
Crude protein	56.9	103.4	122.2	123.6	118.1	124.3	112.7	118.6
Crude fat	8.5	9.7	48.0	49.2	48.8	45.4	43.2	42.0
Crude fibre	12.1	12.2	29.7	30.5	31.4	26.6	27.4	27.1
Calculated:								
Digestible CP	48.5	94.3	102.8	102.8	102.8	104.6	104.6	104.6
Ca	5.6	5.6	5.1	5.1	5.1	5.1	5.1	5.1
Available P	6.9	7.3	6.0	6.0	6.0	6.0	6.0	6.0
Starch	659.9	612.3	527.9	527.9	527.9	527.9	527.9	527.9
Ileal digestible amino acids:								
Lysine	3.8	7.7	7.0	7.0	7.0	7.0	7.0	7.0
Methionine	3.3	4.2	3.5	3.5	3.5	3.5	3.5	3.5
Methi+cystine	3.5	4.6	4.5	4.5	4.5	4.5	4.5	4.5
Threonine	2.5	4.7	4.2	4.2	4.2	4.2	4.2	4.2
Tryptophan	0.80	1.59	1.40	1.40	1.40	1.40	1.40	1.40
Energy content:								
ME (MJ/kg)	14.05	14.04	14.60	14.60	14.60	14.60	14.60	14.60

* A1, A2 and A3 are the diets containing 20% Argentine soybeans treated at 100°C for 40 min., 118°C for 5 min. and 136°C for 1.5 min., respectively. C1, C2 and C3 are the diets containing 20% Chinese soybeans treated at 100°C for 40 min., 118°C for 5 min. and 136°C for 1.5 min., respectively.

2.2 Animals and Management

Thirty-two castrated male piglets (Dutch Landrace x Dutch Yorkshire), with an initial average body weight of 27.9 kg (± 3.2 kg), were housed individually in size-adjustable metabolism cages (the cages can be adjusted to fit the size of animals). The animals were randomly arranged to consume one of the eight different diets (4 animals for each of the diets). The mash diets were administered with water at a ratio of 1:2. No extra water was supplied to the piglets during the experimental period. The piglets were fed twice a day at 08:00 h and 16:00 h during the adaptation (7 days) and collection period (5 days). The daily feed allowance of each animal was calculated as 2.7 times the maintenance requirement of ME (420 KJ ME $kg^{-0.75}$ body weight) based on their individual body weight.

The whole experiment was conducted for 12 days which included a 7 days' adaptation period and a 5 days' collection period. The faeces were collected twice a day after feeding as described by Van Kleef et al. (1994). The fresh faeces collected every day were put in a freezer (-20°C). Urine was collected in plastic buckets, in which 20 ml sulphuric acid (concentration: 25%) had been added. The collected urine was stored in the refrigerator (4 ^{0}C). After the collection period, the faeces and urine of each individual animal were each pooled, and sampled for analysis.

2.3. Laboratory Analysis

All samples of soybeans, diets, faces and urine were analysed in duplicate. The protein dispersibility index (PDI), trypsin inhibitory activity (TIA) and fluorodinitrobenzene (FDNB) reactive lysine content of the soybean samples were determined according to the procedures of the American Oil Chemists' Society (AOCS, 1979), Van Oort et al. (1989) and Booth (1971), respectively. The dry matter (DM), nitrogen (N), crude fat (EE), crude fibre (CF) and ash content of diet and faecal samples were determined using standard methods.

2.4 Calculation of nutrient digestibility coefficients and protein (N*6.25) utilization

Nutrient digestibilities and protein utilization of the different diets were calculated from the corresponding contents in the diets, faeces and urine. The N digestibility and protein utilization of soybeans were calculated as follows:

The casein-digestible N content (Nd, g/kg casein) and casein-deposited N content (Nr, g/kg casein), were calculated from N intake, faecal N and urine N of the animals fed the control-2 diet (average value of 4 animals). Then, the N digestibility and the net protein utilization

(NPU) of soybeans were calculated, respectively, using the following formulae:

D (%) = [(Ni-Nf-a*b*Nd)/(Ni-a*b*Nc)]*100

NPU (%) = [(Ni-Nf-Nu-a*b*Nr)/(Ni-a*b*Nc)]*100

where: D: apparent N digestibility of soybeans(%); NPU: net protein utilization (%) of soybeans; Nd: digestible N content of casein (g/kg); Nr: deposited N content of casein (g/kg); Ni: the total N intake (g) of the piglet fed on a diet containing the soybeans; Nf: the total faecal N (g) of the same piglet; Nu: the total urine N (g) of the same piglet; Nc: N content of casein (g/kg); a: total feed intake (kg); b: ratio of casein in the control-1 diet. The digestibility of other nutrients within the soybeans were calculated using the difference method.

2.5 Statistical analysis

An analysis of variance was conducted using model 1. and model 2. for the diet and soybeans, respectively.

Model 1:

$Y_{ij}=\mu+a_i+e_{ij}$

Y_{ij}: individual observation; μ: expected means; a_i: effect of diet i; e_{ij}: error.

Model 2:

$Y_{ijk}=\mu+a_i+b_j+ab_{ij}+e_{ijk}$

Y_{ijk}: individual observation; μ: expected means; a_i: effect of soybean origin i; b_j: effect of heating treatment $_j$; ab_{ij}: effect of interaction between soybean origin i and heating treatment j; e_{ijk}: error.

3. Results

For both the Argentine and Chinese soybeans, the highest PDI was observed in the soybeans heated at 100 ^{0}C for 40 min., and the lowest PDI in the soybeans heated at 136 ^{0}C for 1.5 min. The PDI of Chinese soybeans, however, was higher than that of Argentine soybeans heated under the same conditions (Table 3). The change of TIA levels was not paralleled by the PDI. The highest level of TIA for both Argentine and Chinese soybeans was observed in the beans treated at 118 ^{0}C for 5 min. Chinese soybeans had a higher TIA than Argentine soybeans treated under corresponding conditions. The FDNB reactive lysine changed irregularly.

Table 3. Trypsin inhibitor activity (TIA), protein dispersibility index (PDI) and FDNB reactive lysine of Argentine and Chinese soybeans heated at different conditions.

Soybeans	TIA (mg/g)	PDI (%)	FDNB-reactive lysine (g/kg)
Argentine soybeans			
100 ^{0}C/40 min.	1.3	25.2	17.5
118 ^{0}C/5 min.	3.1	18.8	20.6
136 ^{0}C/1.5 min.	1.0	9.8	17.7
Chinese Soybeans			
100 ^{0}C/40 min.	2.4	28.2	18.0
118 ^{0}C/5 min.	3.6	24.8	18.0
136 ^{0}C/1.5 min.	1.6	10.0	16.9

Table 4. Nutrient digestibilities of the control and experimental diets (%)

Diet	Dry matter	Nitrogen	Fat
Argentine soybeans			
100 ^{0}C/40 min.	92.4^{bc}	83.1^{b}	56.7^{c}
118 ^{0}C/5 min.	90.2^{d}	78.7^{b}	51.9^{cd}
136 ^{0}C/1.5 min.	91.7^{cd}	81.9^{b}	56.8^{c}
Chinese soybeans			
100 ^{0}C/40 min.	90.7^{cd}	79.0^{b}	47.5^{d}
118 ^{0}C/5 min.	91.5^{cd}	78.9^{b}	50.4^{d}
136 ^{0}C/1.5 min.	91.3^{cd}	79.6^{b}	56.7^{c}
Control-1	93.5^{ab}	79.1^{b}	62.7^{b}
Control-2	95.0^{a}	93.5^{a}	75.2^{a}

^{a,b,c,d} Data in the same column with different superscript differ significantly ($P<0.05$).

Table 5. Effect of soybean origin and processing on nutrient digestibility and protein biological value (PBV) and net protein utilization (NPU) of soybeans

Soybeans	Digestibility(%)			PBV(%)	NPU (%)
	DM	N	Fat		
Means of groups (n=4):					
Argentine soybeans, 100 ^{0}C/40 min.	92.1	77.0	55.2^{a}	67.3	51.2
Argentine soybeans, 118 ^{0}C/5 min.	89.4	70.0	49.2^{ab}	61.7	43.1
Argentine soybeans, 136 ^{0}C/1.5 min.	91.2	74.5	54.5^{a}	62.4	46.4
Chinese soybeans, 100 ^{0}C/40 min.	90.0	70.7	43.8^{b}	67.1	46.7
Chinese soybeans, 118 ^{0}C/5 min.	91.0	69.2	47.3^{b}	59.6	41.0
Chinese soybeans, 136 ^{0}C/1.5 min.	90.7	70.9	55.2^{a}	72.2	51.0
Means of different processing conditions (n=8):					
100 ^{0}C/40 min.	91.1	73.8	49.5^{b}	67.2	49.0^{a}
118 ^{0}C/5 min.	90.2	69.6	48.3^{b}	60.6	42.1^{b}
136 ^{0}C/1.5 min.	91.0	72.7	54.9^{a}	67.3	48.7^{a}
Means of different origins of soybeans (n=12):					
Argentine soybeans	90.9	73.8	53.0^{a}	63.8	46.9
Chinese soybeans	90.6	70.2	48.8^{b}	66.3	46.3
Root SME	1.71	8.50	4.63	7.63	5.39

[a,b] Data in the same column with different superscript differ significantly ($P<0.05$).

Diet	N-intake (g/day.head)	Faecal-N (g/day.head)	Urine-N (g/day.head)	Protein-BV* (%)	NPU** (%)
Argentine soybeans					
100 ^{0}C/40 min.	20.47^{a}	3.41^{ab}	4.53^{a}	73.79^{bc}	61.24^{bc}
118 ^{0}C/5 min.	20.67^{a}	4.44^{a}	4.68^{a}	71.29^{c}	56.02^{c}
136 ^{0}C/1.5 min.	19.94^{ab}	3.59^{a}	4.64^{a}	71.66^{c}	58.65^{bc}
Chinese soybeans					
100 ^{0}C/40 min.	20.83^{a}	4.40^{a}	4.35^{a}	74.08^{bc}	58.27^{bc}
118 ^{0}C/5 min.	19.04^{ab}	3.96^{a}	4.41^{a}	70.98^{c}	55.90^{c}
136 ^{0}C/1.5 min.	19.97^{ab}	4.15^{a}	3.60^{ab}	77.22^{abc}	61.36^{bc}
Control-1	9.81^{c}	2.08^{bc}	1.55^{c}	80.05^{ab}	63.38^{b}
Control-2	17.83^{b}	1.17^{c}	2.72^{bc}	83.61^{a}	78.18^{a}
Root MSE	1.65	0.95	0.97	4.48	4.13

* Protein BV = (N intake - Faecal N - Urine N)/(N intake - Faecal N) * 100.

** NPU = (N intake - Faecal N - Urine N)/N intake * 100

[a,b,c,d] Data in the same column with different superscript differ significantly ($P<0.05$).

Digestibilities of DM, N and fat of the diets and soybeans are given in Tables 4 and 5, respectively. Compared with the diets containing various soybeans, the two control diets, especially control-2 diet, had higher DM, N and fat digestibilities. The fat digestibility of soybeans was found to be significantly different between origins and between heat treatments. Argentine soybeans had a higher digestibility of fat ($P<0.05$), and the high temperature/short time treatment (136 ^{0}C/1.5 min.) resulted in significant improvement in fat digestibility. A significant interaction between soybean origin and heating condition was also observed for fat digestibility. Fat digestibility of Chinese soybeans heated at 100 ^{0}C for 40 min. and 118 ^{0}C for 5 min. was lower than those of other soybeans. The N digestibility of Argentine soybeans was also higher than Chinese soybeans, but the difference was not significant. Although the differences in N digestibilities between heating conditions were not significant, the N digestibility of the soybeans heated at 118 ^{0}C for 5 min. was considerably lower than those treated under other conditions.

The N-balance results (Table 6) showed that the animals consuming soybean diets generally excreted more faecal and urine N than animals consuming the control diets. The protein biological value (BV) of the control-2 diet was significantly higher than soybean diets with the exception of C3 diet; the net protein utilization (NPU) of control-2 diet was significantly higher than all other diets. There were no significant differences between soybean diets in N intake, faecal N and urine N excretion, protein BV and NPU by the cross-bred piglets. In the calculated NPU of soybeans, there was a significant difference between treatment conditions. The NPU of the soybeans heated at 118 ^{0}C for 5 min. was significantly lower than the others. The protein BV of soybeans paralleled their NPU, but did not differ significantly. No significant differences in protein BV and NPU of soybeans were found between the two origins of soybeans.

4. Discussion

The protein quality of Argentine and Chinese soybeans processed under the conditions used in the present experiment, was similar in terms of NPU, a fundamental criterion for evaluating protein nutritional value. With respect to N digestibility and protein BV, however, certain differences between the two origins of soybeans were observed. Argentine soybeans had a 3.7 percentage units higher N digestibility and a 2.6 percentage units lower protein BV than Chinese soybeans. The lower digestibility of N for Chinese soybeans was probably associated with their relatively higher levels of TIA; their higher protein BV may have resulted either from the relatively lower intake of digestible protein of the animals fed the Chinese soybean diets, or from the better quality of the digested protein. The higher residual level of TIA in Chinese soybeans as compared with the Argentine soybeans treated under corresponding conditions resulted from the higher level of TIA in the raw Chinese soybeans (Qin et al., 1996b). This agrees with the result of Friedman et al. (1991b). They also found that the higher the TIA level in the raw soybeans, the higher the residual TIA in the soybeans processed under certain conditions.

There were large differences in N digestibility and NPU between the two control diets (Table 6). The differences resulted mainly from a different N intake between the animals consuming the two control diets, because the protein source was the same for the two diets. This suggests that the ingredient digestibility may have a great error when protein quality of a single feed ingredient containing a high level of protein, such as soybeans, is evaluated by the difference method. Usually there is a considerable difference in protein content between control and experimental diets. This disadvantage of the difference method was overcome to a certain extent by using two control diets in this experiment.

The results show that processing not only influences the digestibility of protein, but also influences protein BV and NPU of the soybeans. The animals fed the diets containing soybeans heated at 100 ^{0}C/5 min. intaked less digestible protein and excreted more urine N than the animals consuming the diets containing the soybeans treated at other conditions. This resulted in a considerably lower protein BV and NPU. Although the analysed TIA of the soybeans heated at 100 ^{0}C/5 min. was not over the threshold value of 4 mg/g (for the samples with 40% protein) recommended by the European Federation of Feed Manufacturers (Monari, 1993), the lower N digestibility, protein BV and NPU value imply that processing soybeans under these conditions was not adequate, and the threshold value of 4 mg/g for the residual TIA is questionable for the soybeans studied in the present experiment. This threshold level may need to be adjusted for soybean origin.

If the NPU is used as the criterion, the best processing condition for Argentine soybeans was 100 ^{0}C/40 min. (low temperature/long time). For the Chinese soybeans, however, it was 136 ^{0}C/1.5 min. (high temperature/short time). These observations show the different heating condition requirements between the two origins of soybeans.

The NPU and the N digestibility of the soybeans, were more closely correlated to their TIA ($R=-0.8189$ and -0.8118, respectively; $P<0.05$), than to FDNB reactive lysine ($R=-0.6179$ and -0.3710, respectively; $P>0.05$) and PDI ($R=-0.2431$ and -0.0866, respectively; $P>0.05$). TIA was a more accurate parameter for evaluating the improvement of protein quality of soybeans processed within the processing range of the present experiment.

The two origins of the soybeans responded differently to steam-heating with respect to their fat digestibility. The low temperature/long time (100 ^{0}C/40 min.) and high temperature/short time (136 ^{0}C/1.5 min.) treatments were similarly effective in the improvement of fat digestibility for Argentine soybeans (55.2 vs 54.5%). For the Chinese soybeans, however, high temperature/short time treatment was much more effective than low temperature/long time treatment (55.2 vs 43.8%). It is possible that the natures or levels of some factors involved in the digestion of fat differed between the two soybean origins.

In a previous study (Qin et al., 1996a), ileal fat digestibility of processed soybeans varied between 82-93%, which was much higher than the faecal fat digestibility (43-56%) obtained in the present study. The large difference between the ileal and the faecal digestibility may have been related to fat production from the fermentation of microorganism in the hind gut. The apparent faecal fat digestibility of the soybeans determined with the difference method in this experiment may be far lower than the true digestibility.

In conclusion, Argentine and Chinese soybeans responded differently to steam-heating in terms of the residual TIA, nutrient digestibility and protein biological value at the conditions used in the present experiment. Argentine soybeans had lower residual TIA and higher N digestibility than the correspondingly treated Chinese soybeans. With respect to fat digestibility and NPU, the most adequate processing condition for Chinese soybeans was high temperature/short time, and for Argentine soybeans, low temperature/long time. For both Argentine and Chinese soybeans, heating at 118 ^{0}C for 5 min. was not effective in improving the nutritional value of the beans satisfactorily.

References

American Oil Chemists' Society, 1979. Protein Dispersibility Index (PDI). AOCS Official Method Ba 10-65, revised 1978. corrected 1979.

Booth, V.H., 1971. Problems in the determination of FDNB-available lysine. J. Sci. Food Agric. 22, 658-666.

Friedman, M., Brandon, D.L., Bates, A.H. and Hymowitz, T., 1991a. Comparison of a commercial soybean cultivar [Williams 82] and an isoline [181-4590] lacking the kunitz trypsin inhibitor : composition, nutritional value, and effects of heating. Journal of Agriculturla and Food Chemistry. 39(2): 327-335.

Friedman, M., Brandon, D.L., Bates, A.H., Hymowitz, T. and Friedman, M., 1991b. Effect of heat on the nutritional quality and safety of soybean cultivars. Adv. Exp. Med. Biol. 289: 339-361.

Huisman, J., Van der Poel, A.F.B., Mouwen, J.M.V.M. and Van Weerden, E.J., 1990. Effect of variable protein contents in diets containing Phaseolus vulgaris beans on performance, organ weights and blood variables in piglets, rats and chickens. Br. J. Nutr. 64: 755-764.

Li, D.F., Nelssen, J.L., Allee, G.L., Stoner, G.R. and Yang, S., 1993. Effect of extrusion on the ileal digestibility of amino acds in full fat soybean for pig. Chinese J. Anim. Sci. 29(2): 6-8.

Liu, X.Y., Lin, G.Q., Zhong, P., Hu, C.P., Zhao, S.W. and Gao, J.Y., 1994. Frequency and geographical distribution of alleles for trypsin inhibitor in seed protein of soybean germplasms in China. Oil Crops of China, 16(4): 32-35.

Melcion, J.P. and Van der Poel, A.F.B., 1993. Process technology and antinutritional factors: principles, adequacy and process optimization. In: A.F.B. van der Poel, J. Huisman and H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds, Proc. 2nd Int. Workshop on Antinutrtional Factors (ANFs) in Legume Seeds. Wageningen, 1-3 December 1993, pp. 419-434.

Mohamed, A.I. and Rangappa, M., 1992. Screening soybean (grain and vegetable) genotypes for nutrients and anti-nutritional factors. Plant Food Hum. Nutr. 42(1): 87-96.

Monari. S., 1993. Fullfat Soya Handbook, 2nd edn. American Soybean Association, Brussels, pp. 6-9.

Noland, P.R., Campbell, D.R., Gage, R.K., Jr., Sharp, R.N. and Johnson, Z.B., 1976. Evaluation of processed soybeans and grains in diets for young pigs. J. Anim. Sci. 43(4): 763-769.

Qin, G.X., Ter Elst, E.R., Bosch, M.W., Van der Poel, A.F.B., 1996a. Thermal processing of whole soya beans: Studies on the inactivation of antinutritional factors and effects on ileal digestibility in piglets. Anim. Feed Sci. Technol. 57: 313-324.

Qin, G.X., Van der Poel, A.F.B. and Verstegen, M., 1996b, Effects of temperature and time during steam treatment on the protein quality of full-fat soybeans of different origins. J. Sci. Food Agric. Submitted for publication.

Sangle, M., Devi, R. and Pawar, D., 1993. Proximate composition and anti-nutritional factors of soybean. J. Maharashtra Agric. Univ. 18(3): 391-393.

Vandergrift, W.L., Knabe, D.A., Tanksley, T.D., Jr. and Anderson, S.A., 1983. Digestibility of nutrient in raw and heated soyflakes for pigs. J. Anim. Sci. 57(5): 1215-1224.

Van der Poel, A.F.B., Mollee, P.W., Huisman, J. and Liener, I.E., 1990a. Variations among species of animals in response to the feeding of heat-processed beans (Phaseolus vulgaris L.). 1. Bean processing and effects on growth, digestibility and organ weights in piglets. Livest. Prod. Sci. 25: 121-135.

Van der Poel, A.F.B., Mollee, P.W., Huisman, J. and Liener, I.E., 1990b. Variations among species of animals in response to the feeding of heat-processed beans (Phaseolus vulgaris L.). 2. Growth and organ weights of chickens and rats and digestibility for rats. Livest. Prod. Sci. 25: 137-150.

Van der Poel, A.F.B., Blonk, J., Van Zuilichem, D.J., and Van Oort, M.G., 1990c. Thermal inactivation of lectins and trypsin inhibitor activity during steam processing of dry beans (Phaseolus vulgaris L.) and effects on protein quality. J. Sci. Food Agric. 53: 215-228.

Van kleef, D.J., Deuring, K. and Van Leeuwen, P., 1994. A new wethod for faeces collection in the pig. Labor. Anim. 28 (1): 78-79.

Van Oort, M.G., Hamer, R.J. and Slager, E.A.,1989. The trypsin inhibitor assay: Improvement of existing method. In: J. Huisman, A.F.B. van der Poel and I.E. Liener (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. PUDOC, Wageningen, pp. 110-113.

Yu, H.G. and Kiang, Y.T., 1993. Genetic variation in South Korean natural populations of wild soybean (Glycine soja). Euphytica. 68(3): 213-221.

Zhao, S.W., Gu, Q.M. and Wang, H., 1995. The zymogram pattern of the new type of SBTi-A2 of seed protein and the crossing with other allelles. Soyb. Gen. Newsl., 22: 83-84.

Chapter 7

The effect of soybean origin and processing on nutrient digestibility and organ morphology in different breeds of pigs

G.X. Qin[1,2], L.M. Xu[1], A.F.B. van der Poel[2], M.W. Bosch[2] and M.W.A. Verstegen[2]

[1] Department of Animal Science, Jilin Agricultural University, Changchun, 130118, P.R. China.
[2] Department of Animal Nutrition, Wageningen Institute of Animal Sciences (WIAS), Wageningen Agricultural University, Marijkeweg 40, 6709 PG Wageningen, The Netherlands.

Abstract

Twenty Landrace and twenty Min piglets, with an average initial body weight of 22.4 kg, were randomly divided into 5 groups with 4 animals per group, within each of the breeds. The piglets were housed in individual concrete pens. Each group of piglets was fed one of five diets. The diets contained either 20% raw Argentine soybeans, 20% processed Argentine soybeans (118°C for 7.5 min.), 20% raw Chinese soybeans, 20% processed Chinese soybeans (118°C for 7.5 min.) or no soybean products (control diet). The feed was provided three times daily as a wet mash with a feed:water ratio of 1:1. The experiment was conducted for 17 days, including a 3 day adaptation period and a 14 day treatment period. Faecal samples were collected on days 6, 7 and 8 of the treatment period. Digestibilities of dietary nutrients were determined with AIA (acid insoluble ash) as a marker. On the day following the termination of the treatment period, three piglets were killed from each of the groups. Tissue samples of small and large intestine were taken immediately after the opening of abdomen for light and electron microscopy examination. Then, the weight or size of relevant organs was measured. The results show that the digestibilities of dry matter (DM), crude protein (CP) and fat were higher in Min than in Landrace piglets ($P<0.05$). The diets containing processed soybeans had a significantly higher CP digestibility than the control diet and the diets containing raw soybeans ($P<0.05$). Significant differences ($P<0.05$) in DM, ash and fat digestibilities were also found between diets. Landrace piglets had heavier and longer small intestines, heavier kidneys and a lighter

spleen than Min piglets ($P<0.05$). The pancreas of the animals fed the diets containing processed soybeans was heavier than that of the animals fed the control diet ($P<0.05$) and diets with raw soybeans. However, the differences between raw and processed soybean diets were not significant. A significant interaction ($P<0.05$) between diet and pig breed was observed in weight of the small intestine. The Landrace piglets increased the weight in their small intestine when they were fed the diets containing soybeans. In the light micrographs and electron scanning micrographs, it was found that the villi of the small intestinal epithelium of animals (especially Landrace piglets) fed the diets containing raw Chinese soybeans were seriously damaged. The transmission electron micrograph showed that a lot of vesicles were located between the small intestinal microvilli of these piglets. The histological examination also indicated that the proportion of goblet cells in the villi and crypts of the piglets consuming the control diet was significantly lower ($P<0.01$ and $P<0.02$, respectively) than those of the animals consuming the diets containing raw or processed soybeans. It was concluded that steam-heating can effectively improve the feeding value of the full-fat soybeans. Raw Chinese soybeans may have more deleterious effects on nutrient digestibilities and animal health than raw Argentine soybeans. Landrace piglets were more sensitive than Min piglets to raw soybean diets.

1. Introduction

Full-fat soybeans contain a high level of energy and protein. They are an ideal protein source in diets for farm animals. However, the nutritional value of soybeans is not consistent because of the variation in their contents of antinutritional factors (ANFs) (Herkelman et al., 1992). The effects of feeding soybeans on animals depend not only on the properties (composition or ANF levels) of the soybeans themselves, but also on the animals consuming them. Different species of animals respond differently to the ANFs in soybeans (Noland et al., 1976; Nitsan and Nir, 1986; Xian and Farrell, 1991) and also to ANFs in other legume seeds (Van der Poel et al., 1990a and b). Pigs are considered more sensitive to ANFs than chickens and rats (Huisman et al., 1990a and b).

The response of pigs to feeding raw or under-processed soybeans varies with their physiological state such as age, pregnancy etc., as reported by Herkelman and Cromwell (1990), Marty and Chavez (1993), Monari (1993) and Qin and Chen (1995). It is not clear whether there are also differences between different breeds or lines of pigs in their ability to tolerate soybean ANFs. Considerable variation in the morphology of the digestive organs and in the digestibility of some dietary nutrients has been observed among different breeds or genotypes of pigs (Qin et al., 1995). If a significant difference in response to soybean ANFs exists between breeds or genotypes of pigs, then the optimal procedure for processing full-fat soybeans could be different for genetically different populations of pigs. This could be of great importance in using full-fat soybeans for pig production.

In the present study, different breeds of pigs were fed diets containing raw or well-heated (Qin et al., 1996) soybeans of Argentine or Chinese origin. Our aim was to investigate the possible differences between the soybean origins in their antinutritive properties, and also the possible differences between pig breeds in their responses to soybean ANFs. Criteria of research were the digestibilities of nutrients as well as the weight of some organs, length of small and large intestines, and the histological examination of the small and large intestinal tissue.

2. Materials and Methods

2.1 Soybean processing

Commercial soybeans (*Glycin max.*) from Argentine and Chinese origins were purchased from Schouten Industries (Giessen, The Netherlands) and Food & Oil Import & Export Company (Jilin province, China), respectively. Both the Argentine and Chinese soybeans were used in the experiment as either raw or steam-toasted at 118°C for 7.5 min. with a laboratory-scale steam toaster as described by Van der Poel et al. (1990a). The processing was carried out at the [Wageningen]Feed Processing Centre, Wageningen, The Netherlands. The procedure was the same as described by Qin et al. (1996). The processed soybeans were air-dried and sent to Changchun, P.R. China, for use in the experimental diets.

2.2 Diet formulation

Five diets, including one control and four treatment diets, were formulated according to the nutritional requirements of swine (NRC, 1988). The control diet did not contain soybeans or soybean products. The four treatment diets contained 20% of either raw or processed soybeans of Argentine or Chinese origin. The composition and nutrient contents of the diets are shown in Tables 1 and 2.

Table 1. Composition of the control and experimental diets

		Argentine soybeans		Chinese soybeans	
	Control	Raw	Processed	Raw	Processed
Ingredients(g/kg)					
Argentine raw soybeans	-	200.0	-	-	-
Argentine treated soybeans	-	-	200.0	-	-
Chinese raw soybeans	-	-	-	200.0	-
Chinese treated soybeans	-	-	-	-	200.0
Corn distillers' dried grain	197.2				
Corn meal	644.2	590.0	590.0	590.0	590.0
Wheat bran	83.9	135.9	135.9	135.9	135.9
Fish meal	50.0	50.0	50.0	50.0	50.0
Bone meal	10.6	5.8	5.8	5.8	5.8
Limestone meal	2.8	6.5	6.5	6.5	6.5
NaCl	1.8	1.8	1.8	1.8	1.8
L-lysine	4.0	-	-	-	-
Premix.	10.0	10.0	10.0	10.0	10.0

Table 2. Nutrient contents of the control and experimental diets

	Control	Argentine soybeans		Chinese soybeans	
		Raw	Processed	Raw	Processed
Nutrient contents (g/kg)					
Calculated:					
Crude protein	175	176	176	176	176
DE (MJ/kg)	13.62	13.76	13.76	13.76	13.76
Lysine	9.5	9.5	9.5	9.5	9.5
Ca	7	7	7	7	7
P	6	6	6	6	6
TIA (mg/g)	0.0	3.04	0.35	4.12	0.76
Analyzed:					
Dry matter	907	906	904	906	906
Crude protein	169	168	168	167	169
Crude fat	45	63	50	51	72
Crude fibre	18	17	21	19	20
Crude ash	42	45	46	51	44
N-free extract	632	613	620	618	600
Acid insoluble ash (AIA)	15	12	11	14	12

2.3 Animals and Management

Twenty Landrace and twenty Min (a native pig breed in the north-east of China) piglets, with an average initial body weight of 22.9 kg for Landrace and 22.0 kg for Min piglets, were randomly divided into 5 groups with 4 animals per group, within each of the breeds. The animals were housed in individual concrete pens for a period of 17 days. This period consisted of a 3 day adaptation period and a 14 day treatment period. Each group of piglets were fed one of the 5 diets. The feed was provided 3 times daily at 08:00, 11:30 and 16:00 h as wet mash with a feed:water ratio of 1:1. Water was available ad libitum in the troughs. During the adaptation period, the feed allowance was adjusted to the appetite of each piglet and this level of intake was then maintained during the experimental period. The pens were cleaned twice a day to ensure that only the diet and water were ingested by the animals.

2.4. Collection of faeces, organ and tissue samples

Faeces were collected from 06:00 to 18:00 h on day 6, 7 and 8 of the treatment period. After collection, the faeces were immediately stored in a plastic bag in the freezer (-20 °C). After the collection period, the faeces of each individual animal were pooled and sampled for analyses.

On the day following the termination of the treatment period, three piglets were randomly taken from each of the groups. After the animals were weighed, they were killed by bleeding. The organs were removed quickly from the abdomen. The small and large intestines, pancreas, liver, spleen, stomach and kidney were weighed after sampling the tissue of the small and large intestine. The length of the small and large intestines were also measured.

Samples of small intestinal tissue were taken at 2 meters below the pyloric sphincter. For the large intestine, the tissue was sampled at the apex of the spiral coil of the colon. After being washed in saline, the samples were fixed in formalin for light microscopy, and in 2.5% glutaraldehyde solution for electronic microscopy.

2.5. Chemical analyses

The trypsin inhibitor activity of all soybean samples was determined according to the modified procedure of Kakade et al. (1974) as described by Van Oort et al. (1989). Acid insoluble ash (AIA) content of the diets and the faecal samples was determined according to the 4N-HCl insoluble method as described by Yang (1983). Nitrogen (N) was determined by the Kjeldahl method, and the crude protein (CP) content was calculated as N*6.25. Dry matter (DM), crude fibre (CF), ash (AS) and crude fat (EE) were determined, and N-free extract (NFE) was calculated according to conventional procedures (Yang, 1983).

2.6. Histological examination

For the light microscopy examination, the tissue samples of the intestines were cut into serial sections of 6 μm thickness. Successive sections were chosen and stained according to conventional H.E.(haematoxylin and eosin) and PAS (periodic acid-schiff) reaction procedures (Humason, 1967), respectively. General pathological examination and depth of colon enteradon (DCE) were conducted on the sections stained with the H.E method. The proportions of goblet cells in the epithelium (number of goblet cells/total number of cells counted) of villus (PGV) and of crypts (PGC) were measured on the sections stained with the PAS method.

Scanning electron microscopy and transmission electron microscopy were conducted with a HITACHI S570 and a HITACHI JEEM1-200, respectively, following the procedures as described by Li and Wen (1990).

2.7. Calculations and statistical analysis

The faecal digestibilities of dietary nutrients were calculated using the content of AIA (as an indigestible marker) and the corresponding nutrients in the diets and faecal samples by the following formula:

$$T\ (\%) = 100-(b*c)/(a*d)*100$$

where T: digestibility of a nutrient (%); a: the content of the nutrient in the diet (%); b: the content of the nutrient in the faecal sample (%); c: AIA content of the diet (%); d: AIA content of the faecal sample (%).

An analysis of variance was conducted for nutrient digestibilities, organ measurements and histological examination data using the following model:

$$Y_{ijk}=\mu+a_i+b_j+(a*b)_{ij}+e_{ijk}$$

where Y_{ijk}: individual observation; μ: the expected mean; a_i: the effect of diet i; b_j: the effect of breed j; $(a*b)_{ij}$: the interaction between a_i and b_j; e_{ijk}: the error term.

Linear correlation analysis was conducted between the relevant parameters. The software of SAS (1989) was used in the statistical analysis.

3. Results and Discussion

3.1. Digestibility of dietary nutrients

For all groups of animals, except the Min piglets fed the control diet, the daily feed intake was nearly the same (about 1065 g/day.animal) (Table 3). The diet nutrient digestibilities are presented in Tables 4 and 5. In Table 4, the digestibilities were compared between the control diet and the soybean-containing diet (pooled data of all soybean-containing diets). The digestibilities for dry matter (DM), fat (ether extract, EE), crude fibre (CF) and ash for the soybean-containing diet were significantly ($P<0.05$) higher than those for control diet. Crude protein (CP) digestibility of the soybean-containing diet was also higher than the control diet, but not significantly so ($P<0.10$). The lower nutrient digestibilities of the control diet were probably caused by the inclusion of corn distillers' dried grains. Distillers' grains have a considerably lower digestibility. This is probably related to the distillation at high temperatures and the high concentration of ethyl alcohol. Its CP and gross energy digestibilities in pigs are only 60-70% (Qin, 1988; Sibrits, 1981). The ash digestibility of the control diet was extremely low, which can partially be explained by the relatively higher level of dietary acid insoluble ash (as shown in Table 2).

DM, EE and CF digestibilities for Min piglets were significantly ($P<0.05$) higher than for Landrace piglets. A significant interaction in CF digestibility was observed between pig breed and diet. The digestibility of CF of the landrace piglets fed the control diet was significantly ($P<0.05$) lower than that of the other treatments. This indicates that the source of dietary fibre may influence difference in CF digestibility between pig breeds. The higher digestibility values, especially the higher CF digestibility, of the Min pigs compared with the Landrace pigs observed in the present study agree with the results reported by Han et al. (1983).

In Table 5, nutrient digestibilities were compared between diets containing different soybeans. The results show that steam-heating significantly ($P<0.05$) improved the digestibilities of dietary DM, CP, EE and ash. The improvement of the digestibilities of these nutrients may be related to the inactivation of soybean ANFs, because the

Table 3. Daily feed intake (g/day.animal)

Pig breed	Control	Argentine soybeans		Chinese soybeans	
		Raw	Processed	Raw	Processed
Landrace	1064	1067	1065	1064	1067
Min	993	1062	1062	1066	1072

Table 4. Effect of inclusion of full-fat soybeans on the digestibility of dietary nutrients

	DM	CP*	Ash	EE	CF	NFE
Means of diet:						
Soya diet[1] (n=32)	81.2^a	77.9	21.2^a	62.3^a	45.8^a	84.9
Control diet (n=8)	78.2^b	72.7	3.9^b	47.7^b	24.9^b	87.2

[1]: Pooled data from the diets containing Argentine and Chinese, raw and heated soybeans.

*: The significance of the difference between diets is "$p<0.10$"

[a,b]: Means in the same column with different superscript differ significantly ($P<0.05$).

Table 5. Effect of soybean origin, processing and pig breed on the digestibility of dietary dry natter (DM), crude protein (CP), ash, fat (EE), crude fibre (CF) and nitrogen free extract (NFE).

	DM	CP	Ash	EE	CF	NFE
Means of treatment group (pig breed/diet, n=4):						
Landrace pigs:						
Argentine raw soybean diet	78.4	70.3	16.7	59.3	47.6	87.4
Argentine processed soybean diet	82.3	81.8	24.5	53.3	41.7	89.1
Chinese raw soybean diet	76.7	69.3	17.2	48.3	42.1	86.0
Chinese processed soybean diet	82.3	82.5	20.2	70.1	42.9	88.5
Min pigs:						
Argentine raw soybean diet	81.5	76.4	23.4	66.4	46.5	88.7
Argentine processed soybean diet	84.1	84.2	28.4	68.5	54.4	84.7
Chinese raw soybean diet	78.6	72.5	18.8	53.6	45.7	87.7
Chinese processed soybean diet	84.1	86.1	20.4	78.8	46.0	88.9
Means of diets (n=8):						
Argentine raw soybean diet	79.9^{ab}	73.4^{b}	20.0	62.8^{b}	47.0	88.1
Argentine processed soybean diet	83.2^{a}	83.0^{a}	26.4	60.9^{bc}	48.0	86.9
Chinese raw soybean diet	77.7^{b}	70.9^{b}	18.0	50.9^{cd}	43.9	86.8
Chinese processed soybean diet	83.2^{a}	84.3^{a}	20.3	74.4^{a}	44.4	88.7
Means of pig breeds (n=16):						
Landrace pigs	79.4^{b}	76.0^{b}	19.6	57.7^{b}	43.5	87.8
Min pigs	82.4^{a}	79.8^{a}	22.7	66.9^{a}	48.1	82.1
Root MSE	3.02	3.90	6.73	6.75	15.75	16.19

*: Means in the same column and same block with different superscript differ significantly ($P<0.05$).

digestibilities of DM and CP were highly and negatively correlated to the dietary TIA (Table 8). This was in agreement with the results reported by Nitsan and Nir (1986), Qin et al. (1996), Vandergrift et al. (1983) and Visser and Tolman (1993).

Soybean origin had no significant ($P<0.05$) effect on the digestibilities of nutrients. However, there was a significant ($P<0.05$) interaction in EE digestibility between soybean origin and heat-processing (Table 5). The EE digestibility of the diet containing raw Chinese soybeans was 23.5 percentage units higher than the diet containing processed Chinese soybeans. For Argentine soybeans, however, the heating did not improve the digestibility of EE. It is possible that the properties and/or levels of ANFs relevant to EE digestion are different between Argentine and Chinese soybeans.

3.2. Organ measurements

Data for organ measurements were compared between pig breeds, between diets and between treatment groups (Table 6). The small intestine of Landrace pigs was significantly ($P<0.05$) longer and heavier than that of Min pigs. For the large intestines, there were no significant differences in the length and weight between the two breeds. The diet did not have a statistically significant influence on the measurements of the intestines, but the small intestinal weight varied considerably between diets ($P<0.25$). The animals which consumed the Chinese raw soybean diet, for example, had a clearly heavier small intestine than those which consumed the other diets. A significant ($P<0.05$) interaction was observed between pig breed and diet for small intestine weight. The small intestine of the Landrace pigs fed the diets containing various soybeans were, in general, heavier than those of the Min pigs consuming the same diets. For the animals fed the control diet, however, the results were contradictory. No significant interactions between pig breed and diet were found for length and weight of large intestine nor for length of the small intestine.

Similar results to those of the present study have been reported previously in the literature. Enlargement of the small intestine of chicks, geese or rats was caused by feeding raw soybeans (Nitsan and Nir, 1986), purified soybean lectin (Grant et al., 1987 and 1988) or kidney bean (*Phaseolus vulgaris*) lectin (De Oliviera et al., 1988). Huisman et al. (1990a) reported that the weight of the small intestine of piglets was increased by feeding raw kidney beans (*Phaseolus vulgaris*) compared to feeding heated beans. According to Grant et al. (1988), the enlargement or increased weight of the small intestine is mainly due to the cellular proliferation caused by ingesting lectin. In the present study, the heaviest small intestine was found in the animals fed the diet containing raw Chinese soybeans, indicating that raw Chinese soybeans may contain a higher level of lectins. Moreover, Landrace piglets were more sensitive to feeding diets containing both raw and processed soybeans. This can

Table 6. Effect of soybean origin, processing and pig breed on pig's organ measurements* (cm or g/kg body weight)

	SIL	LIL	PANW	SIW	LIW	LIVW	SPLW	STOMW	KIDW
Means of treatment groups (pig breed/diet, n=3):									
Lan/ArR	0.68	0.14	1.57	40.12^{abc}	18.86	22.11	1.45	10.97	4.55
Lan/ArP	0.67	0.12	1.56	45.85^{ab}	18.31	22.43	1.45	8.89	4.67
Lan/ChR	0.72	0.15	1.36	50.29^{a}	20.64	27.03	1.32	9.47	5.12
Lan/ChP	0.67	0.13	1.74	44.27^{abc}	19.72	24.19	1.52	9.19	5.52
Lan/Cont.	0.68	0.13	1.12	37.91^{bc}	23.26	21.27	1.57	9.53	4.73
Min/ArR	0.64	0.13	1.53	39.25^{abc}	20.14	24.50	1.74	10.92	3.95
Min/ArP	0.52	0.13	1.79	32.85^{c}	20.31	23.79	2.61	9.82	3.94
Min/ChR	0.58	0.11	1.36	36.95^{bc}	18.50	20.80	2.13	10.17	3.69
Min/ChP	0.52	0.12	1.58	35.12^{bc}	17.95	24.56	1.61	9.78	4.31
Min/Cont.	0.65	0.13	1.35	38.74^{abc}	20.60	24.91	2.00	9.20	4.36
Means of diets: (n=6)									
ArR	0.66	0.13	1.55^{ab}	39.69	19.50	23.31	1.60	10.95^{a}	4.25^{b}
ArP	0.60	0.12	1.68^{a}	39.35	19.31	23.11	2.03	9.36^{b}	4.30^{ab}
ChR	0.65	0.13	1.36^{ab}	43.62	19.57	23.92	1.72	9.82^{ab}	4.41^{ab}
ChP	0.59	0.12	1.66^{a}	39.70	18.84	24.38	1.57	9.49^{ab}	4.92^{a}
Cont.	0.66	0.13	1.24^{b}	38.32	21.93	23.09	1.79	9.36^{b}	4.55^{ab}
Means of pig breeds (n=15):									
Landrace	0.68^{a}	0.13	1.47	43.69^{a}	20.16	23.41	1.46^{b}	9.61	4.92^{a}
Min	0.58^{b}	0.12	1.52	36.58^{b}	19.50	23.71	2.02^{a}	9.98	4.05^{b}
Root SME	0.07	0.02	0.24	4.03	3.03	2.59	0.50	0.89	0.38

* SIL: small intestinal length; LIL: large intestinal length; PANW: pancreas weight; SIW: small intestinal weight; LIW: large intestinal weight; LIVW: liver weight; SPLW: spleen weight; STOMW: stomach weight; KIDW: kidney weight.

[a,b,c] Means in the same column and same block with different superscript differ significantly ($P<0.05$).

be seen in the increased small intestine weight of the Landrace piglets consuming various soybeans.

Chinese native pig breeds normally have heavier intestines, especially the large intestine, compared with Landrace (Zhao, 1989) and Large White pigs (Fevrier et al., 1988). The results of the present study, however, do not agree with these previous observations. This was possibly due to the higher sensitivity of the Landrace piglet to the ANFs of soybeans, because the small intestines of Landrace piglets were heavier than those of the Min piglets when fed the diets containing soybeans, but the opposite was observed when the control diet was fed. The high and negative correlation coefficients of small intestine weight and/or length to crude protein and crude fat digestibilities (Table 8), indicates that animals with heavier small intestines did not digest or absorb dietary nutrients as well as those with lighter small intestines. This suggests that the heavier small intestine of Landrace piglets may have resulted from a pathological effect caused by soybean ANFs.

The relative weight of the intestines may be associated with the age and body weight of animals (Duan, 1984). The large intestine may develop later in life. The great genetic potential for large intestinal development of Min pigs had not been realized when these animals were killed at a body weight of less than 30 kg in the present experiment. This is another explanation for the difference in intestinal weights found in the present study compared with previous reports (Zhao, 1989).

The pancreas weight of piglets was significantly ($P<0.05$) influenced by diet. The animals fed the processed soybean-diets had a heavier ($P<0.05$) pancreas than those fed the control and raw soybean-diets. Feeding raw soybeans, under-processed soybean products, or other legume seeds such as Vicia faba, Pisum sativum and *Phaseolus vulgaris* beans causes enlargement of the pancreas in rats, chicks, mice and geese due to the presence of trypsin inhibitors in these ingredients (Liener et al., 1985; Nitsan and Nir, 1986; Huisman et al., 1990a and b). For pigs, as well as for some other animals whose relative pancreatic weight is normally below 0.3% of the body weight, ingesting soybean trypsin inhibitors may not cause pancreatic hypertrophy (Yen et al., 1974). When the effect of feeding raw compared with heat-processed *Phaseolus vulgaris* beans, it was found that the relative pancreatic weight of the piglets fed the diets containing raw beans was lower (Huisman et al., 1990a; Van der Poel et al., 1990a), or the same as that of the piglets fed the diets containing processed beans (Huisman et al., 1990b). The heavier pancreas of the animals consuming the diets containing treated soybeans in the present study, agreed with that reported in the above mentioned literature. Pancreatic hypertrophy may be a adaptive mechanism to overcome the depressive effects of trypsin inhibitors. The animals which can develop pancreatic hypertrophy may adapt more easily to dietary protease inhibitors than those who cannot develop this mechanism (Nitsan and Nir, 1986). An inability to develop pancreatic hypertrophy may be one of the explanations for the higher sensitivity of piglets to legume ANFs compared with rats and chicks. In the present study, the high and positive correlations between pancreas weight and protein ($P<0.01$) or crude fat ($P<0.01$) digestibilities, and high and negative correlation between pancreas weight and dietary TIA ($P<0.01$) were observed (Table 8). This indicates that the decreased nutrient digestibilities of the diets containing raw soybeans resulted from both the inhibition of digestive enzymes and from the lack of compensative enzyme production by the pancreas.

Landrace piglets had significantly ($P<0.05$) heavier kidney and lighter spleen than Min piglets. The weights of liver and stomach were not significantly different between the pig breeds (Table 6). However, diet treatment had a significant ($P<0.05$) influence on stomach and kidney weights, though not on liver and spleen weights. The stomachs of the animals fed the diets containing raw soybeans were heavier than those of the animals fed the diets containing processed soybeans. The correlation coefficient showed that stomach weight was negatively correlated to the digestibility of CP ($P<0.05$). This means that the increased stomach weight was associated with soybean ANFs. It remains to be studied whether the increased stomach weight was due to a increased secretion caused by ANFs or by other means of the actions of the ANFs.

The processing and origin of soybeans did not evidently influence the kidney weight. However, higher correlations between kidney weight and small intestinal length ($P<0.01$) or weight ($P<0.01$) were observed. This indicates that the enlargement of the small intestine may be accompanied by an enlargement of the kidneys. It is possible that the animals with heavier and/or longer small intestine may be different from other animals in the composition (such as nitrogen) or amount of their urine, which subsequently influence their kidney weight.

3.3. Histological observations

The status of the small intestinal epithelial mucosa of the piglets varied among the treatment groups from normal, in the animals fed the control diet, to seriously damaged in the animals fed the diet containing raw Chinese soybeans. In the light micrographs (Figure 1) and electron scanning micrographs (Figure 2), it can be seen that the upper part of the villi of the piglets fed the diet containing raw Chinese soybeans were seriously damaged. The cells at the top of the villi are sloughed off in these animals. The sloughing off was more serious in Landrace piglets than in Min piglets (see Figures 1 and 2). The damage of the villi was possibly due to lectins in the soybeans. It was reported that soybean lectins bind mainly to the mature cells on the upper part of the villi and may lead to extensive damage of the cells (Pusztai, 1988). In the transmission electron micrographs of small intestine epithelial cells of the animals fed the diet containing raw Chinese soybeans, many vesicles were observed between the microvilli. No vesicles were found in that of the animals fed the control diet (Figure 3). It has been reported that higher numbers of microvillus vesicles are formed in the explants of the pig small intestine mucosa cultured in the presence of air classified common bean (*Phaseolus vulgaris* L.) fraction (Van der Poel et al., 1990), or cultured in the presence of purified *Phaseolus vulgaris* lectin than in that of control animals (Kik et al., 1991). Similar vesicles were also observed in the epithelial cells of rats (King et al., 1982)

Table 7. Proportions (%) of goblet cells in villi (PGV) and crypts (PGC) of small intestine and depth of colon enteraden (DCE)

	PGV(%)	PGC(%)	DCE(μm)
Means of treatment groups (pig breed/diet, n=3):			
Landrace/ArR	8.23	23.47	403.78
Landrace/ArP	10.20	25.07	433.16
Landrace/ChR	8.53	23.83	429.73
Landrace/ChP	10.05	28.03	452.41
Landrace/Control	7.13	21.77	389.52
Min/ArR	11.37	24.10	353.78
Min/ArP	9.25	23.80	372.34
Min/ChR	10.03	21.47	328.18
Min/ChP	8.07	25.13	343.81
Min/Control	6.33	14.67	384.71
Means of Diets (n=6):			
ArR	9.80	23.78	378.78
ArP	9.82	24.56	402.75
ChR	9.28	22.65	378.95
ChP	8.86	26.58	398.11
Control	6.73	18.22	387.11
Means of pig breeds (n=15):			
Landrace	8.74	24.43	421.72[a]
Min	8.99	21.69	356.56[b]
Root SME	2.13	5.04	36.01

Means in the same column and same block with different superscript differ significantly (P<0.05).

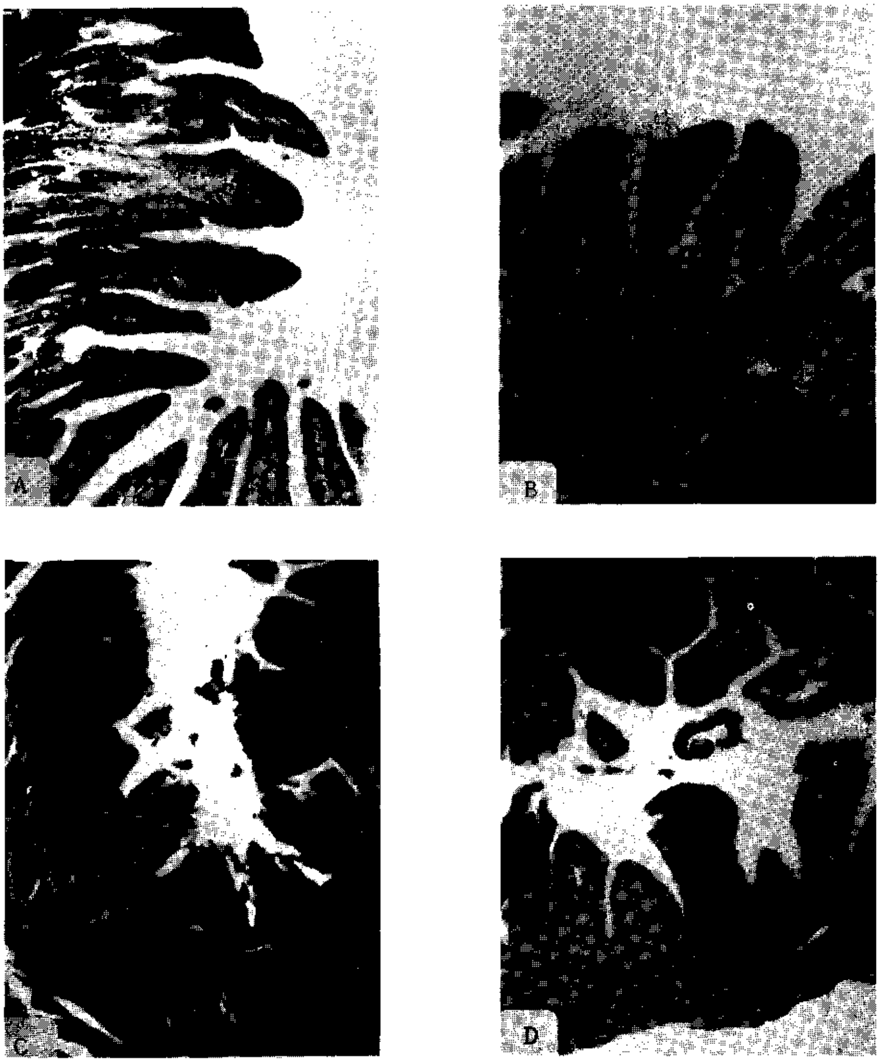

Figure 1. Light microphotograph (X 32) of small intestinal epithelial mucosa of piglet. A: Landrace piglet fed on control diet; B: Min piglet fed on control diet; C: Landrace piglet fed on raw Chinese soybean diet; D: Min piglet fed on raw Chinese soybean diet.

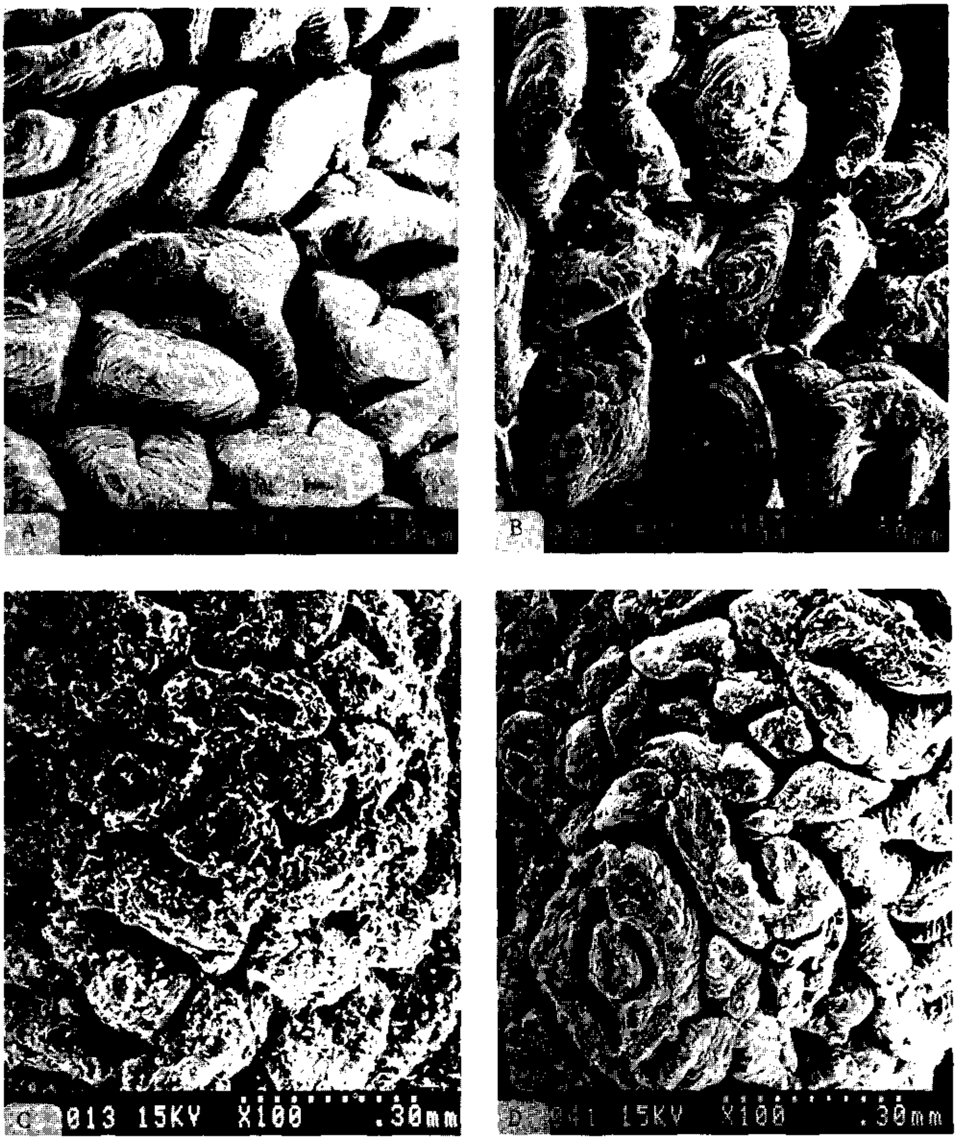

Figure 2. Scanning electron microphotograph of small intestinal epithelial mucosa of piglet
A: Landrace piglet fed on control diet; B: Min piglet fed on control diet; C: Landrace piglet fed on raw Chinese soybean diet; D: Min piglet fed on raw Chinese soybean diet.

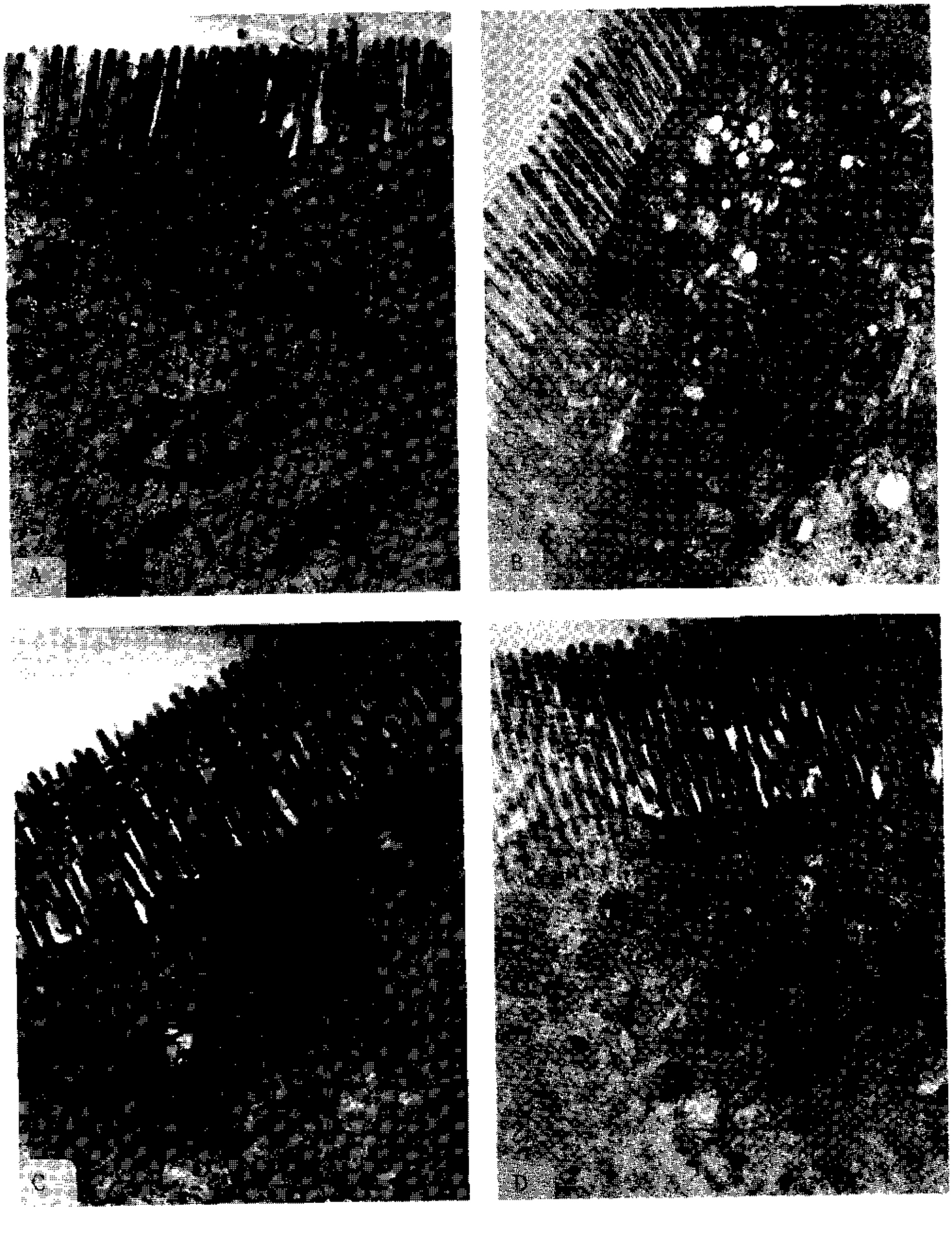

Figure 3. Transmission electron microphotograph (X 12000) of small intestinal epithelial cell of piglet. A: Landrace piglet fed on control diet; B: Min piglet fed on control diet; C: Landrace piglet fed on raw Chinese soybean diet; D: Min piglet fed on raw Chinese soybean diet.

and Caco-2 cells of humans (Hendriks et al., 1991) after exposure to lectin. The presence of these vesicles probably reflects an increased turnover of the microvillus membrane according to Hendriks et al. (1991). The mechanism involved in the development of the vesicles is not clear.

Table 8. Correlation coefficients between relevant parameters

	Correlation coefficient	probability(P<)
D-DM vs TIA	-0.991	0.01
D-CP vs TIA	-0.981	0.01
D-CP vs SIL	-0.593	0.01
D-CP vs PANW	0.495	0.01
D-CP vs STOMW	-0.372	0.05
D-CP Vs SIW	-0.332	0.10
D-CF vs PGC	-0.493	0.01
D-CF vs LIL	0.498	0.01
D-EE vs SIL	-0.576	0.01
D-EE vs PANW	0.415	0.01
D-EE vs SIW	-0.480	0.01
D-ash vs PGC	-0.569	0.01
TIA vs PANW	-0.952	0.01
SIL vs PANW	-0.360	0.05
SIL vs SPLW	-0.567	0.01
SIL vs KIDW	0.506	0.01
SIL vs DCE	0.485	0.01
LIL vs PGV	-0.397	0.05
LIL vs PGC	-0.417	0.05
SIW vs SPLW	-0.588	0.01
SIW vs KIDW	0.759	0.01
SIW vs DCE	0.545	0.01

*: TIA: trypsin inhibitor activity; SIL: small intestinal length; PANW: pancreas weight; STOMW: stomach weight; PGC: proportion of goblet cell in crypts of small intestine; LIL: large intestinal length; SIW: small intestinal weight; SPLW: spleen weight; KIDW: kidney weight; DCE: depth of colon enteraden; PGV: proportion of goblet cell in villi of small intestine; D-DM, D-CP, D-CF, D-EE and D-ash are the digestibility coefficient of dietary DM, CP, CF, EE and ash.

The proportion of goblet cells in the villi (PGV) and crypts (PGC) did not differ significantly between pig breeds, but the PGC of Min piglets tended to be higher than that of Landrace piglets ($P<0.16$). The PGV and PGC of the piglets on the control diet was clearly lower than those of the animals on both the diets with raw and with processed soybeans ($P<0.12$ and $P<0.10$, respectively). Interaction between pig breed and diet was not significant for PGV and PGC (Table 7). The increased PGV and PGC in the piglets fed the soybean diets may have been associated with the production of more mucus on the intestinal mucosal surface (Kik et al., 1988), which is a possible response of the animals to soybean diets. The negative correlation coefficients of PGV and PGC with large intestinal length, and of PGC with digestibilities of crude fibre and ash (Table 8), suggest that increased PGC and PGV, by secreting more mucous, probably shortened the residence time of the digesta inside the digestive tract, especially in the hind-gut since the digestion of fibre and absorbtion of minerals occurs mainly in the large intestine. The increased secretion of mucous and the rapid passage of digesta may be part of the mechanism of diarrhoea caused by feeding soya products to piglets. The similarity in PGV and PGC between the animals consuming raw and processed soybean diets indicates that the increased number of goblet cells in the intestinal epithelium may have resulted from some heat-stable factors in soybeans.

Landrace piglets had significantly ($P<0.05$) deeper colon enteraden (DCE) than Min piglets. There were no evident differences between diets in the DCE. The data of various treatment groups showed that when animals were fed the control diet there was almost no difference between pig breeds in DCE, although Landrace piglets fed any soybean diet showed deeper colon enteraden than Min piglets. The interaction between pig breed and diet for DCE ($P<0.13$) showed that Landrace piglets were more sensitive to soybean diets in DCE than Min piglets. It was also found that the animals with longer and/or heavier small intestines had deeper colon enteraden. The correlation coefficients between DCE and length or weight of small intestines are shown in Table 8.

4. Conclusion

The results of the present study show that the digestibilities of dietary dry matter, crude protein, crude fat, crude fibre, ash and N-free extract are generally higher in Min piglets than in Landrace piglets at a body weight of about 30 kg. Landrace piglets have a longer and heavier small intestine, heavier kidneys, deeper colon enteraden and a smaller spleen than Min piglets, when fed the same diet containing full-fat soybeans. The significant differences in nutrient digestibilities and in organ measurements between animals fed different diets show that steam-heating can effectively improve the feeding value of the full-fat soybeans. Furthermore, raw Chinese soybeans may have more deleterious effects on nutrient digestibilities and animal health than raw Argentine soybeans. The interaction between the pig breed and dietary composition on organ measurements and histological examinations demonstrates that Landrace piglets are more sensitive than Min piglets to raw soybean diets. The proper processing of full-fat soybeans is more important in the feeding for Landrace pigs than for Min pigs.

The digestibilities of dietary dry matter and crude protein, and pancreas weight were highly and negatively correlated to the dietary TIA level. Ingesting a raw soybean diet may cause a decrease in pancreas weight and an increase in the length and weight of the small intestine. Based on the correlation analysis, crude protein and fat digestibility reduction is accompanied by a decrease in pancreas weight and an increase in length and weight of the small intestine.

References

De Oliviera, J.T.A., Pusztai, A. and Grant, G., 1988. Changes in organs and tissues induced by feeding purified kidney bean (*Phaseolus vulgaris*) lectin. Nutrition Research. 8: 943-947.

Duan, Y.C., 1984. Morphological differences in gastrointestinal tract between Harbin White and Min pigs, Journal of Northeast Agricultural College. Suppl(1984): 12-18.

Fevrier, C., Bourdon, D., and Aumaittre, A., 1988. Digestive capacity of the Chinese pig-effect of dietary fibre on digestibility and intestinal and pancreatic enzymes. Proc. 4th Sem. Digestive Physiology in the Pig, 6-10 June, 1988, Jablonna, Poland. pp. 172-179.

Grant, G., Ewen, S.W.B., Bardocz, S., Brown, D.S., Dorward, P.M., Watt, W.B., Stewart, J.C. and Pusztai, A., 1988. Local (gut) and systemic responses of rats to dietary soybean (Glycine Max) proteins. In: J. Huisman, A.F.B. van der Poel and I.E. Liener (editors) Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of the First International Workshop on "Antinutritional Factors (ANFs) in Legume Seeds", November 23-25, 1988, Wageningen, The Netherlands. pp.34-38.

Grant, G., Watt, W.B., Stewart, J.C. and Pusztai, A., 1987. Changes in the small intestine and hind-leg muscles of rats induced by dietary (Glycine max) protein. Medical Science Research. 15: 1355-1356.

Han, W.Z., Xiao, Z.D., Cui, B.H. and Gao, M.Q., 1983. A study on adversity-resistance of Min pigs. Chinese J. Anim. Sci. 30: 15-17.

Hendriks, H.G.C.J.M., Kik, M.J.L., Koninkx, J.F.J.G., Van den Ingh, T.S.G.A.M. and Mouwen, J.M.V.M., 1991. Binding of kidney bean (*Phaseolus vulgaris*) isolectins to differentiated human colon carcinoma Caco-2 cells and their effects on cellular metabolism. In: M.J.L. Kik, Effects of Lectin in Legume Seeds on the Structure and Function of the Small Intestinal Mucosa: In vivo and in vitro studies (Ph.D. Thesis, University of Utrecht). pp. 41-57.

Herkelman, K.L. and Cromwell, G.L., 1990. Utilization of full-fat soybeans by swine reviewed. Feedstuffs. 62(52): 13-16,22.

Herkelman, K.L., Cromwell, G.L., Stakly, S.T., Pfeiffer, T.W. and Knabe, D.A., 1992. Apparent digestibility of amino acids in raw and heated conventional and low-try psin-inhibitor soybeans for pigs. J. Anim. Sci. 70: 818-826.

Huisman, J., Van der Poel, A.F.B., Van Leeuwen, P. and Verstegen, M.W.A., 1990a. Comparison of growth, nitrogen metabolism and organ weights in piglets and rats fed on the diets containing *Phaseolus vulgaris* beans. Br. J. Nutr. 64: 743-753.

Huisman, J., Van der Poel, A.F.B., Mouwen, J.M.V.M. and Van Weerden, E.J., 1990b. Effect of variable protein contents in diets containing *Phaseolus vulgaris* beans on performance, organ weights and blood variables in piglets, rats and chickens. Br. J. Nutr. 64: 755-764.

Humason, G.H., 1967. PAS and feulgen techniques, and related reactions. In: G.H. Humason (editor). Animal Tissue Techniques (Second edition). W.H.Freeman and Company, San Francisco. pp.303-309.

Kakade, M.L., Bersch, J.J., Mcghee, J.E. and Puskai, G., 1974. Determination of trypsin inhibitor activity of soy products: a collaborative analysis of an improved procedure. Cereal Chem. 51: 376-382.

Kik, M., Huisman, J., Van der Poel, A. and Mouwen, J., 1988. Pathological changes of the small intestinal mucosa of piglets after feeding *Phaseolus vulgaris* beans. In: J. Huisman, A.F.B. van der Poel and I.E. Liener (editors) Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of First International Workshop on "Antinutritional Factors (ANFs) in Legume Seeds", November 23-25, 1988, Wageningen, The Netherlands. pp. 49-53.

Kik, M.J.L., Koninkx, J.F.J.G., Vanden Muysenberg, A.J.C. and Hendriksen, E.G.J., 1991. Pathological effects of *Phaseolus vulgaris* isolectins on pig jejunal mucosa in organ culture. In: Maria J.L. Kik, Effects of Lectin in Legume Seeds on the Structure and Function of the Small Intestinal Mucosa: In vivo and in vitro studies (Ph.D. Thesis, University of Utrecht). pp. 41-57.

King, T.P., Pusztai, A. and Clarke, E.M.W., 1982. Kidney bean (*Phaseolus vulgaris*) lectin-induced lesions in rat small intestine. 3. Ultrastructural studies. J. Comp. Pathol. 92: 357-373.

Li, D.X. and Wen, S.H., 1990. Scanning electron microscopy examination of gastric gland mucous membrane in healthy adult hens. Bulletin of Veterinary College of PLA. 10 (1): 56-59.

Liener, I.E., 1980. Protease inhibitors. Toxic constituents of plant foodstuffs. Academic Press. New York, US.

Liener, I.E., Nitsan, Z., Srisangnam, C., Rackis, J.J. and Gumbmann, M.R., 1985. The USDA trypsin inhibitor study. II. Time related biochemical changes in the pancreas of rats. Qualitas Plantarum. Pl. Food Hum. Nutr. 35: 243-257.

Marty, B.J. and Chaves, E.R., 1993. Effects of heat processing on digestible energy and other nutrient digestibilities of full-fat soybeans fed to weaner, grower and finisher pigs. Can. J. Anim. Sci. 13: 411-419.

Monari, S., 1993. Fullfat soybeans in pig feeding. Fullfat Soya Handbook, 2nd edn. American Soybean Association, Brussels, pp. 22-28.

Nitsan, Z. and Nir, I., 1986. Accentuated response to soybean inhibitors by meal-feeding in various species. Adv. Exp. Med. Biol. 199: 199-223.

Noland, P.R., Campbell, D.R.,Gage, R.K., Jr, Sharp, R.N. and Johnson, Z.B., 1976. Evaluation of processed soybeans and grains in diets for young pigs. J. Anim. Sci. 43(4): 763-769.

NRC, 1988. Nutrient Requirement for Domestic Animals. N0. 2. Requirements of Swine. Ninth Revised Ed.. National Academy of Science, National Research Council. Washington D.C.

Pusztai, A., 1988. Biological effects of dietary lectin. In: J. Huisman, A.F.B. van der Poel and I.E. Liener (editors) Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of the First International Workshop on "Antinutritional Factors (ANFs) in Legume Seeds", November 23-25, 1988, Wageningen, The Netherlands. pp. 17-29.

Qin, G.X., 1988. A study on corn distillers' dried grains as protein source for growing and finishing pigs. M.Sc. Thesis, Jilin Agricultural University.

Qin, G.X., Verstegen, M.W.A. and Bosch, M.W., 1995. Variation of digestive capacity between genetically different pig populations: a review. J. Anim. Physiol. a. Ani m. Nutr.. 73: 233-242.

Qin, G.X. and Chen, P., 1995. Antinutritional factors in soybeans, and feeding full-fat soybeans for pigs. Paper presented at the 4th Symposium of Northeast Pig Produ ction Research council. Nov.20-22nd, 1995, Changchun, P.R. China.

Qin, G.X., Ter Elst, E.R., Bosch, M.W. and Van der Poel, A.F.B., 1996. Thermal processing of whole soya beans: Studies on the inactivation of antinutritional factors and effects on ileal digestibility in pigs. Anim. Feed Sci. Technol. 57: 313-324.

Qin, G.X., Van der Poel, A.F.B. and Verstegen, M.W.A., 1996a. Effect of temperature and time during steam treatment on the protein quality of full-fat soybeans from different origins. J. Sci. Food Agric. (Submitted)

SAS, 1989. SAS/STAT[R] User's Guide, Version 6, Fourth Edition, Vol.2, Cary, NC. SAS Institute Inc.

Sibrits, F.K., 1981. The utilization of maize distillers dried grains in pig growth diets. South African J. Anim. Sci. 11(1): 11-15.

Vandergrift, W.L., Knabe, D.A., Tanksley, T.D., Jr. and Anderson, S.A., 1983. Digestibility of nutrients in raw and heated soyflakes for pigs. J. Anim. Sci. 57(5): 1215-1224.

Van der Poel, A.F.B., Aarts, H.L.M. and Kik, M.J.L., 1990. Air classification of bean flour - effects on protein, antinutritional factors and effect of fines fraction on cultured explants of small intestine mucosa. J. Sci. Food Agric. 53: 143-157.

Van der Poel, A.F.B., Mollee, P.W., Huisman, J. and Liener, I.E., 1990a. Variation among species of animals in response to the feeding of heat-processed beans (*Phaseolus vulgaris* L.).1.Bean processing and effects on growth, digestibility and organ weight in piglets. Livest. Prod. Sci. 25: 121-135.

Van der Poel, A.F.B., Liener, I.E., Mollee, P.W. and Huisman, J., 1990b. Variation among species of animals in response to the feeding of heat-processed beans (*Phaseolus vulgaris* L.).2.Growth and organ weights of chicken and rats and digestibility for rats. Livset. Prod. Sci. 25: 137-150.

Van der Poel, A.F.B., Blonk, J., Van Zuilichem, D.J. and Van Oort, M.G., 1990c. Thermal inactivation of lectin and trypsin inhibitor activity during steam processing of dry beans (*Phaseolus vulgaris* L.) and effect on protein quality. J. Sci. Food Agric. 53: 215-228.

Van Oort, M.G., Hamer, R.J. and Slager, E.A., 1989. The trypsin inhibitor assay: improvement of an existing method. In: Recent Advances of Research in Antinutritional Factors in Legume Seeds. J.huisman, A.F.B.van der Poel, I.E.Liener (Editors). PUDOC, Wageningen, The Netherlands, pp: 110-113

Visser, A. and Tolman, G.H., 1993. The influence of various processing condition on the level of antinutritional factors in soya protein products and their nutritional value for calves. In: A.F.B. van der Poel, J. Huisman and H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of 2nd International Workshop on Antinutritional factors (ANFs) in Legume Seeds. Wageningen, The Netherlands, 1-3 december 1993, pp. 447-453.

Xian, J. and Farrell, D.J., 1991. The nutritive value of microwave-processed raw soya beans determined with chickens, rats and rabbits. Anim. Feed Sci. Technol. 34: 127-139.

Yang, S.X., 1983. Nutritional Evaluating Methods for Feedstuffs. People's Publish of Gansu Province, P.R.China.

Yen, J.T., Hymowitz, T. and Jensen, A.H., 1974. Effects of soybeans of different trypsin-inhibitor activities on performance of growing swine. J. Anim. Sci. 38(2): 304-309.

Zhao, G., 1989. In: Research on Min Pigs. Heilongjiang Sci. Technol. Press. pp. 145-185.

Chapter 8

General discussion

1. Introduction

Soybeans contain high levels of energy and protein. They are considered to be a highly valuable feedstuff. Full-fat soybeans have been used on a large scale in feed compounding industry throughout the world (Leysen, 1991; Monari, 1993). However, antinutritional factors (ANFs) in soybeans as well as in other legume seeds limit their feeding value for animals. Therefore, a lot of research on soybean processing has been carried out with the objective of eliminating ANFs. In resent years, increased amounts of full-fat soybeans are also being used in animal feed in China. However, information concerning the antinutritional nature of ANFs in Chinese soybeans, and optimal processing procedure specifically for Chinese soybeans are still needed.

The results of previous literature show that the ANFs in soybeans can be inactivated to various extents by means of physical, chemical or biological treatments (Chapter 2). Pressurized steam heating was found to be one of the most effective (Liener, 1993) and economical (Houdijk et al., 1992) methods. Consequently, steam heating was chosen for the studies described in this thesis.

Previous research has demonstrated that the activities of ANFs (trypsin inhibitor activities, TIA) vary greatly among different cultivars (or varieties) of soybeans (Chapter 2). The residual TIA in processed soybeans is associated with the TIA level in the raw beans (Friedman et al., 1991). Consequently, a similar processing procedure may cause different results for different origins of soybeans. On the other hand, the chemical composition of soybeans may also influence the processing results. For example, Maillard reactions can occur at certain heat processing conditions, in which lysine and reducing sugars combine together and form non-utilizable products (Erbersdobler, 1977). Thus, the quality and quantity of carbohydrates of the soybeans may affect the protein quality of the processed soybeans. Therefore, a specific soybean origin may also need a specific processing condition.

The antinutritive effect of ANFs is not a feature of ANFs themselves. In fact, it is the result of the "interaction" between the feed and the animals consuming the feed. The deleterious effects of soybean ANFs may vary greatly either among products processed differently and among different soybean origins (Chapter 2), or among animal species (Nitsan and Nir, 1986), among animal physiological states (Herkelman and Cromwell, 1990; Marty and Chavez, 1993) and even among individuals (Goihl, 1990; Qin et al., 1996). Therefore, the antinutritive effects of soybean ANFs need to be evaluated by an approach which takes into account both animal factors and soybean origin.

In the research described in this thesis, the processing effects of different processing conditions were compared between soybean origins and between pig breeds, with the aim of providing knowledge and evidence for the optimal processing of specific soybeans for specific pig breed.

2. Variation of TIA among soybean origins

Trypsin inhibitors (TI), the most antinutritive factors of soybeans (Rackis et al., 1986), are proteins. The presence and characteristics of these proteins in the soybeans seeds depend on specific genes. The variation of the genotype among soybean cultivars results in the variation of TIA between the soybean origins. The genetic patterns of soybean TI has already been clarified (Chapter 2), which provides an opportunity for eliminating TI by a plant breeding approach. In USA, a new low TI soybean variety has been successfully developed. The TIA of this variety was only 50% of that of conventional variety. Therefore, plant breeding seems to be an effective way of eliminating soybean ANFs. However, the reduction of ANFs may affect the natural defence abilities of soybeans because these factors play important roles in the defence mechanism of legumes against insect and microbial predation (Liener, 1989).

According to Liu et al. (1994), the distribution of soybean TI genotype follows certain geographical patterns. This indicates that TIA of soybeans may be related to the geographical region in which the soybeans are produced. It was also reported that TI concentration varies with the maturation phases of soybeans (McGrain et al., 1992). Consequently, the variation of climate between production years may influence the maturation of soybeans, and subsequently, influence their TIA level. Summarizing the findings of previous work (Chapter 2) it can be said that the ANFs of soybeans may vary with cultivars, geographical growing regions or producing years. For example, the TIA (23.4 mg/g) of the Argentine soybeans (purchased in 1992) used in the experiment of

Chapter 4 are different from those (15.2 mg/g) described in the Chapters 5, 6 and 7 (purchased in 1994) . In the following text, the Argentine soybeans are referred to as those purchased in 1994. The Chinese soybeans used in all experiments described in this thesis were from the same batch.

In the experiment described in Chapter 5, a large difference was observed between Argentine and Chinese soybeans with regarding to their TIA. The TIA (20.6 mg/g) of Chinese soybeans used in the present studies belongs to a middle level compared with the results of various soybeans reported in literature (Chapter 2), but, it is higher than that (15.2 mg/g) of the Argentine soybeans. This difference was probably due to one or some of the factors already mentioned.

3. Responses of different soybean origins to heat processing

Steam toasting can effectively improve the nutritive value of full-fat soybeans as evaluated with laboratory analysis and animal trials as described in this thesis (Chapter 4, 5, 6 and 7). When soybeans were heated at a given temperature, the TIA and protein dispersibility index (PDI) of the processed beans generally decreased in a logarithmic pattern with prolongation of heating time. However, There were some differences in the patterns between the soybean of different origins studied in the present research (Chapter 5). With respect to the inactivation of TI, the TIA of Argentine soybeans decreased more rapidly with heating time than the Chinese soybeans. Therefore, Chinese soybeans, with a high TIA in the raw beans, probably need more severe processing conditions than the Argentine soybeans to reduce TIA to a safe level. This was in agreement with the results reported by Friedman et al. (1991). They concluded that more energy was needed to inactivate TI for the soybean cultivar having high levels of TI than that having low level of TI. PDI, as an indicator of protein denaturation (Van der Poel et al., 1990) also decreased more rapidly for Argentine soybeans than for Chinese soybeans under different treatment condition. This indicates that the proteins of Argentine soybeans may be more easily denatured by steam heating than those of Chinese soybeans.

Different treatment conditions may be needed to inactivate different ANFs. For instance, lectins are more sensitive to increasing temperature than TI (Chapter 4). Lectins could be inactivated within a short time when heated above 120 °C (Chapter 4). It is possible that soybeans with a high levels of lectins may need a high temperature/short time treatment.

The differences between soybean origins were further demonstrated in the animal trials (Chapter 6 and 7). The digestibilities of dry matter (DM), crude protein (CP) and fat of the diets containing raw Chinese soybeans were lower than those of the diets containing Argentine soybeans (Chapter 7). The results of Chapter 6 showed that the Chinese soybeans heated at 100 °C/40 min., 118 °C/5 min. and 136 °C/1.5 min. had a lower CP digestibility than the Argentine soybeans heated under corresponding conditions. In terms of the protein biological value (PBV, retained-nitrogen/absorbed-nitrogen) and net protein utilization (NPU, retained-nitrogen/ingested-nitrogen), the best result for Argentine soybeans were obtained by low temperature/long time (100 °C/40 min.) processing; for the Chinese soybeans, the best effect was found in the beans processed at high temperature/short time (136 °C/1.5 min.) condition. The higher PBV and NPU of the Chinese soybeans processed at 136 °C for 1.5 min. was probably related to the less denatured protein because the PDI of the Chinese soybeans treated at this condition was higher than that for the Argentine soybeans treated under the same conditions (13.0 vs 9.7%) (Chapter 5).

According to the results of Chapter 6 and 7, heat processing can not only improve the digestibility and the utilization of protein, but also improve the digestibility of fat. The improvement of fat digestibility, however, was different between Argentine and Chinese soybeans. Significant interactions between soybean origin and processing condition in fat digestibility have been described in the relevant chapters. In Chapter 7, the fat digestibility of the diets with raw Chinese soybeans was much lower than that of the diets with raw Argentine soybeans (50.9 vs 62.8%). After being processed, however, the fat digestibility for the Chinese soybean diet was much higher than for the Argentine soybean diet (74.4 vs 60.9%). In Chapter 6, the fat digestibility of soybeans determined by deference method showed that the optimal processing condition for improvement of the fat digestion differed between the soybeans of different origins. The highest digestibility of fat for Argentine soybeans was found in those heated at 100 °C/40 min.; for Chinese soybeans was those heated at 136 °C/1.5 min.. The interaction between soybean origin and processing condition in fat digestion indicates that some ANFs in the soybeans may be directly and/or indirectly involved in the digestion of fat. The levels and/or natures of these ANFs and other factors may differ between the two origins of the soybeans studied in this project. The relationship between fat digestion and soybean ANFs needs to be studied further.

With respect to the CP and fat digestibilities, and the NPU value, 100 °C/40 min. (low temperature/long time) processing was optimal for the Argentine soybeans; while 136 °C/1.5 min. (high temperature/short time) was the best treatment condition for the Chinese soybeans.

Soybean ANFs not only influence digestibility and utilization of nutrients, but also cause some pathological change in relevant organs of the animals. The results of the experiment described in Chapter 7 showed that the animals fed the diet with raw Chinese soybeans had a heavier small intestine and a lighter pancreas than those fed the diet with raw Argentine soybeans as measured by g per kg live body weight. The light and electron microscopy examinations showed that feeding the raw Chinese soybean diet caused more pathological change to intestinal mucosa than feeding the raw Argentine soybean diet. After the soybeans of both the origins were steam-heated at 118 °C/7.5 min., however, the differences in the weights of pancreas and small intestine disappeared between the two soybean origins. This implies that the quality of the Chinese soybeans was improved relatively more by the processing at this condition compared with the Argentine soybeans. Compared with raw soybean diets, the processed soybean diets decreased the small intestine weight by 9.0 and 0.8%, respectively, for Chinese and Argentine origin.

In Chapters 4, 6 and 7, Correlations have been derived between *in vivo* (animal trial) and *in vivo* (laboratory analysis) measurements. Some of the laboratory *in vitro* measurements, such as TIA, were highly correlated to the data obtained in animal trials. This indicates that the laboratory analytic data can be considered as effective tools for evaluating the quality of heat processed soybean products.

4. Responses of different pig breeds to soybean ANFs

The literature review (Chapter 3) concluded that there are considerable variations in digestion capacity among the breeds or genotypes of pigs. Fevrier et al. (1988) and Han et al. (1983) reported that Chinese native pig breeds (Meishan and Min pig), have a higher tolerance to dietary fibre level than Western pig breeds (Large White and Landrace pigs). In the experiment described in Chapter 7, it was also shown that there are differences between Landrace and Min (a native pig breed in north-east of China) pig breeds, in their dietary nutrient digestibilities and the length and weight of the small intestine. The digestibilities of dietary DM, CP and fat in Min pigs were higher than that in Landrace pigs. The small intestine of Landrace pigs, however, was longer and heavier than that of Min pigs. The heavier small intestine of Landrace pigs probably resulted from the higher sensitivity of Landrace pigs to soybean ANFs because there was a significant interaction between pig breed and diet in small intestine weight; the Landrace pigs fed diets containing soybeans had heavier small intestine than others. Lectins are considered to be the main component of the soybean ANFs which may be responsible for the enlargement of the small intestine (Grant et al., 1988). Probably, selection in pigs for increasing performance may have reduced their adaptability to ANFs. It may also mean that pigs should be selected for the characteristic of being less sensitive to feed ANFs.

The light and electron microscopy observations also showed that the pathological effects of soybean ANFs on the gut wall may differ between pig breeds. The ANFs are more deleterious to Landrace pigs than to Min pigs. The villi of the small intestinal mucosa of Landrace pigs were more seriously damaged by feeding the diet containing raw Chinese soybeans than those of Min pigs. It seems that processing is more important for Landrace pigs than for Min pigs when full-fat soybeans are to be used in the diet for young pigs.

5. Conclusion

According to the literature studies and the experimental results present in this thesis, the following conclusions can be drawn:

The TIA levels in soybeans vary greatly between soybeans of different origins. There were obvious differences in the levels of TIA and PDI between the raw Chinese and raw Argentine soybeans studied in the present experiments. Generally, TIA and PDI decreased with longer duration of heating at a given temperature in the soybeans of both origins. Soybeans from different origins, however, responded differently to heat processing. The residual levels of TIA and PDI in the Chinese soybeans were higher than that of Argentine soybeans when both type of soybeans were heated under the same conditions (except under the too severe heating conditions). Based on the improvement on N and fat digestibilities and NPU, the best processing condition for Argentine soybeans was low temperature/long time, and for the Chinese soybeans high temperature/short time. Processing influenced fat digestion more obviously for the Chinese soybeans than for the Argentine soybeans.

Digestive capacity is different between these breeds of pig. There were clear differences between the Landrace and Min pigs in response to soybean ANFs. With respect to intestinal enlargement and histological examinations, feeding raw soybean diets caused more severe pathological change to Landrace pigs than to Min pigs. Soybean heat processing is thus more important when they are to be used in the diets for Landrace pigs than for Min pigs.

6. Future research

In the present studies, described in this thesis, only two soybean origins and two pig breeds were compared using a limited number of parameters. The questions relevant to the differences between soybean origins and between pig breeds in relation to the ANFs have not been fully answered yet. The following aspects of research need to be conducted in the future:

1. To draw full profiles for ANFs of different origins of soybeans.

2. To definite the relations between ANFs profile and the response to heat processing.

3. To definite the variations in response to soybean ANFs among breeds, among physiological status of pigs.

4. To explain the differences between different pigs (breeds, genotypes or ages cte.) reponse to ANFs, both physiologically and biochemically.

5. To create guides for optimal utilization of different soybeans and different pig herds.

References

Erbersdobler, H.F., 1977. The biological significance of carbohydrate-lysine crosslinking during heat-treatment of food protein. In: M. Friedman (Editor). Symposium on Protein Crosslinking: Nutritional and Medical Consequences, New York, Plenum Press. pp. 367-378.

Fevrier, C., Bourdon, D. and Aumaitre, A., 1988. Digestive capacity of the Chinese pig-effect of dietary fibre on digestibility and intestinal and pancreatic enzymes. Proceedings 4th International Seminar on Digestive Physiology in the Pig 6-10th June 1988, Jablonna, Poland, 172-179.

Friedman, M., Brandon, D.L., bares, A.H. and Hymowitz, T., 1991. Effect of heat on the nutritional quality and safety of soybean cultivars. Adv. Exp. Med. Biol. 289: 339-361.

Goihl, J.H., 1990. Amino acid supplementation of soybean diets examined. Feedstuffs. 62 (42): 16-18.

Grant, G., Ewen, S.W.B., Bardoz, S., Brown, D.S., Dorward, P.M., Watt, W.B., Stewart, J.C. and Pusztai, A., 1998. Local (gut) and systemic repones of rats to dietary soybean (Glycine max) proteins. In: J Huisman, A.F.B. van der Poel and I.E. Liener (Editors) Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proceedings of the First International Workshop on "Antinutritional Factors (ANFs) in Legume Seeds", November 23-25, 1988, Wageningen, The Netherlands. pp. 34-38.

Han, W.Z., Xiao, Z.D., Cui, B.H., Gao, M.Q., 1983. A study on adversity-resistance of Min pig. Chinese J. Anim. Sci. 30: 15-17.

Herkelman, K.L. and Cromwell, A.G.L., 1990. Utilization of full-fat soybeans by swine reviewed. Feedstuffs. 62(52): 13-18.

Houdijk, J., Stolp, W. and Van der Poel, A.F.B., 1992. Process cost estimation. Internal Report, Department of Animal Nutrition, Wageningen Agricultural University, The Netherlands.

Leysen, R., 1991. Soybean derived food ingredients. Paper presented at the new products seminar during Food Ingredients Europe, Paris-France, October 1991.

Liener, I.E., 1989. Antinutritional factors in legume seeds. State of the art. In: J. Huisman, A.F.B. van der Poel, I.E. Liener (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds, Proceedings of the First International Workshop on "Antinutritional Factors (ANFs) in Legume Seeds", November 23-25, 1988, PUDOC, Wageningen, The Netherlands, 6-13.

Liener, I.E., 1993. Summary of the presentations and recommendations for the future. In: A.F.B. van der Poel, J. Huisman an H.S. Saini (Editors), Recent Advances of Research in Antinutritional Factors in Legume Seeds. Proc. 2nd International Workshop on Antinutritional Factors (ANFs) in Legume Seeds. Wageningen, 1-3 December 1993, pp. 537-547.

Liu, X.Y., Lin, G.Q., Zhong, P., Hu, C.P., Zhao, S.W. and Gao, J.Y., 1994. Frequency and geographical distribution of alleles for trypsin inhibitor in seed protein of soybean germplasms in China. Oil Crops of China. 16 (4): 32-35.

Marty, B.J. and Chavez, E.R., 1993. Effects of heat processing on digestible energy and other nutrient digestibilities of full-fat soybeans fed to weaner, grower and finisher pigs. Can. J. Anim. Sci. 73: 411-419.

McGrain, A.K., Chen, J.C., Wilson, K.A. and Tan-Wilson, A.L., 1992. Protases catalysing processing and degradation of Kunitz soybean trypsin inhibitor during seed maturation. Phytochemistry. 31(2): 421-426.

Monari, S., 1993. Fullfat Soya Handbook, 2nd Edition. American Soybean Association, Brussels, pp.1-28.

Nitsan, Z. and Nir, I., 1986. Accentuated response to soybean inhibitors by meal-feeding in various species. Adv. Exp. Med. Biol. 199: 199-223.

Qin, G., Ter Elst, E.R., Bosch, M.W., Van der Poel, A.F.B., 1996. Thermal processing of whole soya beans: Studies on the inactivation of antinutritional factors and effects on ileal digestibility in piglets. Anim. Feed Sci. Technol. 57: 313-324.

Rackis, J.J., Wolf, W.J. and Baker, E.C., 1986. Protease inhibitors in plant foods: content and inactivation. In: Advances in Experimental Medicine and Biology Series: M. Friedman (Editor), Plenum press, New York, pp. 299-347.

Van der Poel, A.F.B., Blonk, J., Van Zuilichem, D.J. and Van Oort, M.G., 1990. Thermal inactivation of lectins and trypsin inhibitor activity during steam processing of dry beans (Phaseolus vulgaris L.) and effects on protein quality. J. Sci. Food Agric. 53: 215-228.

Summary

Soybeans (*Glycine max*) have high nutritional value for domestic animals, due to their protein and energy contents. The feeding effects of full-fat soybeans for non-ruminant and immature ruminant animals, however, are limited by the presence of some antinutritional factors (ANFs). Therefore, processing is needed to inactivate these ANFs before the soybeans are used to feed animals. The nature and levels of ANFs may be quite variable between soybeans of different origin, and this can influence the effects of soybean processing. Thus, a similar processing procedure may result in different effects for different soybean origins.

It has been reported that there are differences in the digestive capacity between pig breeds. But, it was not clear whether the responses to soybean ANFs also differ between pig breeds or genotypes.

If soybeans of different origins respond differently to processing, and different pig breeds have different tolerances to dietary ANFs, it is of great importance to establish optimal processing procedures for a specific soybean origin and for a specific pig herd. The objectives of the present studies were to investigate the potential differences between soybean origins in response to heat processing, and the differences between pig breeds in response to dietary soybean treatments.

In Chapter 2, the literature on ANFs of different soybean and soybean products, and on the use of full-fat soybeans in pig diets is reviewed. It is shown that the ANFs (particularly trypsin inhibitor activity, TIA) vary greatly among different soybean origins and soybean products. Literature also shows that there exists a large variation among the physiological stages of pigs in tolerating dietary soybean ANFs. The ability to tolerate soybean ANFs increases with the age of animals. Pregnant sows can tolerate higher dietary levels of raw soybeans than lactating sows.

The weight and/or the size of digestive organs, and dietary nutrient digestibilities vary among breeds or genotypes of pigs according to the results from the literature (Chapter 3). For example, Chinese native pig breeds can tolerate higher levels of dietary fibre than Western pig breeds.

Argentine and Chinese commercial soybeans were used for the present studies. The TIA

for Argentine and Chinese soybeans were 15.2 and 20.6 mg/g, respectively. The two origins of soybeans were steam-heated under various conditions (temperature and time combinations). The heating effects on the two soybean origins were evaluated by both kinetic studies and animal trials. In kinetic studies (Chapter 4 and 5), the TIA and protein dispersibility index (PDI) of the soybeans from both Argentine and Chinese origin decreased in a logarithmic pattern with prolongation of heating time when they were heated at a given temperature. The TIA and PDI of the Chinese soybeans processed under various conditions, however, were higher than that of the Argentine soybeans processed under the same conditions.

In the digestion and balance trials, it was found that the digestibilities of dry matter (DM), crude protein (CP) and fat of the diet containing raw Chinese soybeans were lower than that containing raw Argentine soybeans (Chapter 7). The CP digestibility of the Chinese soybeans heated at 100 °C/40 min., 118 °C/5 min. and 136 °C/1.5 min. was also lower compared with the Argentine soybeans heated under the corresponding conditions (Chapter 6). The highest protein biological value (PBV) and net protein utilization (NPU) were obtained at the heating condition of 100 °C/40 min. for Argentine soybeans, and 136 °C/1.5 min. for Chinese soybeans. The CP digestibility and NPU of soybeans were correlated with their TIA ($R=-0.8118$; $P<0.05$).

Processing can also improve the fat digestibilities of soybeans (Chapter 6) and of the diet containing soybeans (Chapter 7). The effect of processing on the improvement of fat digestion, however, is different between Argentine and Chinese soybeans. A significant ($P<0.05$) interaction was found between soybean origin and processing condition (Chapter 6 and 7). In Chapter 7, the fat digestibility of the diet with raw Chinese soybeans was much lower than that of the diet with raw Argentine soybeans (50.9 vs 62.8%). After the soybeans of the two origins were processed at 118 °C/7.5 min. however, the fat digestibility of the Chinese soybean diet was much higher than for the Argentine soybean diet (74.4 vs 60.9%). In Chapter 6, the fat digestibility of soybeans determined by difference method showed that the optimal processing condition for improving fat digestion differs with soybean origin. The highest digestibility of fat for Argentine soybeans was found in those heated at 100 °C/40 min.; for Chinese soybeans in those heated at 136 °C/1.5 min..

Feeding raw soybean diets may cause pathological changes in some organs of piglets (Chapter 7). The extent of the pathological changes varied with the soybean origin. The pigs fed the diet with raw Chinese soybeans had a heavier small intestine while pancreas weight was decreased compared to those fed the diet with raw Argentine soybeans as measured as g per kg live-weight. The light and electron microscopy examinations showed that the intestinal mucosa is more severely damaged in animals fed raw Chinese soybean diet than for those fed raw Argentine soybeans.

The comparison made between different pig breeds (Landrace and Min pig) indicated that the digestibilities of dietary DM, CP and fat in Min pigs (a native pig breed in north-east China) were higher than in Landrace pigs. When the two breeds of pigs were fed on the diets containing soybeans of any origin, the small intestine of Landrace pigs, however, was longer and heavier than that of Min pigs. Histological examination also showed that the villi of the small intestinal mucosa of Landrace pigs were more seriously damaged by feeding the raw Chinese soybean diet compared with that of Min pigs.

It is concluded that the ANFs, at least TIA, in soybeans vary greatly among soybean origins; Chinese soybeans have higher levels of TIA and PDI than Argentine soybeans as studied in the present experiments. TIA and PDI decrease with longer duration of heating at a given temperature in both Argentine and Chinese soybeans. The residual level of TIA and PDI in the processed Chinese soybeans are higher than that of the Argentine soybeans processed under the same conditions (except at the extreme heating conditions). The best improvement of N and fat digestibilities and net protein utilization (NPU) is obtained at the heating condition of low temperature/long time (100 °C/40 min.) for Argentine soybeans and high temperature/short time (136 °C/1.5 min.) for Chinese soybeans. With respect to intestinal enlargement and histological examination, raw soybean diet can have a more deleterious influence on Landrace than on Min pigs. Thus, soybean heat processing is more important for the Landrace than for the Min pigs when the soybeans are to be used in the diets of these animals.

SAMENVATTING

Sojabonen (*Glycine max*) hebben een hoge voedingswaarde voor mensen en landbouwhuisdieren. Ze hebben een hoge waarde als bron voor aminozuren en zijn ook energierijk. Er zijn echter een aantal bezwaren aan het gebruik van volvette sojabonen in rantsoenen voor niet-herkauwers. Deze nadelen hebben te maken met de aanwezigheid van faktoren die een antinutritionele activiteit (ANF) hebben. Het is daarom nodig dat de ANF's in de bonen geïnactiveerd worden, voordat de sojabonen in het voer voor bovengenoemde dieren kunnen worden opgenomen. Uit de literatuur is gebleken dat de aard en niveau's van deze ANF's tussen sojabonen van verschillende herkomst erg kunnen variëren. Het is daarom te verwachten dat het effect van procestechnologie om ANF's onschadelijk te maken ook kan variëren, afhankelijk van de herkomst van de verschillende soja's. Dat betekent dus dat een bepaalde technologische behandeling afhankelijk van soja-herkomst, een verschillend effekt kan hebben.
Uit de literatuur blijkt dat de verteringscapaciteiten van varkens van verschillende rassen niet gelijk is. Dit betreft verschillen tussen chinese en westerse varkensrassen bij opname van een rantsoen met een hoog ruwe celstof aandeel. Vanuit deze gedachtengang is de hypothese geformuleerd dat de responses van jonge varkens van verschillende rassen op ANF's in soja niet gelijk zijn. Ook kan verondersteld worden dat ANF's in verschillende sojarassen verschillend zullen reageren op technologische behandelingen. De combinatie van soja's van verschillende herkomst met verschillende varkensrassen leidt er wellicht toe dat er een verschillend proces optimum is voor sojarassen, afhankelijk van het varkensras voor welke het bedoeld is.

De doelstellingen van het onderzoek in dit proefschrift waren dan ook:

* Bepalen van het effekt van technologische behandeling van soja van Argentijnse en Chinese herkomst.
* Bepalen van de reactie van Chinese Min varkens (een ras uit Noord-Oost China) en van Landras varkens op rauwe en behandelde bonen.

In Hoofdstuk 2 is de literatuur over ANF-gehalten in sojabonen en sojaprodukten van verschillende herkomst gereviewed. Verder is ook het gebruik van volvette sojabonen in de varkensvoeding bestudeerd. Uit de literatuur blijkt dat er tussen verschillende soja herkomsten een zeer groot verschil is in gehalte aan ANF's. Speciaal is dit het geval voor de trypsine inhibitor activiteit (TIA). De literatuur geeft ook aan dat er een grote variatie is in reactie van varkens op ANF's, afhankelijk van de fysiologische ontwikkeling van het dier. Het vermogen om ANF's te 'tolereren' neemt toe met de leeftijd. Verder is het ook zo dat drachtige zeugen hogere niveau's tolereren dan lacterende zeugen. Wellicht door het lagere voederniveau. In de literatuur worden verschillen tussen gewicht en/of afmeting van vooral de verteringsorganen tussen verschillende rassen of genotypen van varkens

gerapporteerd (Hoofdstuk 3). Chinese varkensrassen tolereren hogere niveau's aan ruwe celstof in het rantsoen dan westerse rassen.

In het huidige onderzoek werden Argentijnse en Chinese commerciële partijen sojabonen gebruikt. De TIA gehalten waren voor deze sojapartijen 15.2 en 20.6 mg/g, respectievelijk. Beide partijen werden blootgesteld aan hete stoom in verschillende combinaties van temperatuur en duur van behandeling. De effekten van deze hittebehandelingen op het TIA-gehalte werden geëvalueerd in zowel 'kinetische' studies als in dierproeven.
In de kinetische studies (Hoofdstuk 4 en 5) werden TIA en PDI (Protein Dispersibility Index) bestudeerd. Beide kenmerken (gehalten) namen bij zowel Argentijnse als Chinese sojabonen logaritmisch af met een toename in de duur van behandeling bij een gegeven temperatuur. De overblijvende niveau's van TIA en PDI van de Chinese sojabonen waren bij elke procesconditie steeds hoger dan van de Argentijnse sojabonen.

In de verteringsproeven en balansstudies werd gevonden dat de verteerbaarheden van droge stof, ruw eiwit en vet van een rantsoen met rauwe (onbehandelde) Chinese bonen lager waren dan van een rantsoen met rauwe Argentijnse bonen (Hoofdstuk 7). Ook bij de gelijk behandelde sojabonen was de ruw eiwit verteerbaarheid in een rantsoen met Chinese bonen die bij 100°C/40 min., 118°C/5 min. en 136°C/1,5 min. behandeld waren lager dan wanneer de bonen van Argentijnse herkomst waren (Hoofdstuk 6). De hoogste biologische waarde (PBV) en eiwitbenutting werd voor rantsoenen met Argentijnse bonen gevonden na behandeling bij 100°C/40 min. en voor de Chinese bonen na behandeling bij 136°C/1,5 min. Het was ook duidelijk dat eiwitverteerbaarheid negatief gecorreleerd was met TIA ($R = -0.8$; $P < 0.05$).

Technologisch behandelen kan ook vetverteerbaarheid van sojabonen beïnvloeden (Hoofdstuk 6) en van rantsoenen met sojabonen (Hoofdstuk 7). Het effekt bij Argentijnse en Chinese soja is echter niet gelijk. Er was duidelijk sprake van een interactie ($P < 0.05$) tussen oorsprong van de soja en technologische behandeling (Hoofdstuk 6 en 7). De schijnbare vertering van vet in een rantsoen met rauwe Chinese soja was veel lager (50.9%) dan van een rantsoen met rauwe Argentijnse bonen (62.8%). Na behandeling bij 118°C/7,5 min. was het effect omgekeerd. Vetverteerbaarheid was nu 74.7% voor het rantsoen met Chinese bonen en 60.9% voor het rantsoen met Argentijnse bonen. Deze resultaten laten duidelijk zien dat voor deze twee soja herkomsten en wellicht ook voor andere soja herkomsten verschillende optimale procescondities nodig zijn. In onze studie was dit 100°C/40 min. voor Argentijnse sojabonen en 136°C/1,5 min voor Chinese sojabonen.

Het voeren van rauwe sojabonen kan pathologische veranderingen teweeg brengen in sommige organen van biggen (Hoofdstuk 7). De mate van veranderingen varieerde echter met de herkomst van de soja in het rantsoen. Varkens gevoerd met rauwe Chinese soja

hadden een zwaardere dunne darm (g/kg lichaamsgewicht), terwijl de pancreas verkleind was vergeleken met de varkens die rauwe Argentijnse soja aten. Microscopisch onderzoek toonde aan dat de mucose ook meer beschadigd was bij de dieren die rauwe Chinese bonen aten. De vergelijking tussen de varkensrassen (Landras en Min) laat zien dat de verteerbaarheden voor droge stof, eiwit en vet bij Min varkens (lokaal ras in Noord-Oost China) hoger was dan bij Landras varkens.
De dunne darm bij Landras varkens was steeds langer en zwaarder dan die van Min varkens op elk soja rantsoen. Voor varkens zonder soja was er geen verschil tussen de rassen. Histologisch onderzoek toonde aan dat de villi van de dunne darm mucosa van Landras varkens meer beschadigd waren dan die van Min varkens. Dit was het geval speciaal bij het voeren van rauwe Chinese bonen.

Uit het onderzoek werd geconcludeerd dat ANF's, althans tenminste de TIA, erg varieert tussen sojabonen van verschillende herkomst. Bij de in dit onderzoek gebruikte bonen waren de TIA en PDI niveau's hoger bij de Chinese sojabonen dan bij de Argentijnse sojabonen. Door technologische behandeling nemen zowel TIA als PDI af. Bij elke temperatuur is de afname groter naarmate de duur van de behandeling langer is.

- Na behandeling bij dezelfde condities waren de restwaarden aan TIA en PDI steeds hoger bij Chinese sojabonen dan bij Argentijnse bonen, behalve na behandeling bij de hoogste temperatuur.
- De beste verbetering van verteerbaarheid van N en vet en ook de hoogste netto eiwitbenutting (NPU) werd gevonden na behandeling bij 100°C/40 min. voor Argentijnse bonen en na behandeling bij 136°C/1,5 min. voor Chinese bonen.
- Er kan ook geconcludeerd worden dat de reactie van het maagdarmkanaal (vergroting en beschadiging) bij Landras varkens veel duidelijker was dan bij de Chinese Min varkens. Dit kan uitgelegd worden als een grotere gevoeligheid van Landras varkens in vergelijking met Chinese Min varkens voor faktoren die in soja aanwezig zijn.
- Daarom kan ook geconcludeerd worden dat voeders voor Landras varkens een beter behandelde sojaboon moet bevatten dan voeders voor Chinese Min varkens.

不同來源大豆的加工處理

___ 不同猪種對大豆飼糧的反應

秦貴信

大豆 （Glycine max）含有豐富的蛋白質和較高能值，對家畜具有很高的營養價值。但是，由于一些抗營養因子（ＡＮＦｓ）的存在，全脂大豆對非反芻動物和未成年反芻動物的飼喂價值受到了限制。因此，大豆在飼用前必需進行加工處理以滅活這些ＡＮＦｓ。在不同來源的大豆間，這些ＡＮＦｓ的特性和含量變化很大，這會影響大豆的加工效果。同樣的加工處理對不同來源的大豆具有不同的效果。

不同猪種間在消化能力上存在着差异。但不同猪種對大豆ＡＮＦｓ的反應是否也有差异尚不清楚。

如果不同來源的大豆對加工處理的反應不同，并且不同猪種對飼糧中的大豆ＡＮＦｓ耐受能力不同，那麽，針對不同大豆和不同猪群建立特定的最優加工處理工藝具有重要意義。本研究的目的在于探討不同來源大豆在對熱處理反應方面可能存在的差异以及不同猪種對飼糧中大豆ＡＮＦｓ反應方面的差异。

在第二章，對有關不同大豆和大豆產品的ＡＮＦｓ，以及全脂大豆在猪飼糧中應用的文獻進行了綜述。從文獻報道結果看，ＡＮＦｓ（主要是胰蛋白酶抑制因子，ＴＩＡ）在不同來源的大豆及大豆產品間差异很大。文獻也表明猪在不同生理階段對飼糧中大豆ＡＮＦｓ的耐受力有明顯不同。其耐受力隨年齡增長而提高。妊娠母猪比哺乳母猪有較高的耐受力。

根據文獻介紹，不同猪種在消化器官的重量和大小以及對飼糧養分消化率方面有明顯不同。與西方猪種相比，中國地方猪種能承受較高的飼糧粗纖維。

本項研究，通過動力學試驗和動物試驗探討了蒸氣熱處理對不同來源大豆（阿根廷和中國商品大豆,兩者的ＴＩＡ值分別爲 15.2 和 20.6 mg/g）的加工效果。動力學試驗表明，阿根廷和中國大豆中胰蛋白酶抑制因子（ＴＩＡ）及蛋白質擴散系數（ＰＤＩ）均隨加熱時間的延長呈對數曲綫規律降低。在相同加熱條件下中國大豆的ＴＩＡ和ＰＤＩ值比阿根廷大豆高。

在消化試驗和氮平衡試驗中發現中國生大豆飼糧的幹物質、粗蛋白及脂肪消化率均比阿根廷大豆低（第七章）。在１００度－４０分鐘、１１８度－５分鐘和１３６度－１.５分鐘條件下處理的中國大豆其蛋白質消化率也比相應條件下處理的阿根廷大豆低（第六章）。從蛋白質生物學效價和蛋白質净利用率的測定結果看，阿根廷大豆的最佳處理條件是１００度－４０分鐘，中國大豆的最佳處理條件是１３６度－１.５分鐘。

加工處理也能提高大豆飼糧的脂肪消化率（第七章）。然而，對于不同的大豆情况有所不同。在第七章，中國生大豆飼糧的脂肪消化率比阿根廷生大豆飼糧低得多（５０.９比６２.８％）。在第六章，用“差别”法測定了大豆脂肪的消化率。從脂肪消化率提高的幅度看，不同來源的大豆對加工處理條件的要求有所不同。對阿根廷大豆和中國大豆脂肪消化率提高幅度最大的加熱條件分别爲１００度－４０分鐘和１３６度－１.５分鐘。

飼喂生大豆飼糧可導致仔猪某些器官的病理變化。但不同大豆引起的病理變化程度不同。與阿根廷生大豆飼糧相比，喂中國生大豆飼糧仔猪的小腸較重，胰臟較輕。光鏡和電鏡觀察結果也表明喂中國生大豆飼糧仔猪小腸粘膜損傷較嚴重。

本研究結果還表明不同猪種的消化能力有所不同。中國民猪對飼糧幹物質、粗蛋白質、及脂肪消化率比蘭德瑞斯猪高。蘭德瑞斯猪的小腸重量和長度受飼糧大豆的影響大。組織學觀察表明，喂生大豆飼糧的蘭德瑞斯猪的小腸粘膜比喂同樣飼糧的中國民猪損傷嚴重。

根據本研究的結果可以得出以下結論：ＡＮＦｓ的活性或含量在不同來源的大豆之間變化很大。從本研究所用的原料來看，中國生大豆和加熱處理大豆的ＴＩＡ和ＰＤＩ均比相應的阿根廷大豆高。從蛋白質和

脂肪的消化率及蛋白質凈利用率方面看，阿根廷大豆的最佳加工條件是低温長時間（１００度－４０分鐘），中國大豆的最佳加工條件是高温短時間 （１３６－１.５分鐘）。根據器官的病理變化和組織學觀察，生大豆飼糧對蘭德瑞斯猪的不良影響比對中國民猪大。由此可見，大豆的加工處理對蘭德瑞斯猪比對中國民猪更重要。

Publication list

Digestibility of dietary nutrients in different pig breeds and their cross-breeds.
Qin, G.X. and Cui, B.H. 1983, Chinese Journal of Animal Science. (1983), No. 6.

Nutritional values of corn gluten for pigs.
Qin, G.X., Gao, Z.Q. and Chen, P., 1988, Journal of Jilin Agricultural University. 10 (1).

Using corn distiller's dried grains as dietary protein source for growing pigs.
Chen, P., Gao, Z.Q., Qin, G.X., and Wang, Y., 1988, Swine Production. 7 (2).

A feeding experiment: substitution soybean meal with corn gluten in the diet for fattening pigs.
Gao, Z.Q., Qin, G.X. and Chen, P., 1989, Journal of Jilin Agricultural University. 11 (1).

Influence of pig breed and dietary type on the digestibility of dietary nutrients.
Qin, G.X., Chen, P. and Gao, Z.Q., 1989, Swine Production. 12 (3).

The feeding value of corn distiller's dried grains for hens.
Qin, G.X., Chen, P. and Gao, Z.Q., 1990, Chinese Feedstuffs. 4.

A sample facilities for drying corn distiller grains.
Hou, J.L., Qin, G.X. and Sun, H., 1990, Journal of Jilin Agricultural University. 12 (4).

Effects of feeds on the quality of animal products.
Qin, G.X., 1990, In: Hu, J. (Editor), Animal Feeding. Jilin Sci. Technol. Press, Changchun. 218-225.

Animal nutritional requirement.
Qin, G.X., 1990, In: Hu, J. (Editor), Animal Feeding. Jilin Sci. Technol. Press, Changchun. 229-251.

A study on feeding Beijing ducks with corn gluten and corn distiller grains.
Lou, Y.J., Gao, Z.Q., Chen, P. and Qin, G.X., 1991, Feedstuff Research. 115: 5.

A study on feeding laying hens with corn gluten.
Qin, G.X., Gao, Z.Q. and Chen, P., 1992, Chinese Feedstuffs. 1992 (1): 33.

Effect of several plant materials on york colour.
Qin, G.X., Jiang, Y.L., Zhang, X.F., 1992, Proceedings of 19th World Poultry Congress, Amsterdam, The Netherlands, 20-24th September, 1992. pp. 665

Effect of extrusion on the digestibility of rice hulls in pigs.
Qin, G.X., Chen, P. and Gao, Z.Q., 1993, Chinese Feedstuffs. 32.

Differences between pig breeds (or lines) in digestive ability.
Qin, G.X. and Chen, P., 1994, Swine Production. 30.

Effect of dietary protein source on feed intake, growth, pancreatic enzyme activities and jejunal morphology in newly weaned piglets.
Makkink, C.A., Negulescu, G.P. and Qin, G.X., 1994, British Journal of Nutrition. 72: 353-368.

Study on utilization of by-product feedstuffs in the diets of fattening pigs and laying hens.
Gao, Z.Q., Chen, P. and Qin, G.X., 1994, Jilin Animal Husbandry and Veterinary medicine. 16 (88).

The effect of chili powder and vegetable oil on the performance and fat deposition in broilers.
Tian, H., Xiao, Z.D., Qin, G.X. and Zhang, X.F., 1994, Journal of Jilin Agricultural University. 16 (3).

The influence of heat treatment on the feeding effect of different genotype soybeans in chickens.
Lou, Y.J., Qin, G.X., E, Z.J., Jiang, H.Z. and Wang, L.M., 1995, Proceedings of the 2nd National Symposium on Feed Science and Nutrition. May, 1995, Zhengzhou.

The effect of dietary nitrogen source on the nitrogen utilization in sheep.
Yang, L.Y, Gao, Z.Q., Qin, G.X., and Deng, B., 1995, Proceedings of the 2nd National Symposium on Feed Science and Nutrition. May, 1995, Zhengzhou.

Soybean antinutritional factors: the variation of activities and responses of pigs to full-fat soybeans.
Qin, G.X. and Chen P., 1995, Presented in the Fourth Congress of Pig Production in North-east of China. November, 1995, Changchun.

Influence of heat treatment on the protein degradation of full-fat soybeans in the rumen of sheep.

Wang, B.D., Yang, L.Y. and Qin, G.X., 1995, Journal of Jilin Agricultural University. 17 (Suppl.).

Variation of digestive capacity between genetically different pig populations: a review

Qin, G.X., Verstegen, M.W.A. and Bosch, M.W., 1995, Journal of Animal Physiology and Animal Nutrition. 73: 233-242.

Effects of Sabtamol on the carcass quality of broilers.

Gong, Q., Qin, G.X., Feng, X.S. and Gao, S.H., 1996, Journal of Jilin Agricultural University. 18 (1).

Decomposition of different dietary protein source in stomach of weaned piglets and influence on their gut.

Qin, G.X. and Chen, P., 1996, Swine Production. 38.

Thermal processing of whole soya beans: Study on the inactivation of antinutritional factors and effects on ileal digestibility in piglets.

Qin, G., Ter Elst, E.R., Bosch, M.W., and Van der Poel, A.F.B., 1996, Animal Feed Science Technology. 57: 313-324.

Acknowledgments

I would like to express my sincere thanks to my supervisors, Professor M.W.A. Verstegen, Dr. A.F.B. van der Poel, Professor N. Ma, and Associate Professor P. Chen, for their helpful guidance.

To this project, a great contribution was made by Dr. M.W. Bosch, Ing. P.L. van der Togt, Ing. T. Zandstra, Dr. H. Boer, Dr. B.A. Willianms, J-M. Muijlaert, M.H. Booij, T. Post, M. van't End, at the Department of Animal Nutrition, Wageningen Agricultural University, and L.M. Xu, W.M. Ruan, H.L. Jiang, Y.J. Lou, B.D. Wang, Y. Liang, S.C. Zhao, H.Z. Jiang, L.M. Wang, at the Department of Animal Science, Jilin Agricultural University, P.R. China. I would like to acknowledge, with thanks, all of them.

I also thank my wife, Lianhua, and my son, Junling for their support and encouragement which kept my spirits high.

Curriculum Vitae

Guixin Qin was born in Shandong province, People's Republic of China on December 24th, 1956. After a 4 years study at the Department of Animal Science, Jilin Agricultural University, he obtained a Bachelor's Degree in the field of animal production of agricultural science in 1982. Then he worked as an assistant teacher in this university. During his work, he completed his MSc study in the same university in 1989. He got a scholarship from the Agricultural Ministry of China in 1991, which supported his study in the Department of Animal Nutrition, Wageningen Agricultural University, The Netherlands, from 1991 to 1992. He started his PhD study in 1993 in the Department of Animal Nutrition, Wageningen Agricultural University.

Guixin Qin is working as the Director of Teaching Affair Section of the Jilin University, Changchun, PR China.