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Effect of nutrient density, NSP source, coarseness of NSP and feed form on performance and behaviour of hens at early lay




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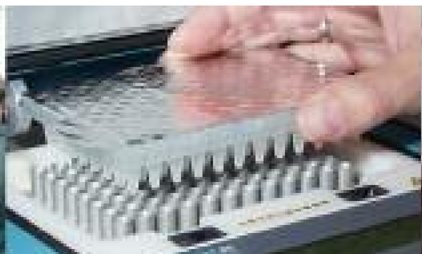

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Abstract
An experiment was conducted to measure the effect of energy dilution and feed structure on performance and behaviour of hens at the beginning of the laying period.
From this experiment we can conclude that feeding low-NSP or high-NSP diets resulted in equal or even improved egg performance of hens at early lay compared with hens that were fed standard diet. Feeding coarse ground meal negatively affects egg production, egg weight, egg mass and body weight, whereas feed form did not affect egg performance. Hens that were fed NSP-high diets spend more time on feed intake during some observations, and had heavier relative gizzard weight and content.

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Samenvatting

Inleiding
De traditionele batterijkooi zal binnen de Europese Unie uiterlijk vanaf 2012 volledig verboden zijn. Een ernstig probleem van alternatieve huisvestingssystemen in vergelijking met batterijkooien is echter een hogere incidentie van verenpikken en kannibalisme (Morgenstern, 1995). In de biologische legpluimveehouderij komen zelfs sterftepercentages van 30% voor als gevolg van kannibalisme (Van der Wouw, 1995). Op dit moment wordt snavelkappen gezien als de belangrijkste maatregel om verenpikken en kannibalisme te voorkomen, maar vanaf 2011 zal er in Nederland een algemeen verbod op snavelkappen van kracht zijn. Juist de combinatie van alternatieve huisvestingssystemen en de afwezigheid van snavelkappen vormt een groot risico voor verenpikken en kannibalisme. De problematiek van verenpikkerij en kannibalisme is voor de legpluimveehouders die hun leghennen nog huisvesten in batterijkooien op dit moment een belangrijke beperking voor omschakeling naar alternatieve huisvestingssystemen.

Het probleem van verenpikkerij en kannibalisme is multifactorieel. Als belangrijke oorzaken hiervoor gelden diereigen factoren, zoals erfelijke aanleg, hormonale status (onvolwassenversus volwassen dieren), mate van angst en sociale factoren, maar ook omgevingsfactoren zoals huisvestingsomstandigheden en voedingsfactoren (Blokhuis, 1989). Het bestrijden van verenpikken vraagt dan ook om een geïntegreerde benadering waarbij rekening wordt gehouden met diverse factoren. Uit een onlangs gepubliceerd literatuuronderzoek [Krimpen, 2005 #332] blijkt dat voedingsfactoren bij kunnen dragen aan het reduceren van de mate van verenpikken en kannibalisme. Een perspectiefvolle benadering lijkt het stimuleren van de tijd die leghennen besteden aan voeropname gerelateerd gedrag, zoals foerageren (het zoeken naar mogelijke voedselbronnen) en voeropname, en het stimuleren van de mate van verzadiging van leghennen. Beide zaken kunnen gestimuleerd worden door verstrekking van energiearme voeders (Lee *et al.*, 2001), of van voeders die rijk zijn aan niet-oplosbare NSP (Non Starch Polysaccharides) (Bearse *et al.*, 1940; Hetland *et al.*, 2002, 2003). Ook de maalfijnheid van de NSP-fractie lijkt van invloed te zijn op de mate van verenpikken. Er zijn aanwijzingen dat een grof gemalen NSP-fractie resulteert in minder verenpikken (Hetland *et al.*, 2002, 2003). Daarnaast zijn positieve resultaten bereikt met het verstrekken van ruwvoer (Steenfeldt *et al.*, 2001). Op dit moment is echter onduidelijk wat de ranking is van bovengenoemde voedingsfactoren of combinatie van factoren in relatie tot het reduceren van verenpikken en wat het werkingsmechanisme ervan is.
We veronderstellen dat hennen die voer met een lagere nutriëntendichtheid krijgen, meer voer gaan opnemen en uiteindelijk een gelijke energieopname realiseren als hennen die een controlevoer met een gangbare nutriëntendichtheid krijgen. Het is echter de vraag of de opnamecapaciteit van de hennen aan het begin van de legperiode voldoende groot is om het verschil in nutriëntendichtheid in het voer te kunnen compenseren, zeker als dit voer ook nog eens een hoog aandeel grof gemalen niet-water oplosbare NSP bevat. Daarnaast is op dit moment nog onvoldoende bekend of de mate van compensatie grondstofafhankelijk is. Onvoldoende compensatie leidt tot een te lage nutriëntenopname, waardoor de dierprestaties afnemen. Bovendien besteden de hennen dan minder tijd aan voeropname, waardoor de positieve effecten op gedrag niet tot uiting komen. Om hierin meer inzicht te krijgen is in opdracht van het Productschap Diervoeder en het Productschap Pluimvee en Eieren een experiment uitgevoerd met hennen aan het begin van de legperiode.

Doel
Het doel van dit experiment was om het effect te meten van nutriëntendichtheid, NSP-gehalte, maalfijnheid van de NSP-fractie en voervorm op de voeropname en de mate van voergericht gedrag van leghennen tijdens de eerste 8 weken van de legperiode.

Materiaal
Er werd gebruik gemaakt van twee identieke afdelingen die elk 24 grondkooien bevatten met afmetingen van 0,90 x 1,50 m. Na aftrek van de oppervlakte van de voertrog (1,0 x 0,2 m) bleef er 1,15 m^2 netto leefoppervlak over. Voor elke grondkooi was een legnest geplaatst. De bodem was ingestrooid met zand. De hennen hadden onbeperkt water en voer ter beschikking. In totaal werden 480 licht getoucheerde ISA Brown hennen ingezet, verdeeld over 48 grondkooien (twaalf behandelingen met vier herhalingen per behandeling). De hennen waren gehuisvest volgens de gangbare oppervlaktenorm voor scharrelkippen (negen hennen/m^2). Ter beheersing van de lichtintensiteit waren de ramen in de afdelingen geblindeerd, zodat geen buitenlicht kon binnendringen. Bij aankomst van de hennen (week 17) kregen de dieren 10 uur licht per dag, oplopend tot 16 uur licht per dag (week 23). De lichtintensiteit werd geleidelijk opgevoerd van 20 lux in week 18 tot 50 lux in week 21.

Behandelingen
In het experiment zijn de volgende 12 behandelingen onderzocht.

Nr.	Behandeling	Verdunning (%)	NSP Klasse	Niveau van oplosbaar NSP	Deeltjesgrootte NSP-fractie	Voervorm
1	Negatieve Controle – M.	0	Gangbaar	Laag	Fijn	Meel
2	Negatieve Controle – Kr.	0	Gangbaar	Laag	Fijn	Kruimel
3	Zand – M.	10	Laag	Laag	Fijn	Meel
4	Zand – Kr.	10	Laag	Laag	Fijn	Kruimel
5	Grit	10	Laag	Laag	Grof	Meel
6	Haverdoppen fijn	10	Hoog	Laag	Fijn	Meel
7	Haverdoppen grof	10	Hoog	Laag	Grof	Meel
8	Bietenpulp	10	Hoog	Hoog	Grof	Meel
9	Arbocell	10	Hoog	Hoog	Grof	Meel
10	Sojahullen	10	Hoog	Hoog	Grof	Meel
11	Stro	10	Hoog	Hoog	Grof	Meel
12	Positieve controle	5	Hoog	Hoog	Fijn	Meel

In dit onderzoek werden verdunde voeders vergeleken met een onverdund controlevoer dat voldeed aan de normen van een gangbaar legvoer (11,8 MJ/kg, 6,7 g dvlysine/kg). De voeders 3 tot en met 11 waren allemaal 10% verdund. Bij de voeders 3 - 5 werd gebruik gemaakt van verdunningsmateriaal dat geen NSP bevatte (zand, maagkiezel), terwijl de voeders 6 - 11 verdund werden met NSP-rijke grondstoffen. Van enkele behandelingen is zowel een meelvorm als een kruimelvorm meegenomen. Meel is de gangbare praktijk, maar het doel van de kruimels was o.a. om na te gaan wat het effect is van voervorm op voeropnametijd. Anderzijds werd hierdoor voorkomen dat er ongewenste voerselectie optrad, waarbij de hennen het zand niet of onvoldoende opnamen, waardoor het effect van nutriëntverdunning verloren gaat.
De gekozen NSP-bronnen varieerden in samenstelling. Haverdoppen bevatten een hoog aandeel lignine. Bietenpulp bevat veel pectine; sojahullen en arbocell veel cellulose. Op basis van de uitgevoerde chemische analyses bleek dat van de NSP-rijke voeders alleen die met haverdoppen een vergelijkbaar gehalte aan water-oplosbare NSP bevatten als de voeders met een laag NSP-niveau. Verwacht werd dat dit ook voor de voerders met arbocell, sojahullen en stro zou gelden, maar dit was niet het geval.
De voeders zijn geoptimaliseerd volgens de behoefte van jonge leghennen en verstrekt aan de hennen in de leeftijd van 18 – 25 weken. T.o.v. de negatieve controle had de positieve controle een 5% lager energieniveau en een ruim 20% hoger NSP-gehalte. In dit voer waren zonnebloemzaadschilfers de belangrijkste NSP-bron.
Uiteindelijk konden de twaalf behandelingen geclusterd worden tot zes hoofdfactoren: 1) controleniveau (meelvoer, gangbaar energiegehalte, laag NSP, fijngemalen voer), 2) effect van laag NSP-niveau, 3) effect van hoog NSP-niveau, 4) effect van kruimel, 5) effect van grof malen en 6) effect van oplosbaarheid van NSP.

Waarnemingen
De voeders zijn chemisch geanalyseerd. Ook is de deeltjesgrootteverdeling bepaald. Wekelijks werden het voerverbruik en de eiproductiegegevens verzameld. De gewichten van de hennen, de kwaliteit van het verenkleed en de voeropnametijd zijn bepaald in week 1, 4 en 8.
Aan het eind van het experiment is bij vier hennen per hok het gewicht en de inhoud van de spiermaag bepaald.

Statistische verwerking
Wekelijks verzamelden we de technische resultaten van de hennen, zodat er sprake was van herhaalde waarnemingen (longitudinale data). Deze resultaten bleken ofwel een exponentieel of een logistisch (S-curvig) verloop te hebben. Dit verloop is gemodelleerd met behulp van een REML-procedure en een non-lineaire parameterschatting. Vervolgens is de Base-Level methode gebruikt om na te gaan of de geschatte modelparameters van de verschillende hoofdfactoren (NSP-laag, NSP-hoog, kruimel, grof malen, oplosbaarheid van NSP) afweken van die van de controlegroep.

Resultaten
De belangrijkste resultaten van dit experiment zijn:
- Leghennen zijn aan het begin van de legperiode goed in staat te compenseren voor voeders, die 10% verdund zijn met NSP-vrije of NSP-rijke grondstoffen, door respectievelijk een 10,5% en 8,0% hogere voeropname (zie figuur 2). De vorm (meel versus kruimel) en de maalfijnheid van het voer hebben geen invloed op de voeropname.

- De hennen die NSP-laag of NSP-hoog voer kregen bereikten eerder hun maximale eiproductie dan de hennen die controlevoer kregen, zodat ze tijdens de proefperiode meer eieren produceerden. Het grof malen van het voer tendeert naar een lager legpercentage, terwijl de vorm van het voer geen invloed heeft op het legpercentage.
- Het startgewicht van de eieren van de hennen die grof gemalen voer kregen was lager dan die van de controlegroep. De toename in eigewicht was lager bij de behandelingen met NSP-hoog en grof gemalen voer.
- Hennen die NSP-laag en NSP-hoog voer kregen produceerden meer eimassa, terwijl hennen die grof gemalen meel kregen juist minder eimassa produceerden dan de controlegroep. De hoeveelheid eimassa werd niet beïnvloed door de vorm van het voer.
- Hennen die NSP-hoog voer kregen hadden een hoger lichaamsgewicht dan de controlegroep, terwijl hennen die grof gemalen voer kregen juist een lager lichaamsgewicht hadden.
- Het verstrekken van voer met veel niet-wateroplosbare NSP's verhoogt het gewicht van zowel de volle als lege spiermaag en van de inhoud van de spiermaag. Het verstrekken van grof gemalen voer verhoogt eveneens het gewicht van de volle en lege spiermaag.
- De tijd die hennen op het controlevoer aan voeropname besteedden nam toe in de loop van de proefperiode van 16,4% in week 4 tot 24,6% in week 9. Het verstrekken van NSP-hoog voer verhoogde de eettijd met 22%, terwijl de andere factoren (NSP-laag, voervorm, maalfijnheid) geen effect hadden op de voeropnametijd.

Toepassing voor de Praktijkonderzoek
Op basis van de resultaten van dit kortlopende onderzoek kunnen we vaststellen dat het verstrekken van NSP-laag of NSP-hoog voer aan hennen in het begin van de legperiode resulteert in vergelijkbare of zelfs verbeterde dierprestaties tijdens de eerste 8 weken van de legperiode in vergelijking met de controlegroep. Het grof malen van het voer vermindert de technische resultaten, terwijl de voervorm hierop geen effect heeft. Hoewel verenpikken zich niet voordeed in dit experiment zijn er toch indicaties dat voer met een hoog gehalte aan niet-wateroplosbare NSP's gunstig kan werken tegen verenpikken. Dieren die dergelijk voer kregen besteedden meer tijd aan voeropname en hadden een hoger spiermaaggewicht (vol en leeg) en spiermaaginhoud. Verhoging van de voeropnametijd en gewicht van de spiermaag zijn beide indicatoren voor meer voeropnamegericht gedrag en een hoger verzadigingsniveau van de hennen. Deze factoren zijn weer gunstig voor het voorkomen van verenpikgedrag. Uit een uit te voeren tweede studie, met een langere looptijd, moet blijken of deze effecten herhaalbaar zijn.

Summary

In 2012, changes in EU-legislation with regard to animal welfare and husbandry will be implemented that might increase the level of feather pecking in layers. These changes include a ban on traditional battery cages as the current housing system for layers in Western Europe. This stresses the need to develop alternative housing systems for layers, such as furnished cages, free range systems, or aviary systems. These systems, however, show much higher incidences of feather pecking and cannibalism compared to cage systems. The most effective tool to prevent feather pecking and subsequent cannibalism is beak trimming, but in some West-European countries (e.g. Great Britain and The Netherlands) a general ban on beak trimming can be expected in the near future too. The bans on battery cages and beak trimming increase the risk of feather pecking and cannibalism.

Feather pecking in layers is a multi factorial problem, which can be caused by environmental, genetic or nutritional factors. From the literature it has been shown that nutritional factors may positively or negatively affect feather pecking behaviour in laying hens. Nutritional factors seem to reduce feather pecking behaviour in laying hens if these factors increase the time spent on feeding behaviour, by affecting foraging and feed intake. Laying hens may spend more time on these feeding behaviours when they are fed 1) mash diets in stead of crumbles or pellets, 2) low energy diets, 3) high (in-)soluble fibre diets or 4) roughages. However, such feeding strategies may not reduce egg performance of the hens, which can be the case when hens are not able to fully compensate for the dilution. Especially hens at early lay can have problems with consuming sufficient feed for maintenance and egg production.
Therefore, by order of the Product Board Animal Feed and the Product Board Poultry & Eggs an experiment was conducted to measure the effect of energy dilution and feed structure on performance and behaviour of hens at the beginning of the laying period.

In this experiment, 12 experimental diets varying in level of dilution, NSP content, solubility of NSP, particle size of NSP, and feed form, were tested.

Overview of the different treatments and their characteristics

	Additive	Dilution (%)	NSP Class	Level of soluble NSP	Particle size of NSP-fraction	Feed form
1	Negative Control – Mash	0	Intermediate	Low	Fine	Mash
2	Negative Control – Crumble	0	Intermediate	Low	Fine	Crumble
3	Sand – Mash	10	Low	Low	Fine	Mash
4	Sand – Crumble	10	Low	Low	Fine	Crumble
5	Grit	10	Low	Low	Coarse	Mash
6	Oat hulls (fine)	10	High	Low	Fine	Mash
7	Oat hulls (coarse)	10	High	Low	Coarse	Mash
8	Beet pulp	10	High	High	Coarse	Mash
9	Arbocell	10	High	High	Coarse	Mash
10	Soya hulls	10	High	High	Coarse	Mash
11	Straw	10	High	High	Coarse	Mash
12	Positive Control	5	High	High	Fine	Mash

Hens were housed in ground pens (10 hens per pen) and pen was the experimental unit. In total 480 hens, divided over 48 pens (4 replicates per diet, were involved in the experiment.

The most important conclusions of this experiment are:

- Laying hens at early lay that were fed NSP-low or NSP-high diets were able to compensate for 10% dietary dilution by a 10.5 and 8.0% higher feed intake, respectively. Feed intake of the soluble NSP diluted diets increased with 6.4%. Feeding crumble or coarsely ground mash did not affect feed intake.
- As a result of the higher rate of increase of hen-day egg production, hens that were fed low-NSP or high-NSP diets on average produced more eggs during this experiment, whereas coarse grinding of the diets tends to a lower egg production. Feed form has no effect on hen-day egg production.
- Coarse grinding of the diets negatively affects initial egg weight, whereas the rate of increase of egg weight decreases when the hens are fed NSP-high or coarse ground diets.
- Egg mass enhances by feeding NSP-low, and both soluble and insoluble NSP-high diets, and decreases by feeding coarse ground meal. Egg mass was not affected by feed form.
- Mean bodyweight of hens that were fed (in-) soluble NSP-high diets is higher than the control, whereas feeding of coarse ground meal reduces mean bodyweight.

- Feeding insoluble NSP-high diets increases full and empty gizzard weight and gizzard content. Coarsely ground diets increases full and empty gizzard weight.
- Eating time of the hens fed the undiluted diets increased over the experimental period from 16.4 to 24.6%, but was not affected by sand or grit addition, particle size distribution or feed form. Feeding NSP-high diets increased eating time with 22%, although eating time of the hens that were fed soluble NSP-high diets over week 7 and 9 was comparable with the undiluted diets.

Practical implications

Based on the literature, feeding diets diluted with NSP-free or NSP-high raw materials were expected to reduce feather pecking behaviour in laying hens. The hens should compensate for dietary dilution by higher feed intake, resulting in a higher proportion of time spend on feed intake, by which less time will remain for feather pecking. However, such feeding strategies may not reduce egg performance of the hens, which can be the case when hens are not able to fully compensate for the dilution.

From this experiment we can conclude that feeding low-NSP or high-NSP diets resulted in equal or even improved egg performance of hens at early lay compared with hens that were fed a standard diet. Feeding coarsely ground meal negatively affects egg production, egg weight, egg mass and body weight, whereas feed form did not affect egg performance. Although feather pecking behaviour in this experiment not occurred, some results of this study are indicating that insoluble NSP-rich diets can have anti feather pecking properties. Hens that were fed these diets spent more time on feed intake and had heavier relative gizzard weight and content. Increased eating time and gizzard weight are both indicators for more feed related behaviour and/or a higher satiety level of the hens, which can prevent feather pecking behaviour.

Content

1 Introduction

In 2012, changes in EU-legislation with regard to animal welfare and husbandry will be implemented that might increase the level of feather pecking in layers. These changes include a ban on traditional battery cages as the current housing system for layers in Western Europe. This ban is the result of a societal debate from which the conclusion was drawn that battery cages could not fulfil the birds' need to express their natural behaviour. This stresses the need to develop alternative housing systems for layers, such as furnished cages, free range systems, or aviary systems. These systems, however, show much higher incidences of feather pecking and cannibalism compared to cage systems (Morgenstern, 1995, Mollenhorst, 2005). Feather pecking, especially the severe type, negatively affects the welfare of laying hens (Blokhuis and Wiepkema, 1998). Moreover, feather pecking causes feather loss of pecked birds resulting in higher feed intake, worse feed conversion ratio, and as a consequence higher feed costs (Tauson and Svensson, 1980; Herremans *et al.*, 1989; Peguri and Coon, 1993). In deep litter systems and organic farming, mortalities of even up to 30%, as a result of feather pecking and cannibalism, have been reported (Morgenstern, 1995, Mollenhorst, 2005). The most effective tool to prevent feather pecking and subsequent cannibalism is beak trimming, but in some West-European countries (e.g. Great Britain and The Netherlands) a general ban on beak trimming can be expected in the near future too. The bans on battery cages and beak trimming increase the risk of feather pecking and cannibalism.
Feather pecking in layers is a multi factorial problem, which can be caused by environmental, genetic or nutritional factors (Blokhuis, 1989). From the literature it has been shown that nutritional factors may positively or negatively affect feather pecking behaviour in laying hens (Krimpen *et al.*, 2005). Some investigations, indeed, show that feather pecking behaviour is a substitute for normal feeding behaviour (Hoffmeyer, 1969, Blokhuis, 1989). Until now, the mode of action of these nutritional factors is not fully understood. Dietary deficiencies, resulting in a marginal supply of nutrients, such as protein (Ambrosen and Petersen, 1997), amino acids (Al Bustany and Elwinger, 1987a, Al Bustany and Elwinger, 1987b, Elwinger *et al.*, 2002), or minerals (Schaible *et al.*, 1947, Hughes and Whitehead, 1979), may increase feather pecking behaviour and cannibalism. Nutritional factors seem to reduce feather pecking behaviour in laying hens if these factors increase the time spent on feeding behaviour, by affecting foraging and feed intake. Laying hens may spend more time on these feeding behaviours when they are fed 1) mash diets in stead of crumbles or pellets, 2) low energy diets, 3) high (in-)soluble Non Starch Polysaccharides (NSP) diets or 4) roughages (Krimpen *et al.*, 2005). The particle size of NSP-high raw materials also seems to affect feather pecking behaviour. In the current experiment we will focus on low energy and NSP-high diets, also called low-nutrient density diets.
Nutrient density can be decreased by addition of NSP-low raw materials, like sand and grit, or by NSP-high raw materials, like oat hulls, soya hulls, beet pulp and straw. NSP-high raw materials may differ in water solubility of the NSP fraction, which can affect feed intake, viscosity of the chymus and feed passage rate (Hartini *et al.*, 2003). However, the combined effects of nutrient density, and water solubility and particle size of the NSP fraction, on feed intake behaviour is unknown. Laying hens, which were fed low nutrient density diets, normally will compensate for the lower nutrients by increased feed intake (Savory, 1980; Lee *et al.*, 2001). However, feed intake capacity of modern laying strains at early lay, even when fed undiluted diets, often seems not to be sufficient to meet their requirements. Therefore, a reduction in nutrient density could result in too low nutrient intake at early lay, and as a consequence in reduced layer performance. By order of the Product Board Animal Feed and the Product Board Poultry & Eggs an experiment was conducted to measure the effect of different nutritional factors (nutrient density, NSP-content, solubility of NSP-fraction, particle size of NSP-fraction, feed form) on feed intake behaviour and performance of laying hens at early lay. Sand and grit were added as NSP-free dilution materials, whereas oat hulls, beet pulp, arbocell, soya hulls and straw were added as NSP-high dilution materials. Most of the diets were offered in meal form. To exclude the possibility of selective feed intake, however, the sand-rich diets were provided both in meal and crumble form. These treatments were compared with control diets in meal and crumble form (diet 1-2). To measure the effect of particle size of the NSP fraction, both coarsely and finely ground oat hulls were added. The low-nutrient density diets (diet 3-11) were diluted by 10%, adding 10% diluents to 900 grams of control diet. Diet 12 was an intermediate diet, only diluted with 5%, by addition of 10% extracted sunflower seed as dilution material. From this experiment the nutritional factors, which seemed to have the most anti feather pecking properties, have been selected for further research.

2 Materials and methods

This chapter describes the design of the experiment. The animal experiment committee of ASG-Lelystad, the Netherlands, approved this experiment.

2.1 Definitions

In this report a number of specialist terms is used, which in this chapter are explained.

- NSP = Non starch polysaccharides. It's plant cell wall material, which is calculated as: 1000 – ash – crude protein – fat – starch – sugar (dry matter base).
- NSP (structural) = the water insoluble plant cell wall material, which is determined by the NDF analysis.
- Water soluble (non structural) NSP can be calculated as: NSP – NDF.
- NSP-low diets are diets, which are diluted with sand or grit.
- NSP-high diets are diets, which are diluted with NSP-rich raw materials like oat hulls, beet pulp, arbocell, soya hulls and straw.
- Grinding structure: diets with an average particle size of 0.82 mm or lower were considered as fine, whereas diets with an average particle size of 0.85 of higher were considered as coarse.

2.2 Birds and management

Hens were housed in two rooms, both measuring 9 x 9 metres. Each of the rooms contained 24 floor pens, divided over three rows, and three sliding doors. The room design is shown in Appendix 1. The pens measured 90 x 150 centimetres each. Subtracting the area of the feeding trough – 20 x 100 centimetres – results in 1,15m^2 for 10 hens, that is 9 hens per m^2, which is the density required for free-range chickens. The pens were built from wires and hens could see the chickens in the other pens.
A laying nest was placed at the outside of the pen. In the back of the pen, 2 perches were present at two different suitable heights. A feeding trough was placed at the long side of the pen, between the laying nest and the perches. The water tube with nipple drinkers was placed at the front side of the pen, between the laying nest and the feeding trough.
Two times a day, a check-up was done to control the (health) status of the hens. Temperature was set to 20°C. The animals used were ISA Brown laying hens. The hens were obtained from a commercial poultry trader. The hens arrived at 16 weeks of age. The hens were not beak trimmed, but the beaks had been touched. Beak length, however, showed a large variety. Initially, the hens were housed with eleven animals per pen. Three days after the arrival, all hens were selected based on their bodyweight. Hens were allowed to weigh between 1130 and 1550 grams. Lighter or heavier hens were removed from the experiment. All selected hens were marked with a wing mark and their numbers were listed. Finally, 10 hens per pen were placed.
At arrival, the hens were fed a commercial diet ($OE_{Broiler}$= 2600 Kcal) for rearing laying hens, ageing over 6 weeks. When the hens were 17.5 weeks old, the start of the experiment was made and all hens received their experimental laying diet. Every pen had an own, marked bucket with cover, containing weighed feed. Weekly, the feeding troughs were emptied in buckets and the leftovers of the feed were weighed. After that, new feed was put in the bucket and weighed again. Twice a week the troughs were filled from the bucket. Hens were fed *ad libitum*. Water was given unrestricted. Each pen had three or four nipple drinkers.
At arrival, on the age of 16 weeks, the hens got 10 hours of light per day. The hens only received artificial light; the windows were covered with black agricultural plastic. Weekly, the light period was extended with one hour, by switching on the light one hour earlier, till they had 16 hours of light per day at the age of 22 weeks. To induce feather pecking behaviour, light intensity was increased three times. Starting light intensity was around 10 lux, using bulbs. The first light increase was done when the hens were 18 weeks old to 20 lux and at the age of 19.5 weeks to 20-30 lux. At 21.5 weeks, the bright lights were used all day, giving a light intensity varying between 40 and 60 lux, depending on the place in the room.
Weekly, together with the fill of the feeding trough, the sand of the pens was turned over to transport dryer sand to the places in the pen where most droppings fell. The moister sand was placed to the dust bathing part, so it could dry. Then, the laying nests were also vacuum cleaned, as was the rest of the room.

Water delivery problems
The water supply was hampered during two days in department 2 in the fourth week of the experiment, resulting in a reduced average feed intake in that week. Because the experimental design was balanced per department,

all treatments were equally affected by this. To correct for this effect, a factor was included in the statistical model which predicts feed intake.

2.3 Experimental design

In total, 12 treatments with each 4 replications were divided among the rooms. In each of the two rooms, 2 replications were present. Each room was divided in two blocks (see Appendix 1). To correct for differences in light intensity, air movements and other environmental parameters, the first four pens of each row in a room were allocated to one block, as were the last four. In each block one complete replication was present. The division of treatments between the two rooms is shown in Appendix 2.
Two NSP-low dilution materials were tested (diet 3-5). Five different NSP-sources, differing in the content of soluble NSP, were tested (diet 6-11). Some diets were produced as crumble (diet 2 and 4) and some diets were coarsely ground (diet 5, 7-11) to test the effect of feed form (meal vs crumble) and particle size of the NSP-fraction (finely versus coarsely ground meal).. The control diet met the needs of the laying hens. Diets 3-11 were 10% diluted, adding 100 grams diluents to 900 grams of control diet. Finally, a positive control diet was tested (treatment 12). The dilution level of this diet was 5% and the diet composition deviated from the other diets; it contained less wheat and soybean meal expeller, mostly compensated by peas. The characteristics of the different treatments are shown in Table 1, while the diet composition and calculated chemical analysis are shown in Appendix 3.

Table 1 Overview of the different treatments and their characteristics

	Additive	Dilution (%)	NSP Class	Level of soluble NSP	Particle size of NSP-fraction	Feed form
1	Negative Control – Mash	0	Intermediate	Low	Fine	Mash
2	Negative Control – Crumble	0	Intermediate	Low	Fine	Crumble
3	Sand – Mash	10	Low	Low	Fine	Mash
4	Sand – Crumble	10	Low	Low	Fine	Crumble
5	Grit	10	Low	Low	Coarse	Mash
6	Oat hulls (fine)	10	High	Low	Fine	Mash
7	Oat hulls (coarse)	10	High	Low	Coarse	Mash
8	Beet pulp	10	High	High	Coarse	Mash
9	Arbocell	10	High	High	Coarse	Mash
10	Soya hulls	10	High	High	Coarse	Mash
11	Straw	10	High	High	Coarse	Mash
12	Positive Control	5	High	High	Fine	Mash

Diets 1 and 2 were considered as standard diets, diets 3-5 as diets with low NSP-level; diets 6-11 as NSP-high diets, whereas diet 12 was an intermediate diet. The NSP sources were added to the feed after grinding, except for the oat hulls of diet 6, which were hammer milled together with the other raw materials.

2.4 Observations

Chemical analysis of the diets and particle size distribution

The diets were chemically analysed on dry matter, ash, crude protein (nitrogen x 6.25), fat, crude fibre, starch, sugar, NDF, ADF, ADL (= Lignin), potassium, sodium, phosphor, calcium, chloride, copper, zinc and iron. The content of cellulose was calculated as ADF minus ADL, whereas the hemi-cellulose content was calculated as the difference between NDF and ADF. The soluble NSP content on dry matter base was calculated as: 1000 – ash – crude protein – fat – starch – sugar – NDF.
The particle size distribution of the meal diets was analysed according to the dry sieve method. To make the particle size of the meals and crumbles comparable, the particle size distribution of diets 1 – 4 (control and sand diets in both meal and crumble form) were analysed by using the wet sieve method (Zandstra, 2001). For this method 200 g of feed has to be dissolved in 500 ml water, soaked for 45 min, after which this solution has to be flushed by the sieves. The content of each sieve is dried and weighed. Seven particle size fractions were distinguished by using sieves with diameters of 0.25, 0.50, 1.25, 2.50, 3.15 and 5.0 mm respectively. The average particle size was calculated as:

(Fraction < 0.25 * 0.125) + (Fraction 0.25 – 0.50 * 0.375) + (Fraction 0.50 – 1.25 * 0.875) + (Fraction 1.25 – 2.50 * 1.875) + (Fraction 2.50 – 3.15 * 2.830) + (Fraction 3.15 – 5.00 * 4.07) + (Fraction > 5.00 * 6.50)/100. An average particle size of 0.82 mm or lower was considered as fine, whereas an average particle size of 0.85 mm or higher was considered as coarse. The diets to which the coarsely ground NSP sources were added, and also the grit diet were defined as course; the other diets as fine.

Start of the experiment
The experiment started on the 26th of April, when the hens aged 17.5 weeks, and lasted 8 weeks till the 20th of June. In week 9, no performance parameters but only video observations were recorded. For some analyses, three periods were distinguished, as shown in Table 2.

Table 2 Time periods in the experiment

Period	Experimental week	Starting Tuesday	Age of the hens (weeks)	Ending Monday
1	1-3	26 April	17.5	16 May
2	4-6	17 May	20.5	6 June
3	7, 8	7 June	23.5	20 June

Climate
Twice a day, temperature and air humidity of both rooms was recorded, together with the check-up of the hens.

Egg production
Daily, eggs laid per pen per day were counted, together with the amount of ground eggs, shell-less eggs, and broken eggs. Weekly, eggs per pen were collected and sorted. Egg weight per pen was based on the amount of 'normal' egg mass, i.e. all clean and dirty (blood- or faecal-stained), normal graded eggs. The remaining 'abnormal' egg mass consisted of broken, cracked, shell-less, double-yolked and very small (< 30 g) eggs. For the trait 'total egg mass' the entire egg mass production was calculated, assuming shell-less and cracked eggs to weigh the mean 'normal' egg weight of that specific pen and week.

Feed intake
Weekly, the weight of the refusals and the bucket at the end of the week was subtracted from the weight of the full bucket at the start of the week, resulting in the amount of feed eaten in that week. Feed intake per hen per day was calculated as the weekly amount of feed intake, divided by the number of hens present in that week, multiplied by 7. Water consumption was not recorded.

Body weight
All hens have been weighed five times; individually in the pre-experiment period, and per pen in week 1, 4, 7 and 9 of the experiment.

Video observations
In week 4, 7 and 9, video observations have been made from which eating time per cage could be calculated. The day was divided in three blocks, from 9 am to 11 am, 11.30 am to 1.30 pm and from 2 pm to 4 pm. In each block on every day, eight cages were observed using 4 cameras. Each observation lasted one hour. From these, the number of hens, who were eating (between 0 and 10), was recorded continuously until the end of each observation. A computer, programmed with the Observer 4.1/5.0 software (Noldus, 1993) was used to analyse the observations. Based on the video observations, the total number of eating minutes per cage per observation period was calculated. Then, this number was divided by the number of hens per cage and by the duration of the observation period, resulting in the average percentage of time spent on feed intake per cage. Relative eating rate (eating minutes/g feed intake) on a weight base was calculated as daily eating minutes divided by feed intake (g). Eating minutes per day were not determined, but calculated as the number of hours with light on (16 h) multiplied by the percentage of observed eating time.

Feathers
In week 1 and week 9 the feathers of all hens have been scored, using the method of (Bilcik and Keeling, 1999). The scoring values are shown in Table 3. Based on the experience of experts, the scoring could be restricted to four places – neck, back, rump and belly of the hen. Feather scoring was done together with the weighing. The same person has done scoring all the time.

Table 3 Description of feather scoring system (Bilcik and Keeling, 1999)

Score	Body	Skin injuries
0	Intact feathers	No injuries or scratches
1	Some feathers scruffy, up to 3 missing feathers	<5 pecks or scratches
2	More damaged feathers, >3 feathers missing	5 or more pecks and scratches or 1 wound <1 cm diameter
3	Bald patch <5 cm diameter or <50% of the area	Wound >1 cm in diameter but <2 cm
4	Bald patch >5 cm diameter or >50% of the area	Wound >2 cm in diameter
5	Completely denuded area	-

Dissection

On the Friday of week 9, 24 June, two hens per pen were selected ad random, based on the number on their wing mark. These hens were killed using an injection containing pentobarbital sodium 200 mg/ml. Dosing used was 1 ml per 2 kg of live weight. Dead hens were weighed, after which the gizzard was removed. The weights of the full and empty gizzard were calculated, related to the weight of the corresponding hen, resulting in grams per kilogram of hen. The gizzard surface was scored, using the values as mentioned in Table 4.

Table 4 Gizzard erosion scores

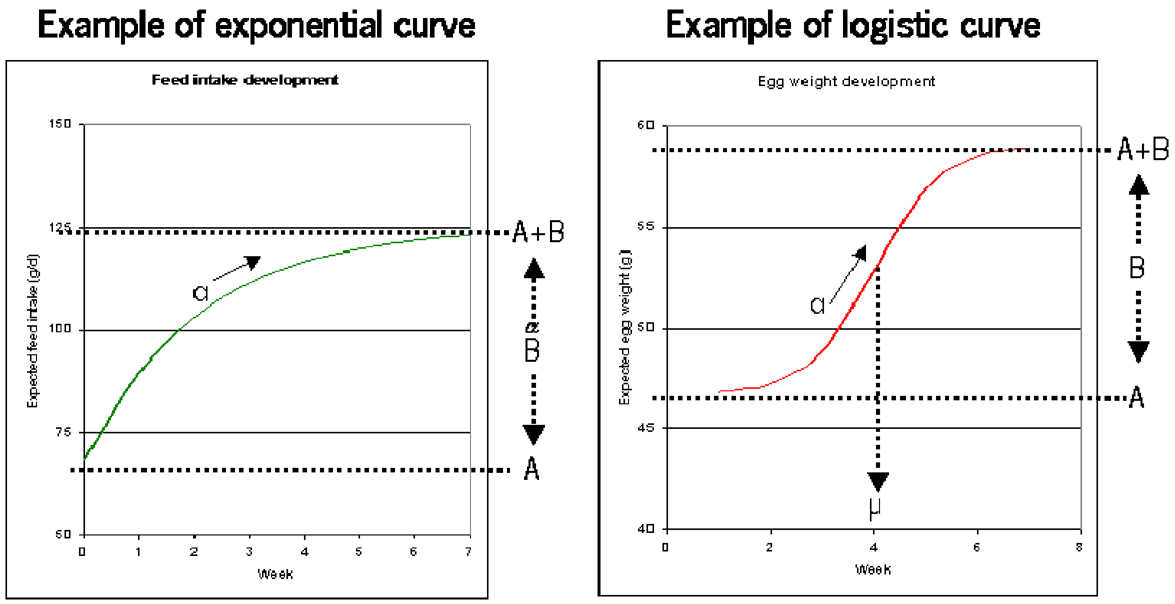
Score	Description
0	No erosion
1	Light erosion (roughness of epithelia)
2	Modest erosion (roughness and gaps)
3	Severe erosion (roughness, gaps and ulcus on stomach wall

2.5 Statistical analysis

Curve fitting procedure

During the experimental period performance data from the same experimental units were generated at regular intervals as longitudinal data. Furthermore, performance data of laying hens normally show a nonlinear development. For instance, hen-day egg production starts at 0% and increases to nearly 100%, following and exponential pattern. An appropriate method to model the development of such data is the use of general, nonlinear mixed effects models for repeated measures data (Lindstrom and Bates, 1990).
The choice for a type of model is presumed on the knowledge of the development of the specific performance parameters. A REML procedure in (Genstat_8_Committee, 2002) was used to estimate the parameters of the model. The nonlinear parameters are estimated by using a two-step iterative procedure, starting from a first order Taylor approach (Lindstrom and Bates, 1990; Engel *et al.*, 2003). Exponential curves are used for modelling feed intake and bodyweight, while logistic curves are used for modelling hen-day egg production, egg weight and egg mass. These curves can be characterised by the parameters Y, t, A, B, α and μ , as shown in Figure 1.

Figure 1 Examples of exponential and logistic curves



The explanation of the parameters of the curves is as follows:

Y	performance parameter (expected value)
t	point in time, is equal to week number-1
A	performance value on $t = -\infty$
B	maximum increase of performance value, therefore on $t = \infty$ the maximum value is $A + B$
α	velocity parameter of the increase of the performance parameter.

Feed intake of laying hens starts at an initial value and increases to a maximum asymptotic value, following an exponential course. Therefore, an exponential curve was used to model feed intake (Model 1).

Model 1 $$Y = A + B\left(1 - e^{-\alpha t}\right) + \Delta$$

The water supply was hampered during two days in room 2 in the fourth week of the experiment, resulting in a reduced average feed intake in that week. Because the experimental design was balanced per room, all treatments were equally affected by this. To correct for this effect, a factor (Δ) was included in the statistical model which predicts feed intake.
At $t = -\infty$ (moment of birth) egg production of the hens is zero. Egg production usually starts at a low level, but increases within a number of weeks to a value near to 100%, following a S-shape pattern. Therefore a logistic curve without intercept (Model 2) was used to model egg production.

Model 2 $$Y = \frac{B}{1 + e^{-\alpha(t-\mu)}}$$

Egg weight starts at a low level, but increases within a number of weeks to a asymptotic value, following a S-shape pattern. Therefore a logistic curve with intercept (Model 3) was used to model egg weight.

Model 3 $$Y = A + \frac{B}{1 + e^{-\alpha(t-\mu)}}$$

Mean body weight of the hens at the start of the experiment was equal for all treatments and increased to a asymptotic value, following an exponential course. Therefore an exponential curve (Model 4) was used to model body weight development.

Model 4 $Y = A + B\left(1 - e^{-\alpha t}\right)$

Curves for egg mass per treatment are generated by multiplying the values for hen-day egg production and egg weight and dividing these values by 100.

Statistical analysis
When the curves are fitted, the BASE LEVEL method is used to test if the model parameters were affected by the experimental factors (low and high NSP level, coarse grinding, crumbles, and – within the high NSP treatments – soluble versus insoluble NSP), compared to the level of the control group (average NSP level, fine grinding, form is meal). In this experimental design the factor 'dilution' is entwined with 'NSP'.
The models are discounted for:
random block effects and week effects per block (both negligible small)
random pen effects
heterogeneity of the variance during time
dependency during time inside pen (first order power).
The number of weighed eggs in the analysis of egg weight was used as weighing factor, because the average weight of the first eggs varied highly as a result of low number of eggs. A residual term was added because of records with weighing 0 (no eggs).
Full and empty relative gizzard weight and relative gizzard content were analysed using REML. The following model was used:

Fixed model:	Constant + NSP- + NSP+ + grinding + feed form + treatment
Random model:	Block + pen

For each observation week (week 4, 7 and 9) a REML analysis was done to test the effects of treatment, feed form, grinding, NSP sources, dilution and period of the day, on percentage of time spent by hens to feed. The following model was used:

Response variate:	% time eating
Fixed model:	Constant + period of the day + NSP- + NSP+ + grinding + feed form + treatment
Random model:	Block + pen

2.6 General coarse of the experiment

In general it can be concluded that the experiment was performed according the instructions. The hens had no health problems and no mortality occurred. Although we tried to arouse feather pecking by increasing light intensity, no feather pecking behaviour was observed.
However, during the experiment two disturbances occurred.

1) As already mentioned, the water supply was hampered during two days in room 2 in the fourth week of the experiment, resulting in a reduced average feed intake in that week. Because the experimental design was balanced per room, all treatments were due to this equally affected. To correct for this effect, a factor was included in the statistical model which predicts feed intake.
2) Unfortunately, one of the four used video recorders did not function well, resulting in a lot of empty video tapes. Consequently, we had a number of incomplete records during some observation periods (see appendix 16).

3 Results

3.1 Chemical analyses of the diets

The results of the chemical analyses of the diets are given in Table 5.

Table 5 Analysed chemical composition (g/kg as-fed basis) of the diets

	1	2	3	4	5	6	7	8	9	10	11	12
Treatment	Neg. Control	Neg. Control	Sand	Sand	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Pos. control
Feed Form	Meal	Crumble	Meal	Crumble	Meal	Meal	Meal	Meal	Meal	Meal	Meal	Meal
Dry matter	875	873	891	880	889	878	879	883	880	879	881	881
Ash	125	113	209	185	194	109	105	108	103	106	117	104
Crude protein	157	161	145	149	147	148	147	154	150	156	151	173
Crude fat	39	44	39	38	36	29	29	30	29	37	33	27
Crude fibre	25	27	21	23	23	51	53	42	68	56	54	41
Starch	370	370	338	342	345	358	351	335	340	332	334	359
Sugar	37	42	35	37	35	35	35	43	34	37	36	39
Total NSP	147	144	124	130	132	199	211	213	224	212	210	179
NDF (structural NSP)	78	79	71	70	71	138	144	113	144	123	131	101
Non structural NSP	69	65	53	60	61	61	67	100	80	89	79	78
ADF	31	33	29	29	29	68	69	53	108	70	66	47
Lignin	10	12	12	11	9	19	18	11	12	11	12	16
Cellulose	21	21	16	18	20	49	51	41	96	59	54	32
Hemi cellulose	47	46	43	41	42	70	75	60	35	53	64	54
Potassium	6.6	6.9	6.0	6.2	6.1	6.4	6.5	6.6	6.2	7.2	7.4	7.6
Sodium	1.7	1.5	0.8	0.8	0.7	0.7	0.9	0.8	0.8	0.7	1.8	1.4
Phosphor	5.2	5.2	4.6	4.8	4.8	4.9	4.7	4.6	4.8	4.6	4.6	5.4
Calcium	38.6	33.3	32.9	30.5	33.7	33.8	31.8	33.9	32.2	33.5	32.8	32.1
Chloride	2.8	2.9	3.3	1.8	1.7	1.6	1.7	1.7	1.6	1.6	1.9	2.8
Copper	7.4	10.6	8.3	10.9	12.6	10.1	10.2	9.7	8.8	8.0	12.2	14.2
Zinc	75.2	72.7	66.8	69.6	73.4	81.2	74.7	72.9	64.2	76.9	66.8	79.6
Iron	228.2	209.1	216.7	261.1	938.4	238.0	218.8	252.4	184.4	245.2	232.3	233.0

Addition of 10% sand or grit to the control diet increased the ash content with 69 (grit) to 84 g/kg (sand, meal). The contents of the other Weende components, the fibre fractions and most of the minerals were diluted up to 10%. However, the sodium and chloride content were reduced with about 50% and 40% respectively compared with the control diets. The addition of grit resulted in a quadruple increase of the iron content.
Addition of 10% fibre rich raw materials to the control diet decreased the contents of ash, protein, fat, starch and some of the minerals up to 10%. In line with the diets containing sand or grit, the sodium and chloride content were also reduced with 50% and 40% respectively. The crude fibre content of the NSP-high diets increased from 17 g/kg (beet pulp) to 43 g/kg (arbocell). The insoluble NSP content was mostly increased after addition of oat hulls and arbocell, whereas the soluble NSP content especially increased after addition of beet pulp, and soya hulls. Addition of oat hulls to the diet had an elevating effect on the lignin content. Addition of arbocell and soya hulls increased the cellulose content of the diet, whereas the hemi cellulose content especially increased after oat hulls, beet pulp and straw addition. In some NSP-high diets the crude fat content was decreased with about 25%, 15% more than expected. The contents of the commercial anti FP diet were intermediate between the control and the fibre rich diets.

3.2 Particle size distribution of the diets

The results of the particle size distribution of the meal diets, analysed with the dry sieve method, are given in Table 6. In the control diet 45.1% of the particles felled inside the fraction 0.50 – 1.25 mm, 23.9% inside the fraction 0.25 – 0.50 mm and 14.7% inside the fraction < 0.25%, whereas 16.4% of the particles had a size > 2.5 mm. Addition of 10% sand or finely ground oat hulls had no substantial effect on the average particle size, compared with the control group. Grit addition had the biggest effect on particle size, increasing the average size with 0.3 mm compared with the control meal diet, especially as a result of a relative high fraction of particles > 2.5 mm. Compared with the control diet coarse grinding of the oat hulls increased the average particle size with 0.12 mm, mostly as a result of a decreased amount of the fraction 0.25 – 0.50 mm and an increased amount of the fraction 1.25 – 2.50 mm. Addition of 10% beet pulp, arbocell, soya hulls of straw also increased the average particle size with 0.04 – 0.10 mm, mainly as a result of a decreased amount of particles within the fraction < 0.25 mm. The particle size distribution of diets 1 – 4, analysed with the wet sieve method, are presented in table 7. Crumbling reduced the average particle size with 0.12 mm (sand diet) to 0.21 mm (control diet), mostly because a decrease of the portion of particles within the fraction 1.50 – 2.50 mm and an increase of particles within the fraction < 0.25 mm. The results of the dry and wet sieve methods are not identical. Compared with the dry sieve method wet sieving increased the average particle size of the control meal (0.82 vs 0.87 mm), whereas the opposite was the case with the sand meal diet (0.81 vs 0.71).

Table 6 Particle size distribution of the meal diets determined by the dry sieve method

	1	3	5	6	7	8	9	10	11	12
Treatment	Control	Sand	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
Feed Form	Meal	Meal	Meal	Meal	Meal	Meal	Meal	Meal	Meal	Meal
Particle Size (mm)										
Fraction < 0.25	14.7%	12.1%	13.6%	10.8%	10.2%	7.8%	7.8%	9.2%	8.5%	9.0%
Fraction 0.25 – 0.50	23.9%	32.0%	21.8%	30.5%	23.7%	28.6%	21.1%	26.2%	26.0%	30.5%
Fraction 0.50 – 1.25	45.1%	39.8%	38.7%	44.8%	44.3%	46.7%	53.0%	47.2%	45.2%	47.3%
Fraction 1.25 – 2.50	15.4%	14.7%	14.8%	13.0%	20.0%	15.8%	17.1%	16.5%	18.2%	12.3%
Fraction 2.50 – 3.15	0.8%	0.7%	3.8%	0.7%	1.3%	0.5%	0.7%	0.5%	1.2%	0.7%
Fraction 3.15 – 5.00	0.2%	0.7%	7.3%	0.3%	0.5%	0.7%	0.3%	0.5%	1.0%	0.3%
Fraction > 5.00	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Average particle size (mm)[1]	0.82	0.81	1.12	0.80	0.92	0.86	0.91	0.87	0.92	0.80

[1] Calculated as: (Fraction < 0.25 x 0.125) + (Fraction 0.25 – 0.50 x 0.375) + (Fraction 0.50 – 1.25 x 0.875) + (Fraction 1.25 – 2.50 x 1.875) + (Fraction 2.50 – 3.15 x 2.830) + (Fraction 3.15 – 5.00 x 4.07) + (Fraction > 5.00 x 6.50)/100

Table 7 Particle size distribution of the control and sand diets (meal and crumble) determined by the wet sieve method

	1	2	3	4
Treatment	Control	Control	Sand	Sand
Feed Form	Meal	Crumble	Meal	Crumble
Particle Size (mm)				
Fraction < 0.25	34,0%	39,7%	37,3%	42,5%
Fraction 0.25 – 0.50	11,5%	12,7%	17,0%	18,7%
Fraction 0.50 – 1.25	30,7%	33,5%	28,7%	27,7%
Fraction 1.25 – 2.50	17,8%	13,2%	14,7%	10,0%
Fraction 2.50 – 3.15	5,3%	0,7%	1,3%	1,2%
Fraction 3.15 – 5.00	0,7%	0,2%	1,0%	0,0%
Fraction > 5.00	0,0%	0,2%	0,0%	0,0%
Average particle size (mm)[1]	0,87	0,66	0,71	0,59

[1] Calculated as: (Fraction < 0.25 x 0.125) + (Fraction 0.25 – 0.50 x 0.375) + (Fraction 0.50 – 1.25 x 0.875) + (Fraction 1.25 – 2.50 x 1.875) + (Fraction 2.50 – 3.15 x 2.830) + (Fraction 3.15 – 5.00 x 4.07) + (Fraction > 5.00 x 6.50)/100

3.3 Hen performance

3.3.1 Feed intake

In general, feed intake of laying hens starts at an initial value and increases to a maximum asymptotic value, following an exponential course. Therefore, an exponential curve was used to model feed intake (Model 1). Due to blocked water delivery, feed intake was reduced in room 2 during week 4 of the experiment. To correct for it, parameter Δ was added to the model.

Mode1 1

$$Y = A + B\left(1 - e^{-\alpha t}\right) + \Delta$$

The estimates of the parameters of this model per treatment group are given in Table 8.

Table 8 Values of A, B and alpha (standard error between brackets) of the exponential curve to predict feed intake (as-fed; g/hen/d) of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

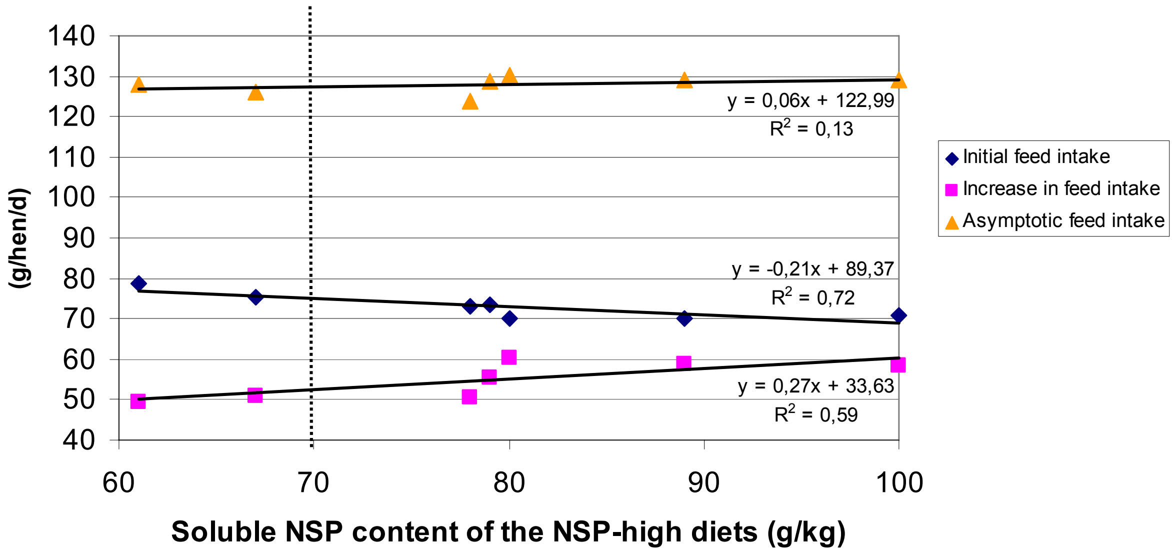
Treatment grouping	Diet	Initial feed intake (g) (A)	Increase in feed intake (g) (B)	Rate of increase (α)	Asymptotic feed intake level (g) (A+B)
Level control group	1	67.96 (3.22)	57.03 (3.57)	0.478 (0.08)	124.99
		Differences in parameter estimates compared with the control group			
NSP-Low	3-5	3.425 (3.13)	**8.391*** (3.32)**	0.075 (0.06)	11.816
NSP-High	6-12	**9.407* (3.72)**	-3.306 (3.97)	0.056 (0.08)	6.101
Coarse grinding	5, 7-11	0.484 (2.41)	1.431 (2.58)	-0.075 (0.05)	1.915
Crumble form	2,4	**-9.257** (3.14)**	**7.448* (3.31)**	0.071 (0.06)	-1.809
Level NSP-High class	6-12	77.37 (3.72)	53.72 (3.97)	0.534 (0.08)	131.09
		Differences in parameter estimates compared with the NSP-High class			
NSP-High Soluble	8-12	**-5.710* (2.84)**	**5.415# (3.04)**	0.011 (0.06)	-0.295

= p < 0.10; * = p < 0.05; ** = P < 0.01; *** = p < 0.001

During the first week of the experiment hens of the control group consumed on average 68.0 g/d (**A**), while the maximum feed intake of this treatment was estimated on 125.0 g/d (**A+B**). The initial feed intake of hens that were fed the NSP-high diets (NSP+) was 9.4 g/d higher than the control, whereas hens that were fed crumbles

then consumed 9.3 g/d less. The initial feed intake of the hens that were fed the soluble NSP-high diets was 5.7 g/d less compared with the hens that were fed the insoluble NSP-high diets. Feeding low-NSP diets (NSP-) or coarse ground diets did not effect the initial feed intake. Hens that were fed low NSP diets, however, had a higher (+8.4 g/d) maximum increase in feed intake (**B**) than the control. Although the hens that were fed crumble had a lower initial value, their maximum increase in feed intake was higher (+ 7.5 g/d) than the control, resulting in a comparable maximum feed intake (**A+B**) as the control. The maximum increase in feed intake of hens that were fed soluble NSP-high diets tended to 5.4 g/d higher, compared with hens that were fed insoluble-rich diets. The rate of increase in feed intake during time (**α**) was not affected by the treatments. The average effect of the blocked water delivery in room 2 during week 4 (Δ) on feed intake is estimated on – 36.4 (2.71) g/hen/d. The values of the calculated feed intake were corrected for this effect.
Diets with less than 70 g/kg soluble NSP were classed as low-soluble, whereas diets with more than 70 g/kg soluble NSP were classed as high-soluble. The dietary level of soluble NSP seemed to have a linear relationship with initial feed intake (R^2 = 0.72) and increase in feed intake (R^2 = 0.59), as shown in Figure 2. Asymptotic feed intake level was not affected by the soluble NSP content of the diet. Thus, increasing the soluble NSP content of the diet may result in a longer adaptation phase of the birds before reaching their maximum feed intake level. For feed intake parameters, a classification in two levels of dietary soluble NSP content (lower of higher than 70 g/kg soluble NSP) seems not to be the most accurate one.

Figure 2 Relation between dietary soluble NSP content of the NSP-high diets (g/kg) and feed intake parameters



Based on Model 1 and the estimated values of the model parameters, the development of feed intake (as-fed; g/hen/d) per week was calculated (Table 9).

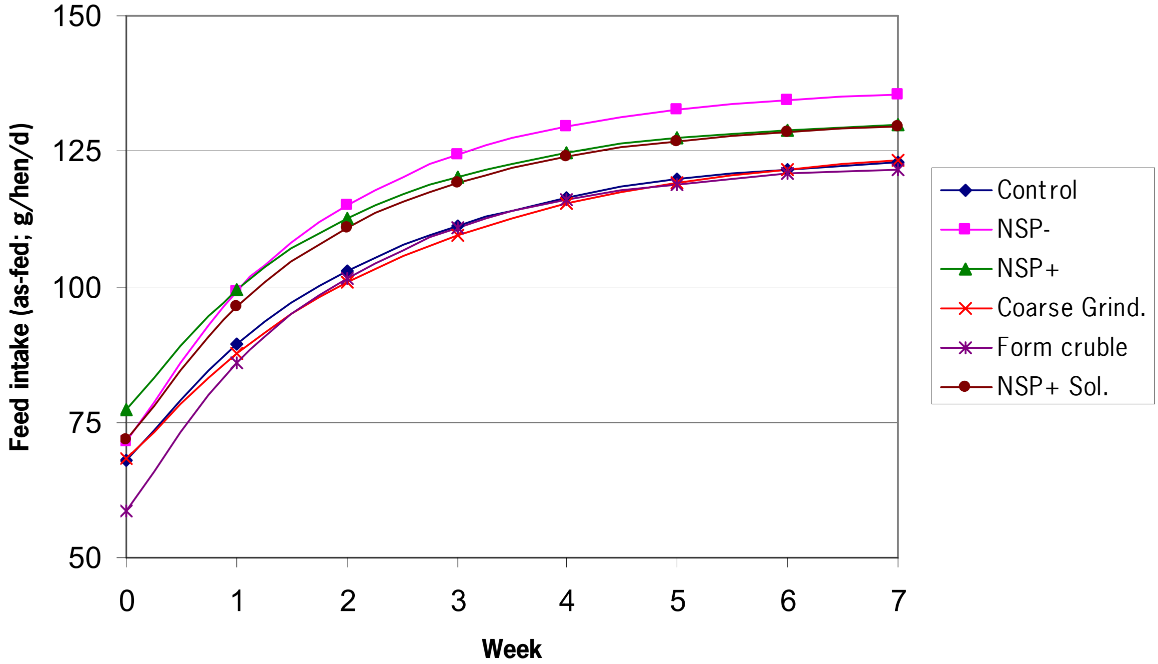
Table 9 Calculated feed intake (as-fed; g/hen/d) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Week	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
0	67.96	71.39	77.37	68.44	58.70	71.66
1	89.62	99.17	99.59	87.83	85.92	96.49
2	103.05	115.15	112.62	100.78	101.64	110.90
3	111.38	124.35	120.26	109.44	110.73	119.26
4	116.55	129.64	124.74	115.23	115.99	124.10
5	119.75	132.68	127.37	119.10	119.02	126.91
6	121.74	134.43	128.91	121.69	120.78	128.54
7	122.98	135.44	129.81	123.42	121.79	129.49
Average	106.63	117.78	115.09	105.74	104.32	113.42

During this 8-week experimental period the compensation in feed intake was on average 10.5% for the low-NSP treatments, 8.0% for the NSP-high (soluble and insoluble) treatments and 6.4% for the soluble NSP-high treatments. Feeding crumble or course ground meal did not affect the average feed intake. Finally, we can conclude that laying hens during early lay are able to compensate for dietary dilution with NSP-free or NSP-high raw materials with higher feed intake. Uncorrected data of feed intake per treatment per week and per treatment class are shown in Appendix 4. The modelled and realised feed intake per pen are shown in Appendix 5.

The development of calculated feed intake during the observation period is graphically shown in Figure 3.

Figure 3 Development of calculated feed intake (as-fed; g/hen/d) per week of the treatment groups: Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



3.3.2 Hen-day egg production

At $t = -\infty$ (moment of birth) egg production of the hens is zero. Egg production usually starts at a low level, but it increases within a number of weeks to a value near to 100%, following a S-shape pattern. Therefore a logistic curve without intercept (Model 2) was used to model egg production.

Model 2:

$$Y = \frac{B}{1 + e^{-\alpha(t-\mu)}}$$

The estimates of the parameters of this model per treatment group are given in Table 10.

Table 10 Values of A, B, α and μ (standard error between brackets) of the logistic curve to predict hen-day egg production (%) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Treatment grouping	Diet	Increase in hen-day egg production (%) (B)	Rate of increase (α)	Point of inflection (wk – 1) (μ)
Level control group	1	97.35 (2.02)	1.531 (0.12)	3.032 (0.13)
		Differences in parameter estimates compared with the control group		
NSP-Low	3-5	1.824 (1.89)	**0.334**** **(0.12)**	-0.211 (0.13)
NSP-High	6-12	-1.239 (2.23)	**0.411**** **(0.16)**	-0.150 (0.15)
Coarse grinding	5, 7-11	-1.034 (1.28)	**-0.155**$^{\#}$ **(0.09)**	0.075 (0.08)
Crumble form	2,4	-2.129 (1.87)	0.137 (0.12)	-0.043 (0.12)
Level NSP-High class	6-12	96.11 (2.23)	1.941 (0.16)	2.882 (0.15)
		Differences in parameter estimates compared with the NSP-High class		
NSP-High Soluble	8-12	1.018 (1.72)	-0.111 (0.13)	0.090 (0.11)

= $p < 0.10$; ** = $P < 0.01$

The hen-day egg production of the control group increased from 0% to maximal 97.4%. The maximum increase in egg production was not affected by treatments. Hens that were fed low-NSP diets or NSP-high diets both had a higher rate of increase (**α**), which means that these hens reached the level of maximum egg production earlier than the control, resulting in more eggs during the experimental period. The rate of increase was enhanced by both the soluble and insoluble NSP sources. The rate of increase of the hens that were fed coarse grounded diets tended to a lower value compared to the control. The point of inflection of the control group was reached in week 4 ($t-1 = 3$), which means that from week 4 the rate of increase of hen-day egg production shifts to lower values. Point of inflection was not affected by treatments.
Based on Model 2 and the estimated values of the model parameters, the development of hen-day egg production (%) per week was calculated (Table 11).

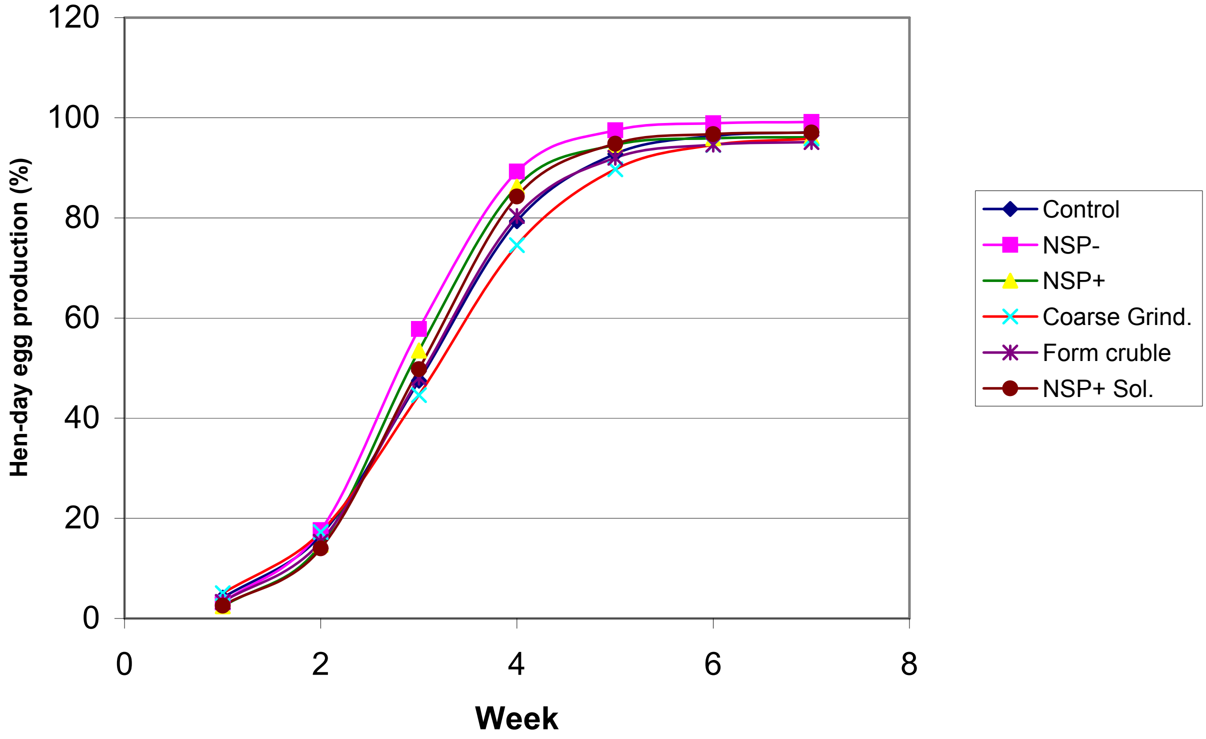
Table 11 Development of the calculated hen-day egg production (%) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Week	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
1	4.15	3.21	2.42	5.03	3.33	2.56
2	16.63	17.63	14.68	17.25	15.34	14.02
3	47.48	57.79	53.52	44.63	48.05	49.80
4	79.33	89.27	86.27	74.51	80.35	84.29
5	92.79	97.50	94.56	89.69	92.01	94.81
6	96.33	98.91	95.89	94.55	94.60	96.75
7	97.13	99.13	96.08	95.86	95.10	97.07
Average	61.98	66.21	63.35	60.22	61.26	62.76

As a result of the higher rate of increase, hens that were fed low-NSP or high-NSP diets on average produced more eggs during this experiment, whereas coarse grinding of the diets tended to a lower egg production. Feed form had no effect on hen-day egg production. Uncorrected data of hen-day egg production per treatment per week and per treatment class are shown in Appendix 6. The modelled and realised hen-day egg production per pen are shown in Appendix 7.

The development of calculated hen-day egg production during the observation period is graphically shown in Figure 4.

Figure 4 Development of calculated hen-day egg production (%) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



3.3.3 Egg weight

Egg weight starts at a low level, but increases within a number of weeks to a asymptotic value, following a S-shape pattern. Therefore a logistic curve with intercept (Model 3) was used to model egg weight.

Model 3

$$Y = A + \frac{B}{1 + e^{-\alpha(t-\mu)}}$$

The estimates of the parameters of this model per treatment group are given in Table 12.

Table 12 Values of A, B, alpha and mu (standard error between brackets) of the logistic curve to predict egg weight (g) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Treatment grouping	Diet	Initial egg weight (g) (A)		Increase in egg weight (g) (B)		Rate of increase (α)		Point of inflection (wk – 1) (μ)		Asymptotic egg weight level (g) (A+B)
Level control group	1	46.72	(1.55)	12.35	(1.68)	1.569	(0.29)	4.015	(0.20)	59.07
		Differences in parameter estimates compared with the control group								
NSP-Low	3-5	-0.091	(1.95)	1.034	(2.29)	-0.346	(0.27)	0.185	(0.25)	0.943
NSP-High	6-12	-4.134	(3.85)	7.037	(4.59)	**-0.730***	**(0.32)**	-0.345	(0.49)	2.903
Coarse grinding	5, 7-11	**-3.269#**	**(2.02)**	3.689	(2.40)	**-0.237#**	**(0.14)**	-0.242	(0.25)	0.420
Crumble form	2,4	-1.002	(2.60)	2.333	(3.24)	-0.252	(0.31)	-0.060	(0.32)	1.331
Level NSP-High class	6-12	42.59	(3.85)	19.39	(4.59)	0.839	(0.32)	3.67	(0.49)	61.97
		Differences in parameter estimates compared with the NSP-High class								
NSP-High Soluble	8-12	-2.225	(4.21)	3.540	(5.04)	-0.045	(0.16)	-0.041	(0.52)	1.32

= $p < 0.10$; * = $P < 0.05$

Initial egg weight of the control group was 46.7 g, increasing with 12.4 g to a maximum value of 59.1 g. Feeding coarse ground diet reduced initial egg weight with 3.3 g compared with the control. The rate of increase of egg weight was lower when the hens were fed NSP-high or coarse ground diets. Therefore the maximum egg weight of these treatments was reached at a later time compared with the control. Egg weight parameters were not affected by low-NSP diets, feed form or solubility of the NSP sources.
Based on Model 3 and the estimated values of the model parameters, the development of egg weight (g) per week was calculated (Table 13).

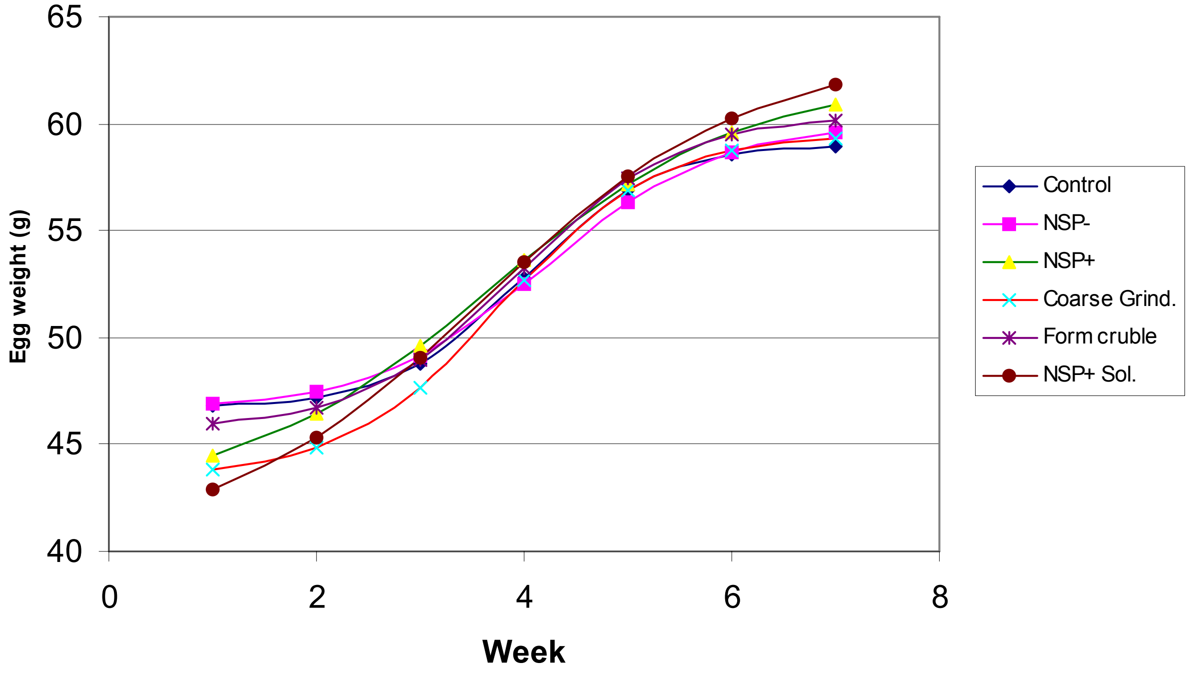
Table 13 Development of the calculated egg weight (g) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Week	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
1	46.83	46.89	44.45	43.84	46.01	42.88
2	47.22	47.48	46.42	44.83	46.76	45.29
3	48.81	49.14	49.62	47.67	48.97	49.02
4	52.82	52.51	53.61	52.67	53.28	53.50
5	56.90	56.36	57.19	56.87	57.44	57.52
6	58.54	58.68	59.57	58.70	59.47	60.26
7	58.96	59.59	60.86	59.28	60.14	61.82
Average	52.87	52.95	53.10	51.98	53.15	52.90

In conclusion, coarse grinding of the diets negatively affects initial egg weight, whereas the rate of increase of egg weight decreases when the hens were fed NSP-high or coarse ground diets. Uncorrected data of egg weight per treatment per week and per treatment class are shown in Appendix 8. The modelled and realised egg weight per pen are shown in Appendix 9.

The development of calculated egg weight development during the observation period is graphically shown in Figure 5.

Figure 5 Development of calculated egg weight (g) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



3.3.4 Egg mass

Egg mass is the result of the earlier calculated parameters (hen-day egg production * egg weight)/ 100, and is therefore not separately statistically analysed. When treatments significantly differ for egg production or egg weight, this will also be the case for the result of both. As a consequence of it we can conclude that maximal egg mass production is not affected by treatment. The rate of increase of egg mass is higher for NSP-low diets and lower for coarse grounded diets, compared with the control. When hens were fed NSP-high diets, the rate of increase of hen-day egg production increased, but the rate of increase of egg weight decreased. The final result of it is located between the level of the control and the NSP-low diet (Figure 4). The estimates of the parameters of this model per treatment group are given in Table 14.

Table 14 Values of A and B of the exponential curve to predict egg mass (g/hen/d)) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Treatment class	Diet	Initial value (A)	Max. increase (B)	Max. value (A+B)
Level control group	1	0	57.50	57.50
		Differences in parameter estimates compared with the control group		
NSP-Low	3-5	0	2.02	2.02
NSP-High	6-12	0	2.06	2.06
Coarse grinding	5, 7-11	0	-0.20	-0.20
Crumble form	2,4	0	0.01	0.01
Level NSP-High class	6-12	0	59.56	59.56
		Differences in parameter estimates compared with the NSP-High class		
NSP-High Soluble	8-12	0	2.70	2.70

Based on Models 2 and 3 and the estimated values of the model parameters, the development of egg mass development (g/hen/d) per week was calculated (Table 15).

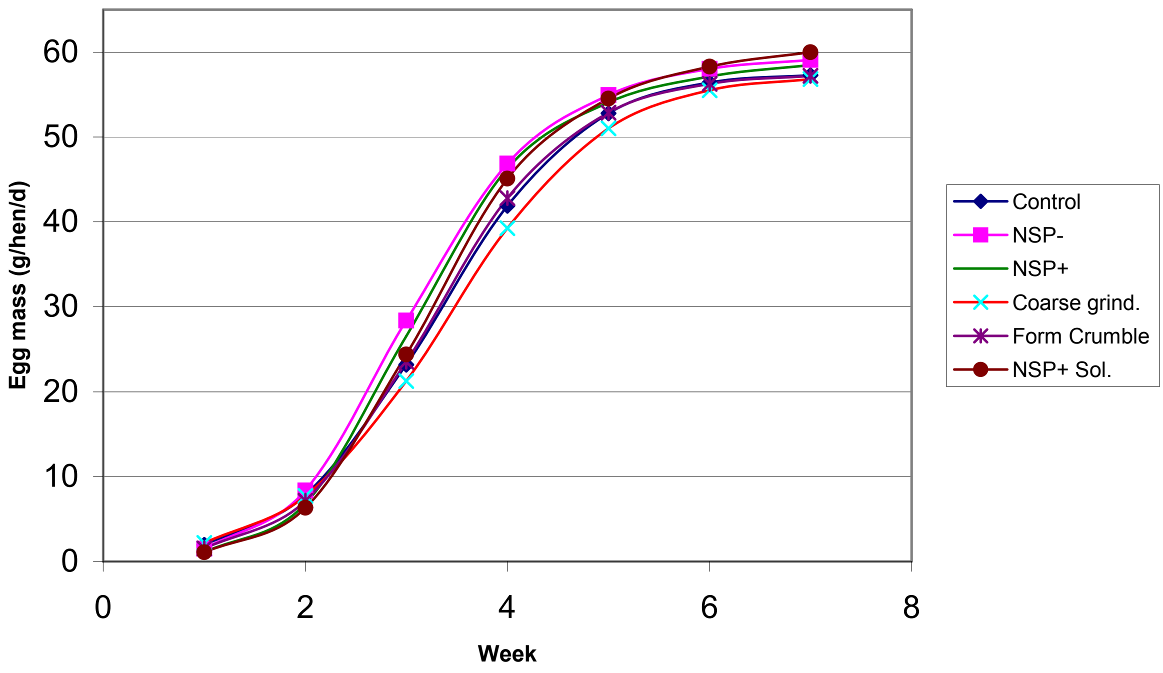
Table 15 Calculated egg mass development (g/hen/d) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Week	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
1	1.94	1.51	1.08	2.21	1.53	1.10
2	7.85	8.37	6.81	7.73	7.17	6.35
3	23.18	28.39	26.56	21.27	23.53	24.41
4	41.90	46.87	46.25	39.25	42.81	45.09
5	52.80	54.95	54.08	51.01	52.85	54.53
6	56.39	58.04	57.12	55.51	56.26	58.31
7	57.26	59.07	58.47	56.82	57.19	60.00
Average	34.48	36.74	35.77	33.40	34.48	35.68

In conclusion, average egg mass during the observation period enhances by feeding NSP-low, and both soluble and insoluble NSP-high diets, and decreases by feeding coarse ground meal. Average egg mass was not affected by feed form. Uncorrected data of egg-mass per treatment per week and per treatment class are shown in Appendix 10.

The development of calculated egg mass development during the observation period is graphically shown in Figure 6.

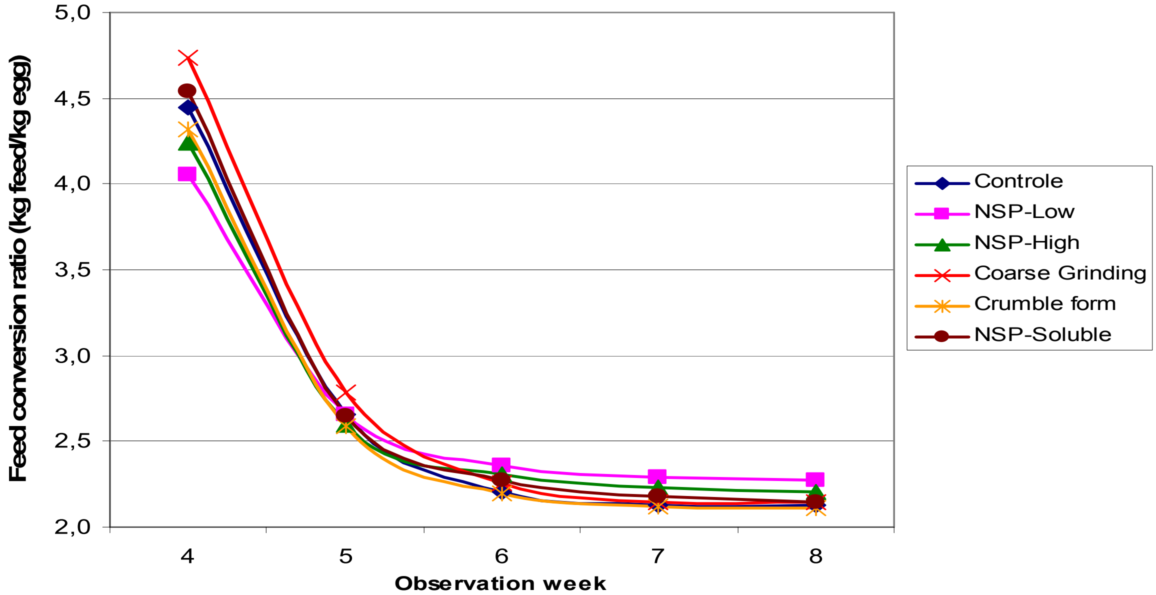
Figure 6 Development of calculated egg mass (g) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



3.3.5 Feed and Energy conversion Ratio

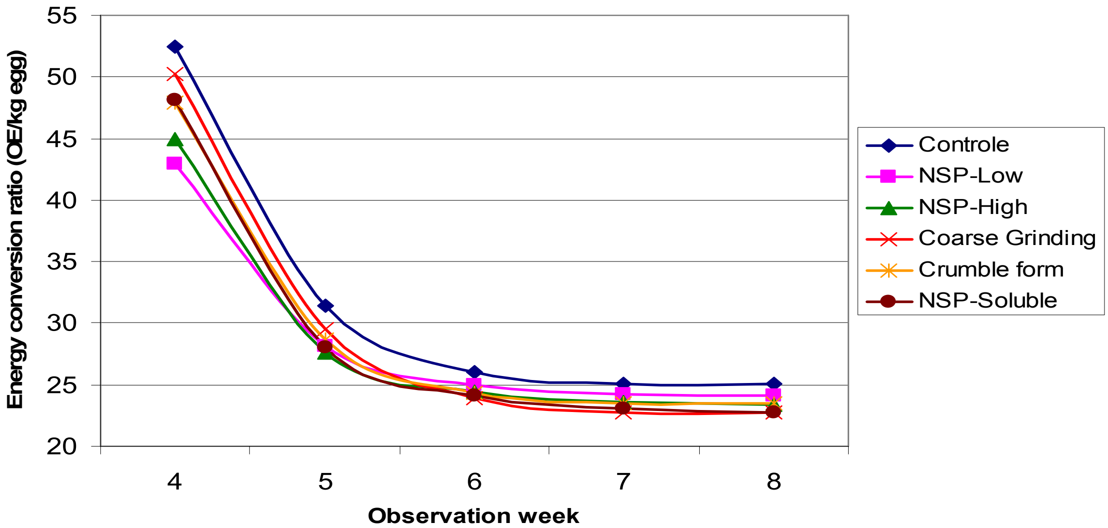
The development of feed conversion ratio and energy conversion ratio per treatment group are shown in Figure 7 and 8, respectively. Energy conversion ratio was expressed as amount of energy (MJ) necessarily for the production of one kg of eggs.

Figure 7 Development of feed conversion ratio (kg feed/kg egg) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



Over week 4, feed conversion ratio of the control group was 4.45 and decreased over time until 2.13 over week 8. Feed conversion ratio of the NSP-low group was somewhat lower over week 4, similar over week 5 and somewhat higher over week 6 to 8, compared with the control group. Coarse grinding increased feed conversion ratio over week 4 to 6, and was similar to the control group over week 7 and 8. Over week 4 – 8, average feed conversion ratio of the crumble diet was 2% lower, whereas feed conversion ratio of the coarse ground diet was 4% higher than the control group.

Figure 8 Development of energy conversion ratio (OE/kg egg) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



Over week 4 to 8, all the experimental groups had a better energy conversion ratio, resulting in an improved average energy conversion ratio of 7% to 10%, compared with the control group.

3.3.6 Bodyweight development

Mean body weight of the hens at the start of the experiment was equal for all treatments and increased to a asymptotic value, following an exponential course. Therefore an exponential curve (Model 4) was used to model body weight development.

Model 4

$$Y = A + B\left(1 - e^{-\alpha t}\right)$$

The estimates of the parameters of this model per treatment group are given in Table 16.

Table 16 Values of A, B and alpha (standard error between brackets) of the exponential curve to predict bodyweight (kg) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Treatment class	Diet	Initial value (A)	Max. increase (B)	Rate of increase (α)	Max. value (A+B)
Level control group	1	1.382 (0.01)	0.502 (0.03)	0.288 (0.03)	1.890
		Differences in parameter estimates compared with the control group			
NSP-Low	3-5	0	-0.031 (0.03)	0.045 (0.03)	-0.031
NSP-High	6-12	0	-0.044 (0.03)	**0.095*** **(0.05)**	-0.044
Coarse grinding	5, 7-11	0	**-0.035*** **(0.02)**	0.016 (0.03)	-0.035
Crumble form	2,4	0	0.007 (0.03)	-0.016 (0.03)	-0.007
Level NSP-High class	6-12	1.382	0.458	0.383	1.845
		Differences in parameter estimates compared with the NSP-High class			
NSP-High Soluble	8-12	0	-0.006 (0.02)	0.005 (0.04)	-0.006

* = $p < 0.05$

Mean bodyweight of the hens at the start of the observation period was 1.382 kg. Initial bodyweight was equal for all treatments, because of allotting hens to the pens on the basis of weight. The maximum increase in body weight was estimated on 0.5 kg for the control. As a consequence of the relatively short observation period, maximum body weight was not reached during this experiment. Coarse grinding of the diet reduced the maximum increase of bodyweight with 35 g. Addition of (in-)soluble NSP-high sources to the diet enhanced the rate of increase of bodyweight development compared with the control.
Based on Model 4 and the estimated values of the model parameters, the development of bodyweight (kg) per week was calculated (Table 17).

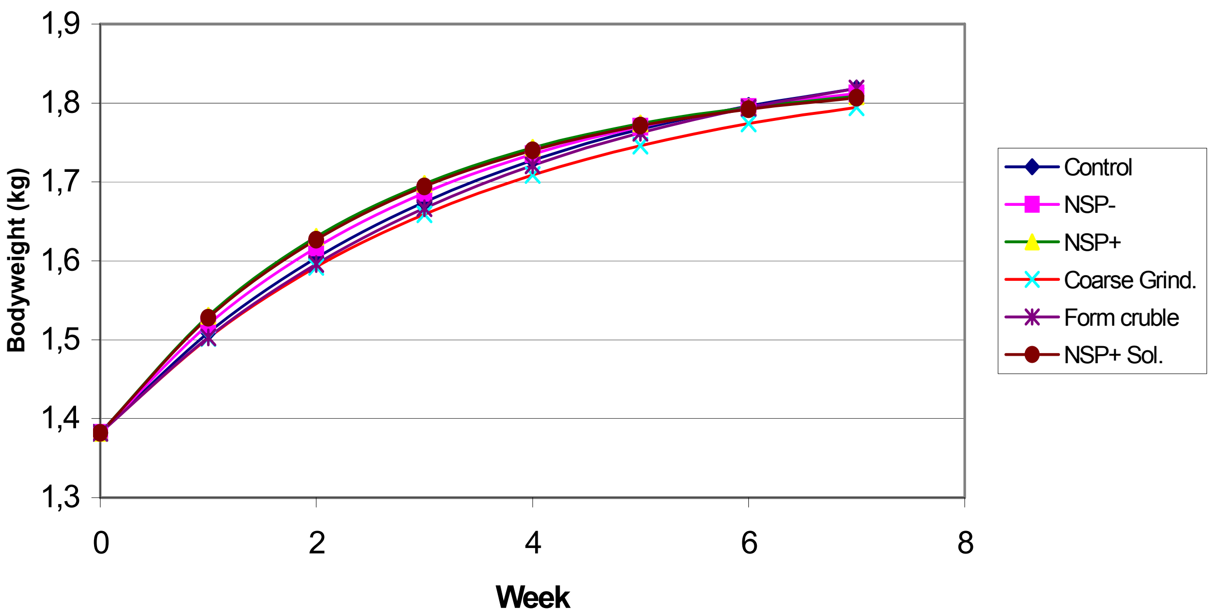
Table 17 Development and the calculated bodyweight (kg) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP

Week	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
0	1.382	1.382	1.382	1.382	1.382	1.382
1	1.509	1.517	1.530	1.506	1.505	1.529
2	1.604	1.614	1.630	1.597	1.598	1.629
3	1.676	1.683	1.699	1.665	1.669	1.697
4	1.729	1.733	1.745	1.714	1.723	1.743
5	1.769	1.769	1.777	1.751	1.765	1.774
6	1.800	1.794	1.799	1.778	1.796	1.795
7	1.822	1.812	1.814	1.798	1.820	1.809
Average	1.661	1.663	1.672	1.649	1.657	1.670

Mean bodyweight of hens that were fed (in-)soluble NSP-high diets was higher than the control, whereas feeding coarse ground meal reduced mean bodyweight. Uncorrected data of bodyweight per treatment per week and per treatment class are shown in Appendix 11. The modelled and realised bodyweight per pen are shown in Appendix 12.

The development of calculated body weight development during the observation period is graphically shown in Figure 9.

Figure 9 Development of calculated body weight (kg) per week of the treatment groups Control, Low NSP, High NSP, Coarse grinding, Crumble and High soluble NSP



The effect of the individual diets on egg performance per period are shown in Appendix 13.

3.4 Gizzard parameters

Results of the dissection (relative full and empty gizzard weight and relative gizzard content) are shown in Table 18. To correct for differences in bodyweight between hens, these parameter are expressed as gram per kg bodyweight of the hen.

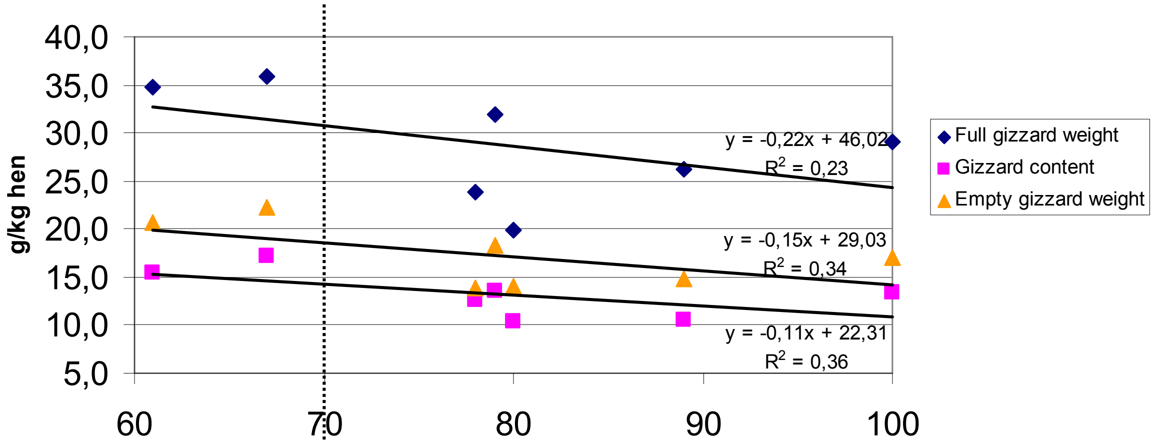
Table 18 Effect of Low NSP, High NSP, Coarse grinding, Crumble and Solubility of NSP+ on relative full and empty gizzard weight and relative gizzard content (g/kg hen) compared with the control group (standard error between brackets)

Treatment class	Diet	Full gizzard weight	Empty gizzard weight	Gizzard content
Level of the control (g/kg hen)	1	24.48 (1.720)	14.49 (0.865)	9.99 (0.9691)
		Differences in parameter estimates compared with the control group		
NSP-Low	3-5	1.710 (1.849)	0.415 (0.930)	1.297 (1.042)
NSP-High	6-12	**9.467 (2.231)***	**6.014 (1.122)***	**3.456 (1.257)**
Coarse Grinding	5, 7-11	**2.912 (1.401)***	**1.899 (0.704)**	1.003 (0.789)
Crumble form	2,4	-2.550 (1.867)	-1.215 (0.939)	-1.338 (1.052)
Level NSP-High Class	6-12	33.95 (2.231)	20.50 (1.122)	13.45 (1.257)
		Differences in parameter estimates compared with the NSP-High class		
Effect of soluble NSP+	8-12	**-9.413 (1.657)***	**-6.434 (0.832)***	**-2.994 (0.934)***

* = p < 0.05; ** = p < 0.01; *** = p < 0.001

The control group had a relative full gizzard weight of 24.48 g/kg hen, a relative empty gizzard weight of 14.49 g/kg hen and a relative gizzard content of 9.99 g/kg hen. Coarse grinding increased both full and empty gizzard weight with 2.912 and 1.899 g/kg hen respectively. Gizzard parameters were not affected by feeding NSP-low or crumbled diets. Feeding NSP-high diets increased the full gizzard weight with 9.467 g/kg hen as a result of 6.014 g/kg hen higher empty gizzard weight and 3.456 g/kg higher gizzard content. The increase of these gizzard parameters was mainly due to the treatments that were fed low-soluble NSP sources. Within the NSP-high class the gizzard parameters of most of the high-soluble NSP-sources fed hens were reduced to the level of the control group. Diets with less than 70 g/kg soluble NSP were classed as low-soluble, whereas diets with more than 70 g/kg soluble NSP were classed as high-soluble. No significant linear relationships were found between the level of soluble NSP and gizzard parameters, as shown in Figure 10. Therefore, we may conclude that dietary soluble NSP levels higher than 70 g/kg will not affect gizzard parameters. The effects of the individual diets on gizzard parameters are shown in appendix 14.

Figure 10 Relation between soluble NSP content of the NSP-high diets (g/kg) and gizzard parameters



3.5 Eating time and eating rate

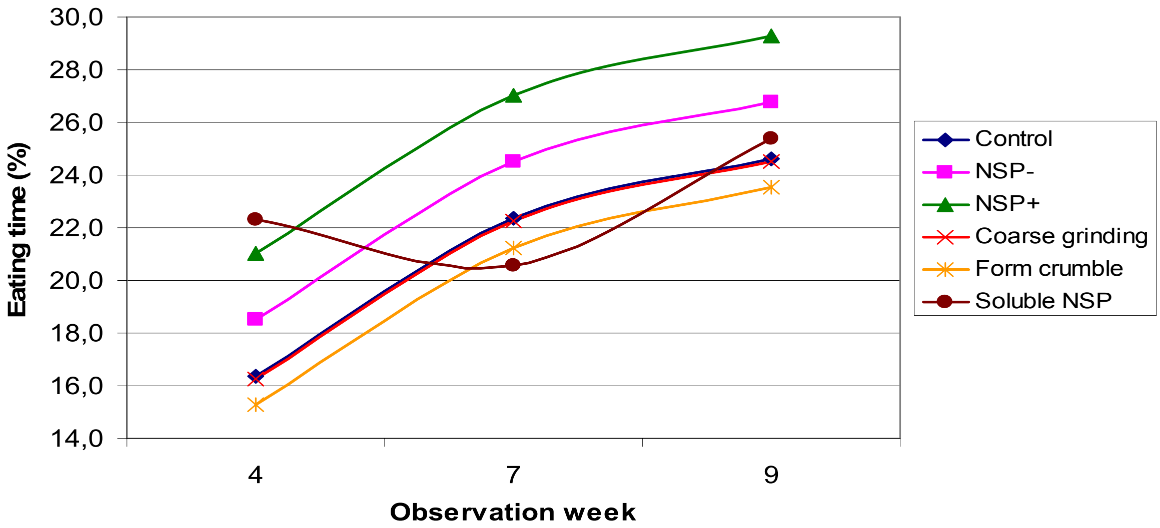
Based on video observations the percentage of time the hens were spending on feed intake was recorded. Eating behaviour was observed during week 4, 7 and 9 of the experiment. The results are summarised in Table 18 and Figure 11.

Table 18 Effect of Period of the day, Low NSP, High NSP, Coarse grinding and Crumble on eating time (% of observation period) compared with the control group per week (standard error between brackets)

		Week		
Treatment grouping	Diet	**4**	**7**	**9**
Basic level control group (%), week 4, period 1 (9.00 – 11.00h)	1	13.21 (2.457)		
Effect of week		-----	**7.27 (2.284)*****	**9.21 (2.446)*****
Effect of Period 2 (11.30 - 13.30h)		-0.48 (2.166)	3.05 (2.930)	3.95 (2.930)
Effect of Period 3 (14.00 - 16.00h)		**10.00 (2.249)****	-6.92 (3.662)	-6.82 (3.662)
Total level control group (%)	1	16.4	20.5	22.4

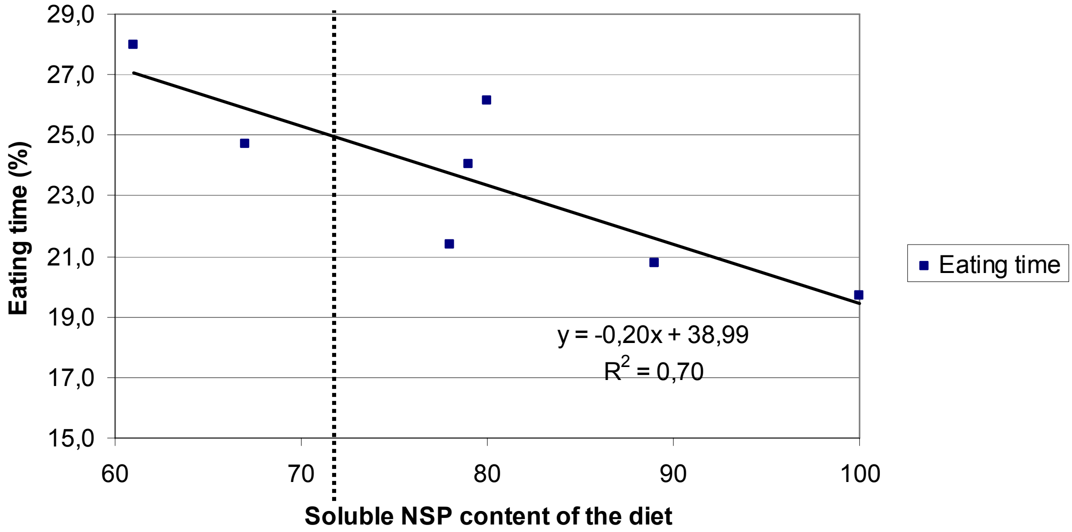
** = P < 0.01; *** = p < 0.001 (all in bold)

Figure 11 Eating time (%) of the treatment groups Control, Low NSP, High NSP, Coarse grinding and Crumble over week 4, 7 and 9



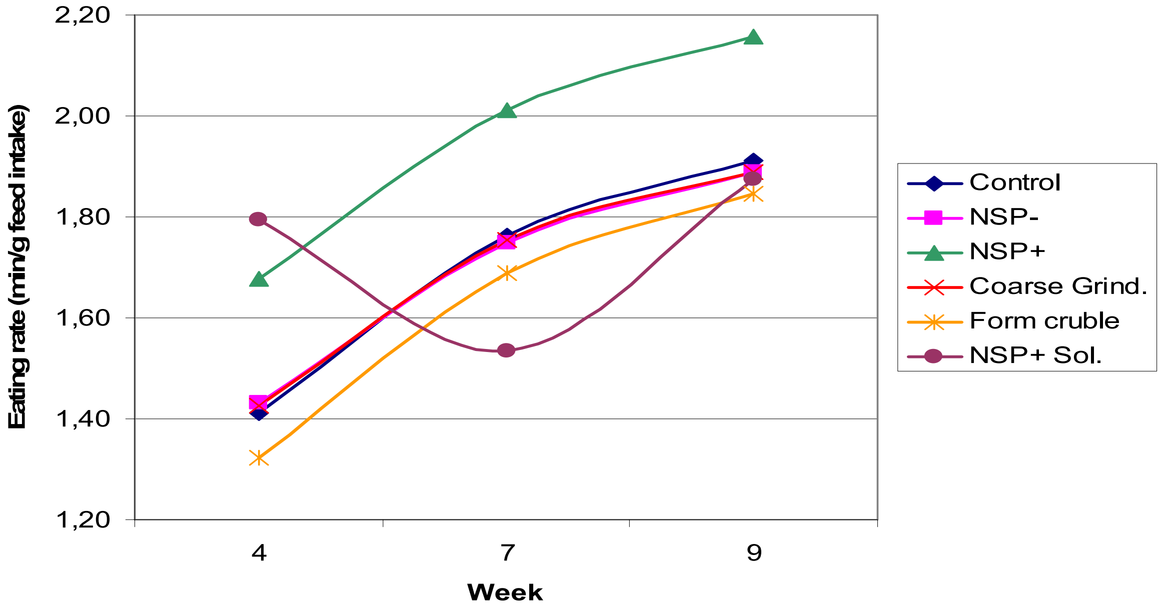
Eating time increased over the experimental period. In week 4, 7 and 9 the control group spent respectively 16.5%, 22.4% and 24.6% of their time on feed intake. In week 4, eating time was significantly affected by period of the day; over period 3 eating time was 10.0% higher than over period 1 and 2. Eating time was not affected by feeding NSP-low, coarsely ground or crumbled diets. Hens that were fed NSP-high diets on average spent 4.6% more time on feed intake (p=0.06) over the whole experimental period. Over week 4, eating time of the soluble NSP treatment did not differ from the level of the NSP-high treatment. Eating time, however, significantly (p=0.007) reduced over week 7 (-7.7%) and week 9 (-5;2%), compared to the NSP-high treatment.
Diets with less than 70 g/kg soluble NSP were classed as low-soluble, whereas diets with more than 70 g/kg soluble NSP were classed as high-soluble. The dietary level of soluble NSP seemed to have a linear relationship with eating time (R^2 = 0.70), as shown in Figure 12. Increasing the soluble NSP content of the diet may result in a decreased eating time. For eating time, a classification in two levels of dietary soluble NSP content (lower of higher than 70 g/kg soluble NSP) seems not to be the most accurate one.

Figure 12 Relation between soluble NSP content of the NSP-high diets (g/kg) and eating time (average of week 4, 7 and 9)



Relative eating rate (feed intake (g)/eating minute) data is shown in Figure 13.

Figure 13 Relative eating rate (eating minutes/g feed intake) of the treatment groups Control, Low NSP, High NSP, Coarse grinding and Crumble over week 4, 7 and 9



Relative eating rate increased over the experimental period. Over week 4 relative eating rate of the control group was 1.4 min/g, increasing to 1.9 min/g over week 9. Hens that were fed NSP-low or coarsely ground diets had a similar relative eating rate as the control group. Crumbling of the diet reduced relative eating rate (- 0.06 to - 0.08 min/g), whereas dilution with NSP-rich raw materials increased relative eating rate (0.25 min/g). Relative eating rate of the soluble NSP-group was interacted with observation week, resulting in a increased eating rate over week 4 (0.38 min/g), an decreased eating rate over week 7 (- 0.23 min/g) and an almost similar eating rate over week 9, compared to the control group.

3.6 Feather condition scores

As a consequence of the young age of the hens and the absence of feather pecking behaviour, the feather condition was perfect for all treatments.

4 Discussion

Effect of dietary density

From this experiment it can be concluded that feeding low density diets to hens at early lay resulted in an equal or even better egg performance compared with hens that were fed standard diet. These results are in accordance with other experiments, although these trials are mostly executed with hens of higher age. Feeding non-debeaked laying hens a low density diet (11.05 MJ ME/kg, 51 g/kg crude fat), in which all nutrients were decreased by 5%, not adversely affected egg performance compared to hens that were fed a standard diet (11.55 MJ ME/kg, 65 g/kg crude fat) (Lee *et al.*, 2001). Even a up to 30% reduction of the dietary density of the diet (by adding 10, 20, 25 or 30% sand) had no adverse effect on the egg productivity of the hens (Van der Meulen*, et al.*, submitted), although the increase in body weight was less for the hens that had to take up larger amounts of feed. In that experiment the hens (34-37 weeks of age) fully compensated the effect of added sand in the diet by increasing their daily feed intake. The nutrient to egg conversion ratio of the hens that were fed the sand diets was equal of even lower than the ratio of the hens fed the control diet, indicating that the presence of sand may have a stimulating effect on nutrient utilisation. The mode of action of this effect is not clear. Possibly, the sand particles have a grating effect, resulting in a better pre-digestion of the diet. Laying hens that were fed roughages (20 – 54 weeks of age) were even able to increase their daily feed consumption (as-fed base) with 70% compared with the control group, without negatively affecting productivity (Steenfeldt *et al.*, 2001).
We can conclude that hens had a large ability to compensate for dietary dilution, resulting in an almost equal nutrient intake compared to undiluted diets. This suggests that laying hens fed diets with a lower nutrient density spend more time on feed intake, and so less time is remaining for feather pecking behaviour. This is in accordance with the results of Savory (1980) who fed male Japanese quail diluted (with 40% cellulose) and undiluted diets. Those receiving the diluted mash consumed about 40% more feed (14.9 vs 10.8 g/d), spent a higher proportion of total time (24 h) on feed intake (23.8 vs 9.1%), had a longer meal length (1.54 vs 0.87 min), a shorter inter-meal interval length (4.98 vs 8.92 min) and more meals per day (128 vs 86).
In the current experiment, however, eating time was only enhanced by addition of NSP-high raw materials as dilution source and not by sand or grit. Possibly, this is due to the differences in specific gravity of the dilution sources. Sand has a higher specific gravity compared to some NSP-high raw materials, e.g. oak wood (1600 versus 780 kg/m^3) (Jansen, 1977). Therefore, when the hens are supplemented sand-rich diets less volume of feed has to be consumed for reaching the same amount of feed intake, than by supplementing NSP-high diets. Savory (1980) also suggested that the difference in meal length was related to dietary bulk.
Reducing the energy content of the diet may positively affect feather pecking behaviour. Decreasing the energy content of layer diets (12.2, 11.7, 11.2 and 10.7 MJ/kg) resulted in a tendency to lower mortality and a significant increase in feather condition (Elwinger, 1981). The hens that were fed the low density diet in the above mentioned experiment of Lee *et al.* (2001) showed an improved plumage condition compared to hens that were fed the standard diet. So, reducing the dietary density seems to reduce feather pecking behaviour and to improve plumage condition. Unfortunately, the hens in the present experiment showed no feather pecking behaviour at all. Therefore, no remarks concerning the effect of the tested dilution sources on feather pecking behaviour can be made.
The reduction in dietary density always is confounded with changes in other ingredients, protein and NSP levels. Until now, the pure effects of energy dilution and NSP supplementation on eating time and feather pecking behaviour are unknown. Furthermore, questions will remain regarding the most effective dietary dilution source and inclusion level, and the mode of action of these sources, to prevent feather pecking behaviour. More research should be initiated to answer these questions.

Effect of NSP-source

The class of NSP-high diets was subdivided into a soluble and insoluble NSP group and the results of these groups were separately analysed. However, NSP seems not to be a very unambiguous nutrient for making subclasses. NSP content was not directly chemically analysed but indirectly calculated as a residual value after subtracting the content of ash, crude protein, fat, starch and sugar of 1000 (on dm-base). Therefore, all kind of analysing errors might accumulate in the NSP content. The soluble NSP content was calculated as the total NSP content minus the chemically analysed NDF content. In the current experiment, the two oat hull diets were classed as high insoluble NSP diets and the other NSP-high treatments as high soluble NSP diets. However, the oat hull treatments were not only specific in a low soluble NSP content but also in a high lignin content, compared with the other NSP-rich diets. The fact that lignin is insoluble (McPherson, 1985) is an extra argument to maintain these subclasses.
The source of dilution of the diet (NSP-low versus NSP-high diets) and the solubility of the NSP-sources (insoluble versus soluble NSP) had only little effect on egg performance parameters. Gizzard parameters and eating time, however, were affected by dilution source. Relative gizzard weight and gizzard content were higher, when the

hens were fed insoluble NSP-high diets, compared with hens that were fed soluble rich diets. Feeding NSP-high diets also resulted in an increased eating time during the first part of the experimental period, compared with the NSP-low treatments. Higher gizzard weight and enhanced eating time are indicators for reduced feather pecking behaviour.
Hartini *et al.*, (2003) performed a number of feeding experiments in which they used (in)soluble NSP-high diets. In line with the current experiment, they found that addition of NSP-high raw materials (like millrun, barley, rice hulls and oats) to the diet had no adverse effects on egg performance. Egg performance was also not affected by solubility of the NSP-source. In contrast with the current experiment, however, Hartini *et al.*, (2003) supplied isocaloric and isonitrogenous diets, whereas the nutrient density of the NSP-high diets in the current experiment was decreased with 10%.
Insoluble NSP plays an important role in modulating gut development and digestive function. Feeding a supplement of wood shavings (an insoluble NSP-high raw material) to laying hens fed wheat-based diets increased starch digestibility (Hetland and Choct, 2003a). The improvement of starch digestibility may, in part, be due to enhanced emulsification of lipids as a result of a higher content of bile acids in the gizzard. Possibly this phenomenon declares the improved hen-day egg production of the hens fed NSP-high diets in the current experiment. The total content of bile acids in the gizzard increased in proportion to the amount of wood shavings retained in the gizzard. Consumption of 4% of feed as wood shavings resulted in a 50% percent heavier gizzard of broiler chickens, whereas including 40% whole wheat in a wheat-based mash diet increased the gizzard weight by only 10% (Hetland *et al.*, 2002), indicating that wood shavings has a higher impact on gizzard weight than whole wheat. In line with these findings, we found in the current experiment no effect of course grinding on gizzard weight, whereas gizzard weight increased by feeding NSP-high diets.
The insoluble fibre content in the gizzard of chickens fed wood shavings was twice as much as the content in the feed (Hetland and Choct, 2003b). This suggests that insoluble fibre accumulates in the gizzard and is retained longer than other nutrients, probably because it has to be ground to a critical particle size before entering the small intestine (Hetland *et al.*, 2002, Hetland and Choct, 2003b). In line with this, birds fed an oat-based diet had a significantly heavier gizzard and a larger content of the gizzard compared with those fed a wheat-based diet when housed in cages (Hetland and Svihus, 2003). Coarse fibre also decreases the passage time of fine particles when it is fed to broiler chickens (Hetland and Svihus, 2001, Svihus *et al.*, 2002). The fact that insoluble fibre accumulates in the gizzard may also indicate a slower feed passage rate when the level of coarse fibre is increased in the diet. This confirms that the gizzard is almost like a point of regulation for digestion, selectively retaining different feed particles and letting nutrients pass for further digestion. It is thought that accumulation of insoluble fibre in the gizzard triggers a temporary satiety, but once passed the gizzard, it passes through the gut quickly. This could make the bird feel more satisfied between feeding bouts, but more hungry after gizzard emptying (Hetland and Choct, 2003a)
It is known that an increase in the oat hull content of the diet for growing and laying pullets can markedly reduce feather pecking and cannibalism. Increasing the crude fibre content from 29 to 123 g/kg (by substituting corn with oat hulls) decreased feather pecking and cannibalism (Bearse *et al.*, 1940). A number of studies have confirmed that the insoluble fibre fraction in the diets of laying hens is beneficial in preventing pecking behaviour (Aerni *et al.*, 2000, El Lethey *et al.*, 2000, Hartini *et al.*, 2002, Hetland and Choct, 2003a, Hartini *et al.*, 2003). Some experiments showed that both insoluble (mill run) and soluble (barley) fibre were effective in reducing and controlling cannibalism in laying hens (Hartini *et al.*, 2002; Hartini *et al.*, 2003).
Birds fed diets high in insoluble fibre spent more time eating and appear calmer than those fed low-fibre diets (Hetland and Choct, 2003a)..
The relationship between fibre content of the ration and prevention of feather pecking is only partially understood. Conceivably, it may be related to the increased consumption of feed resulting in a higher level of satiety, or the time occupied in eating. It was also postulated that ingestion of insoluble dietary fibre would increase gut viscosity and gut fill (Hartini *et al.*, 2002). However, due to the absence of feather pecking behaviour, the current experiment could not answer the question which dietary fibre source is most effective in reducing feather pecking behaviour.

Feather pecking behaviour

Although the main focus of this experiment was directed to the effect of energy dilution on egg performance of the hens, in the meanwhile we tried to induce feather pecking behaviour too. Because we have planned more experiments in the same accommodation, in which feather pecking behaviour is the most important objective, we tried to find the sensitive housing conditions for arousing feather pecking. Increasing light intensity seems to increase the level of severe feather pecking (Allen and Perry, 1975, Kjaer and Vestergaard, 1999). Laying hens that were reared in 3 lux developed stereotypic gentle feather pecking, showing about 20 times more gentle pecking than hens that were reared at 30 lux. Severe pecks, however, were 2 - 3 times more frequent in laying hens that were reared at 30 than at 3 lux. During the laying period, the immediate effects of the two light intensities on pecking behaviour were less pronounced than during rearing (Kjaer and Vestergaard, 1999). Savory

(1995) mentioned high risk of feather pecking and cannibalism when the light is bright and/or blue, and less risk when light is dimmed and/or red. Light colour may also play a role in social recognition in laying hens (D' Eath and Stone, 1999). Some authors suggested a threshold-model for the start up of feather pecking (El-Lethey *et al* (2000). The threshold needs to be exceeded by a cumulating number of stressors, before hens will start feather pecking. Light intensity could be such a stress factor for laying hens, resulting in an outbreak of feather pecking when it reaches a certain level. Other stressors could be increasing group size (Keeling, 1994, Bilcik and Keeling, 1999) or stocking density (Appleby *et al.*, 1988, Savory and Mann, 1999), whereas increasing age also could be a possible stressor (Huber Eicher and Sebo, 2001). To induce feather pecking behaviour in the current experiment the light intensity was increased from 10 to 60 lux during the experimental period, but feather pecking was not observed at all. Possibly, in the current experiment the amount of stress was not enough (light intensity too low, group size too small, hens were too young, or the combination of these factors was too favourable) to show feather pecking behaviour.

5 Conclusions

The most important conclusions of this experiment are:

- Laying hens at early lay that were fed NSP-low or NSP-high diets were able to compensate for 10% dietary dilution by a 10.5 and 8.0% higher feed intake, respectively. Feed intake of the soluble NSP diluted diets increased with 6.4%. Feeding crumble or coarsely ground mash did not affect feed intake.
- As a result of the higher rate of increase of hen-day egg production, hens that were fed low-NSP or high-NSP diets on average produced more eggs during this experiment, whereas coarse grinding of the diets tends to a lower egg production. Feed form has no effect on hen-day egg production.
- Coarse grinding of the diets negatively affects initial egg weight, whereas the rate of increase of egg weight decreases when the hens are fed NSP-high or coarse ground diets.
- Egg mass enhances by feeding NSP-low, and both soluble and insoluble NSP-high diets, and decreases by feeding coarse ground meal. Egg mass was not affected by feed form.
- Mean bodyweight of hens that were fed (in-) soluble NSP-high diets is higher than the control, whereas feeding of coarse ground meal reduces mean bodyweight.
- Feeding insoluble NSP-high diets increases full and empty gizzard weight and gizzard content. Coarsely ground diets increases full and empty gizzard weight.
- Eating time of the hens fed the undiluted diets increased over the experimental period from 16.4 to 24.6%, but was not affected by sand or grit addition, particle size distribution or feed form. Feeding NSP-high diets increased eating time with 22%, although eating time of the hens that were fed soluble NSP-high diets over week 7 and 9 was comparable with the undiluted diets.

Practical implications

Based on the literature, feeding diets diluted with NSP-free or NSP-high raw materials were expected to reduce feather pecking behaviour in laying hens. The hens should compensate for dietary dilution by higher feed intake, resulting in a higher proportion of time spend on feed intake, by which less time will remain for feather pecking. However, such feeding strategies may not reduce egg performance of the hens, which can be the case when hens are not able to fully compensate for the dilution.

From this experiment we can conclude that feeding low-NSP or high-NSP diets resulted in equal or even improved egg performance of hens at early lay compared with hens that were fed a standard diet. Feeding coarsely ground meal negatively affects egg production, egg weight, egg mass and body weight, whereas feed form did not affect egg performance. Although feather pecking behaviour in this experiment not occurred, some results of this study are indicating that insoluble NSP-rich diets can have anti feather pecking properties. Hens that were fed these diets spent more time on feed intake and had heavier relative gizzard weight and content. Increased eating time and gizzard weight are both indicators for more feed related behaviour and/or a higher satiety level of the hens, which can prevent feather pecking behaviour.

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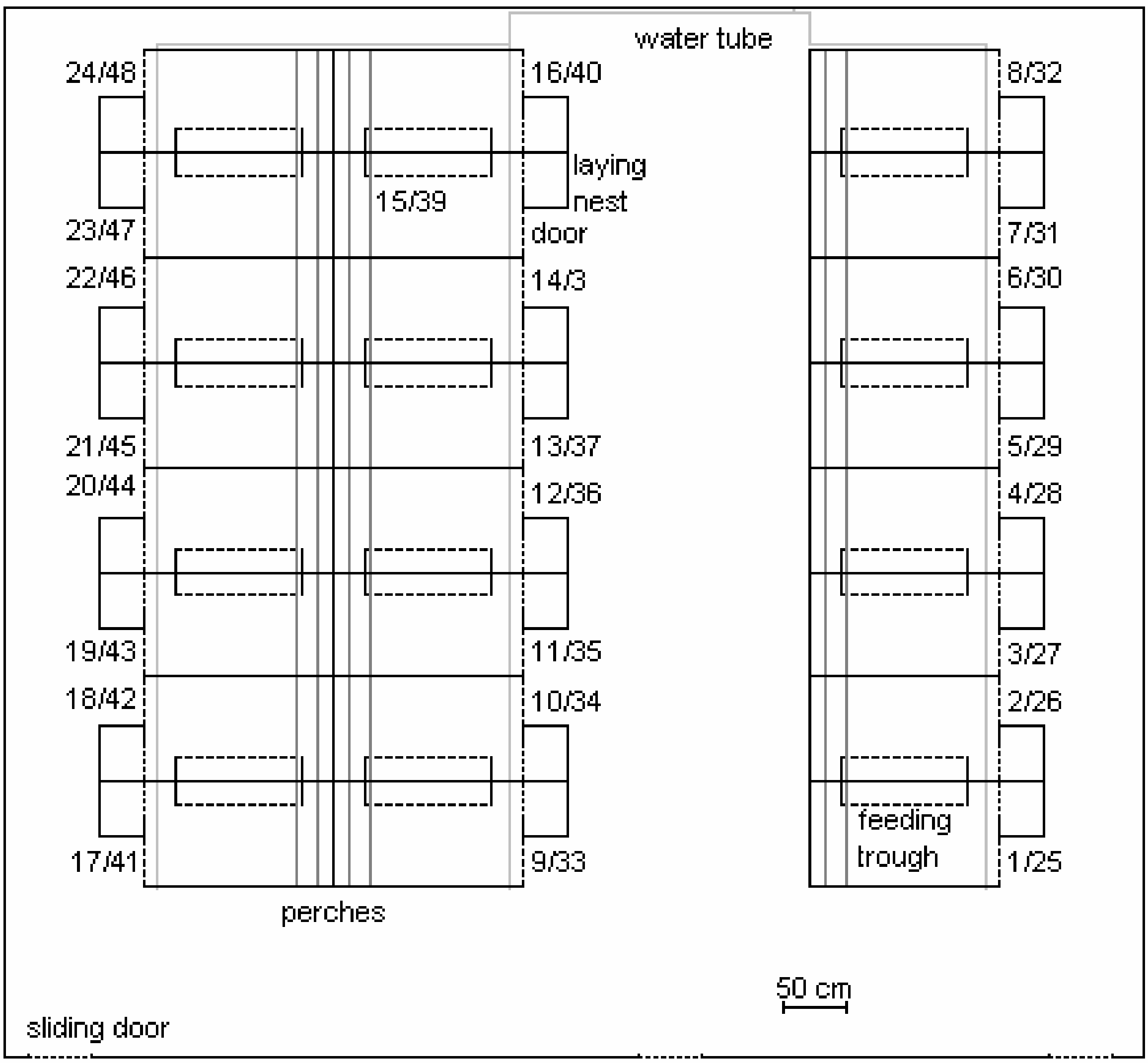
Appendix 1 Design of the experimental room



Appendix 2 Division of experimental treatments

Pen no	*Block no*	*Treatment no*
1	1	8
2	1	2
3	1	9
4	1	3
5	2	4
6	2	12
7	2	11
8	2	5
9	1	10
10	1	6
11	1	11
12	1	5
13	2	8
14	2	2
15	2	9
16	2	3
17	1	7
18	1	1
19	1	4
20	1	12
21	2	7
22	2	10
23	2	6
24	2	1

Pen no	*Block no*	*Treatment no*
25	3	1
26	3	12
27	3	9
28	3	2
29	4	9
30	4	7
31	4	6
32	4	8
33	3	8
34	3	11
35	3	10
36	3	4
37	4	1
38	4	3
39	4	2
40	4	12
41	3	7
42	3	5
43	3	6
44	3	3
45	4	5
46	4	11
47	4	10
48	4	4

Appendix 3 Diet composition

The composition of the experimental diets (%)

Diet no.	*1, 2*	*3, 4*	*5*	*6, 7*	*8*	*9*	*10*	*11*	*12*
Name	*Control*	*Sand*	*Grit*	*Oat hulls*	*Beet pulp*	*Arbocell*	*Soybean hulls*	*Straw*	*Commercial*
Ingredient									
Soybean oil	2.9	2.6	2.6	2.6	2.6	2.6	2.6	2.6	2.3
Chalk - fine grounded	2.0	1.8	1.8	1.8	1.8	1.8	1.8	1.8	1.8
Limestone	7.3	6.6	6.6	6.6	6.6	6.6	6.6	6.6	7.0
Monocalcium phosphate	0.80	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.70
Salt	0.37	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33
L-Lysine	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.07	
DL-Methionine	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.09
Maize	35.1	31.6	31.6	31.6	31.6	31.6	31.6	31.6	35.0
Wheat	30.0	27.0	27.0	27.0	27.0	27.0	27.0	27.0	16.5
Peas									12.5
Rapeseed, extracted	3.6	3.3	3.3	3.3	3.3	3.3	3.3	3.3	0.9
Soybean meal	17.3	15.5	15.5	15.5	15.5	15.5	15.5	15.5	12.4
Premix laying hen	0.50	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.48
Dried see sand		10.0							
Grit			10.0						
Oat hulls				10.0					
Beet pulp					10.0				
Arbocell						10.0			
Soybean hulls							10.0		
Wheat straw								10.0	
Sunflower seed, extracted									10.0

Calculated contents of the experimental diets (g/kg)

Diet no.	*1. 2*	*3. 4*	*5*	*6. 7*	*8*	*9*	*10*	*11*	*12*
Name	*Control*	*Sand*	*Grit*	*Oat hulls*	*Beet pulp*	*Arbocell*	*Soybean hulls*	*Straw*	*Commercial*
Nutrient									
DM	888	899	899	890	889	889	888	883	888
Ash	127	215	215	121	121	117	120	121	124
Protein (N x 6.25)	155	140	140	143	149	140	153	143	165
Fat	50	45	45	47	46	45	48	45	44
Crude Fibre	30	27	27	57	45	115	58	90	50
NDF	95.3	85.8	85.8	141.5	124.6	155.8	141.5	149.2	119.1
ADF	37.8	34	34	74.2	54.8	74	74.2	74	60.7
ADL	6.5	5.9	5.9	7.1	7.0	25.9	7.1	15.9	10.4
Ca	38.0	34.2	34.2	34.3	35.0	34.2	34.8	34.2	36.0
Avail. P	2.8	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.7
K	6.8	6.1	6.1	6.6	6.5	6.1	7.4	6.1	7.5
Na	1.5	1.3	1.3	1.4	1.4	1.3	1.3	1.3	1.4
Cl	2.8	2.5	2.5	2.6	2.6	2.5	2.5	2.5	2.5
Oelh	11.8	10.6	10.6	10.8	11.1	10.6	10.6	10.6	11.2
dLys	6.7	6.0	6.0	6.1	6.3	6.0	6.0	6.0	6.5
dMet	3.5	3.2	3.2	3.2	3.3	3.2	3.2	3.2	3.2
dM+C	5.8	5.2	5.2	5.3	5.4	5.2	5.2	5.2	5.2
dThr	4.5	4.1	4.1	4.2	4.2	4.1	4.1	4.1	4.9
dTrp	1.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.5
C18:2	24.0	21.6	21.6	22.4	21.6	21.6	23.0	21.6	21.3
C18:3	2.7	2.4	2.4	2.5	2.4	2.4	2.6	2.4	2.2
NSP	142	128	128	193	194	202	193	202	170

Appendix 4 Uncorrected feed intake data

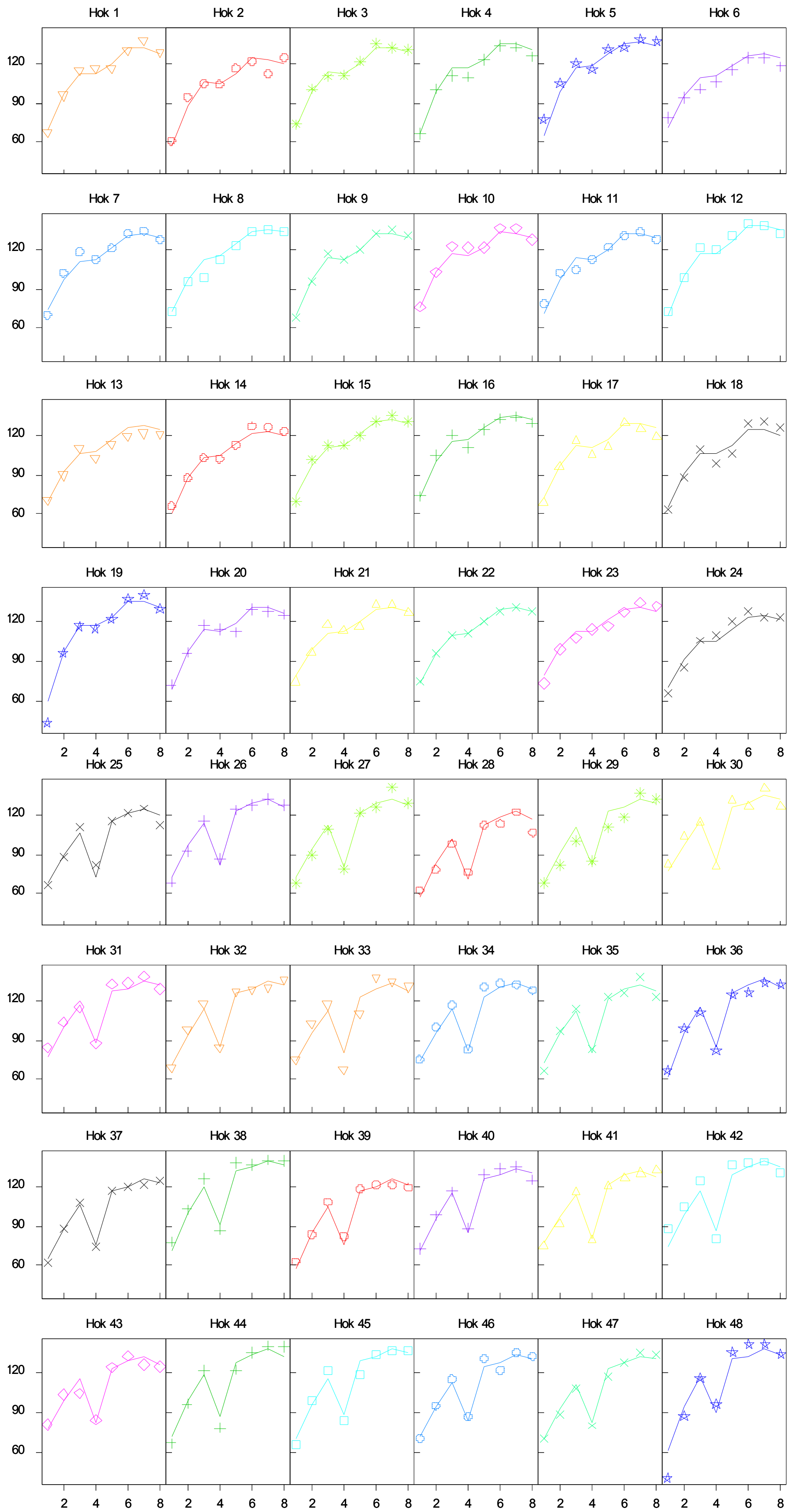
Uncorrected data of the average feed intake (g/hen/d) per treatment per week.

Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Week	Control	Control – Crumble	Sand	Sand – Crumble	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
1	64.7	63.3	71.1	57.1	74.5	78.6	75.3	70.7	69.9	70.2	73.6	73.2
2	87.2	86.0	101.0	96.2	99.2	102.3	97.1	96.4	93.3	94.2	99.7	95.2
3	108.2	103.5	119.6	115.8	116.5	112.3	115.8	115.0	107.6	112.3	113.6	112.3
4	90.7	91.2	96.4	102.1	99.7	101.7	94.6	92.7	97.1	96.7	98.6	98.7
5	114.9	114.9	126.9	128.2	126.9	123.6	119.2	116.4	118.3	120.1	126.0	119.8
6	124.6	120.8	134.4	134.4	136.2	132.2	128.8	128.7	127.3	128.3	129.4	128.6
7	125.0	120.4	136.9	137.8	137.3	133.8	131.6	130.9	135.8	134.8	133.8	129.8
8	121.5	118.3	133.5	133.1	133.2	128.1	126.2	129.2	130.3	129.1	128.9	123.8
Mean	**104.6**	**102.3**	**115.0**	**113.1**	**115.4**	**114.1**	**111.1**	**110.0**	**109.9**	**110.7**	**112.9**	**110.2**
Sd	**5.2**	**6.3**	**6.6**	**8.1**	**7.6**	**6.6**	**6.5**	**7.6**	**6.6**	**5.2**	**5.5**	**6.1**

Uncorrected data of the average feed intake (g/hen/d) per treatment class per week

Category	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
Treatments	1	3-5	6-11	5, 7-11	2, 4	8-12
1	64.7	67.6	73.1	72.4	60.2	71.5
2	87.2	98.8	96.9	96.6	91.1	95.8
3	108.2	117.3	112.7	113.5	109.7	112.2
4	90.7	99.4	97.1	96.5	96.7	96.7
5	114.9	127.3	120.5	121.2	121.5	120.1
6	124.6	135.0	129.1	129.8	127.6	128.5
7	125.0	137.3	132.9	134.0	129.1	133.0
8	121.5	133.3	127.9	129.5	125.7	128.3
Mean	**104.6**	**114.5**	**111.3**	**111.7**	**107.7**	**110.7**

Appendix 5 Modelled and realised feed intake (g/h/d) per week per pen



Appendix 6 Uncorrected hen-day egg production data

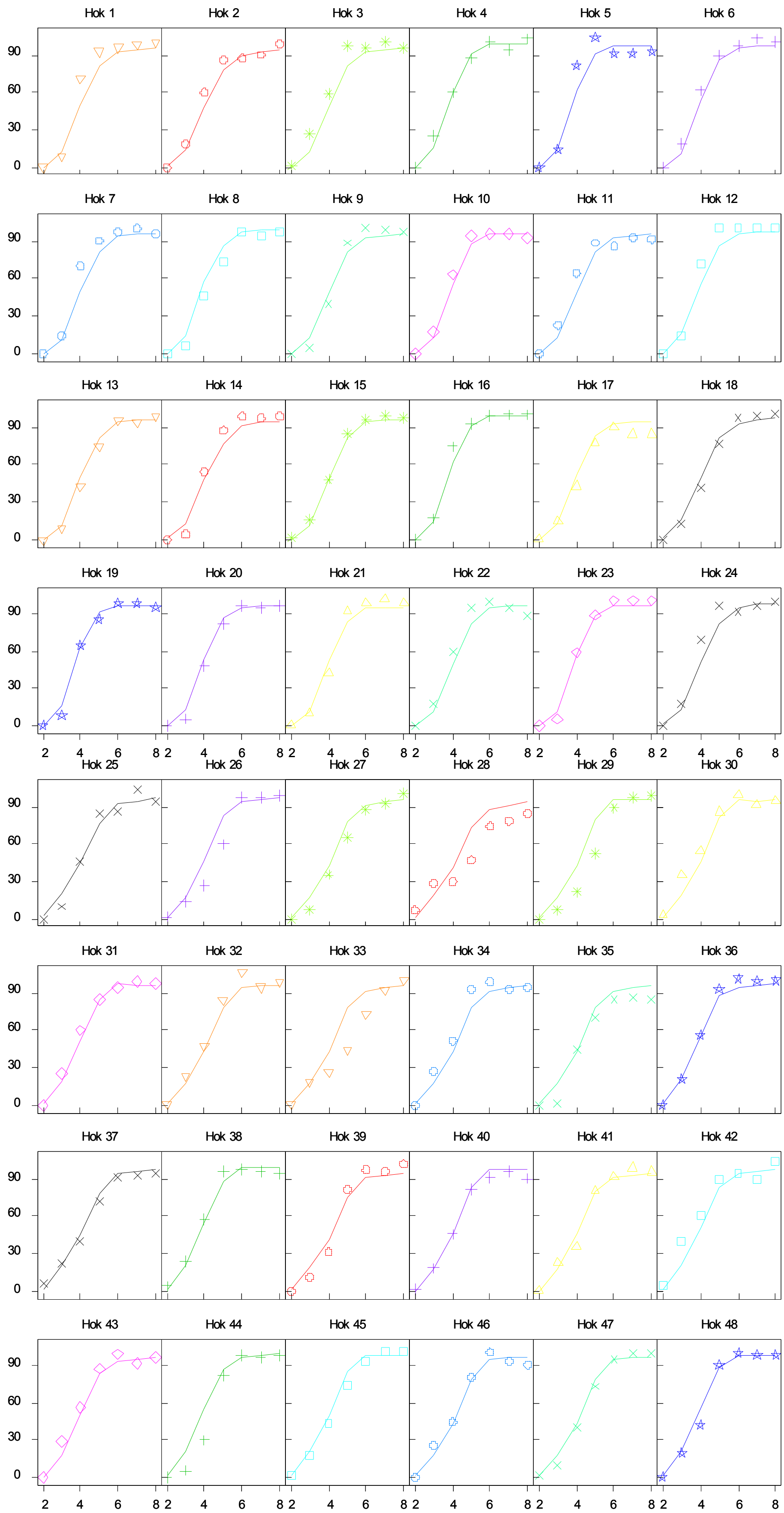
Uncorrected data of the average hen-day egg production (%) per treatment per week.

Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Week	Control	Control – Crumble	Sand	Sand – Crumble	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
1	1.4	1.8	1.1	0.0	1.4	0.0	0.7	0.7	0.7	0.4	0.0	0.7
2	16.1	15.7	18.2	16.1	19.6	19.3	20.7	14.6	14.3	8.2	22.5	14.3
3	48.9	43.9	55.4	60.7	55.0	59.3	43.9	47.1	41.1	46.1	57.5	45.7
4	82.1	75.4	89.3	93.2	84.3	88.6	83.6	73.9	75.0	81.4	87.9	78.2
5	91.4	89.3	98.2	97.9	96.1	97.1	94.6	92.5	91.8	94.3	95.4	95.4
6	97.5	90.4	96.4	96.8	96.1	96.4	93.9	94.6	97.1	94.3	94.6	97.5
7	96.8	95.7	98.6	96.1	100.7	96.4	93.2	99.3	97.9	92.1	92.9	96.1
Mean	**62.0**	**58.9**	**65.3**	**65.8**	**64.7**	**65.3**	**61.5**	**60.4**	**59.7**	**59.5**	**64.4**	**61.1**
sd	**5.5**	**9.5**	**5.5**	**5.2**	**6.7**	**3.4**	**5.7**	**8.2**	**6.9**	**6.1**	**4.5**	**5.6**

Uncorrected data of the average hen-day egg production per treatment class per week.

Category	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
Treatment	1	3-5	6-11	5, 7-11	2, 4	8-12
1	1.4	0.8	0.5	0.7	0.9	0.5
2	16.1	18.0	16.3	16.7	15.9	14.8
3	48.9	57.0	48.7	48.5	52.3	47.5
4	82.1	88.9	81.2	81.0	84.3	79.3
5	91.4	97.4	94.4	94.1	93.6	93.9
6	97.5	96.4	95.5	95.1	93.6	95.6
7	96.8	98.5	95.4	96.0	95.9	95.6
Mean	**62.0**	**65.3**	**61.7**	**61.7**	**62.3**	**61.0**

Appendix 7 Modelled and realised hen-day egg prod. (%) per week per pen



Appendix 8 Uncorrected egg-weight data

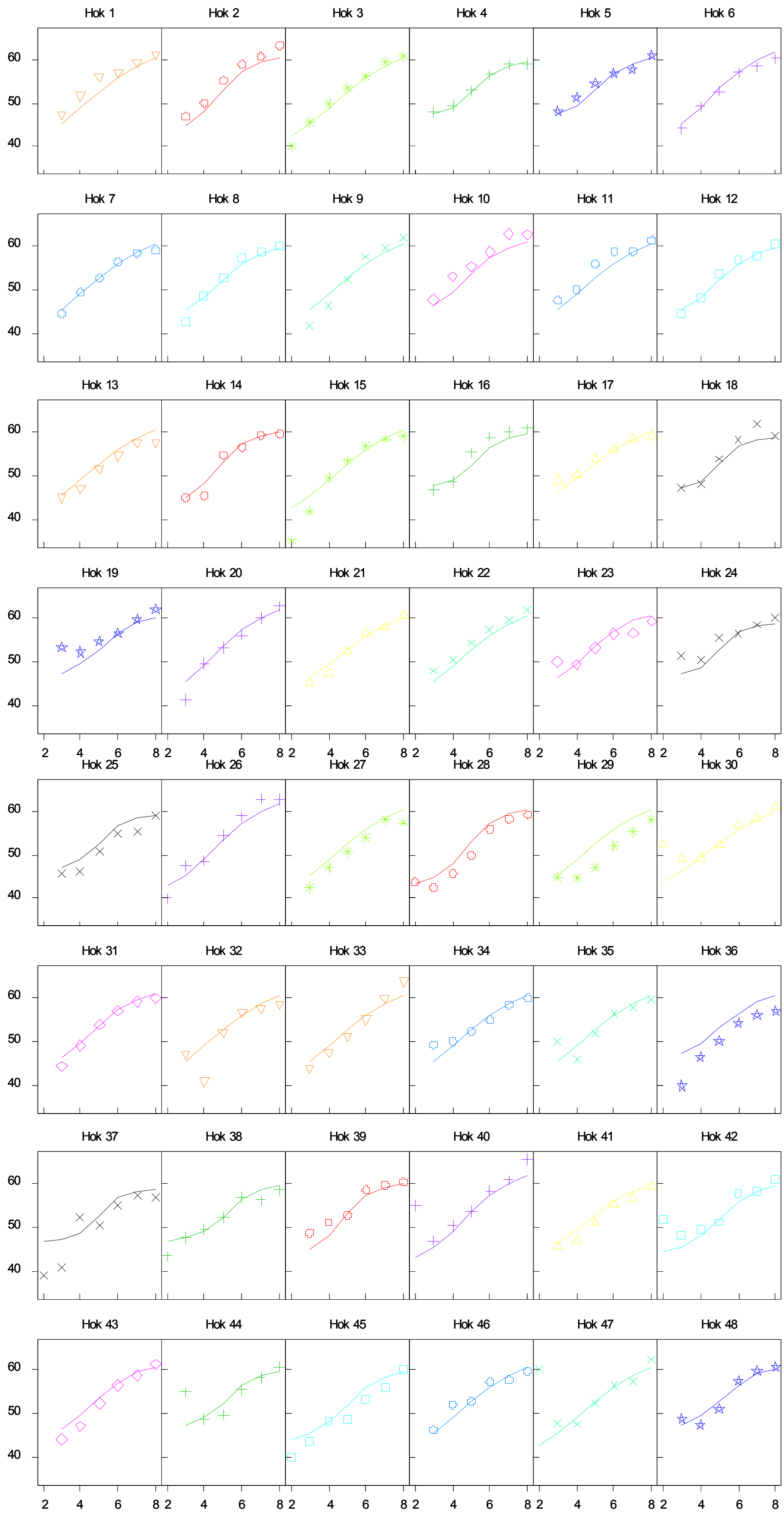
Uncorrected data of the average egg weight (g/egg) per treatment per week.

Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Week	Control	Control – Crumble	Sand	Sand – Crumble	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
1	39.0	44.0	43.0		46.0		52.0		37.5	60.0		47.5
2	46.5	45.8	49.5	47.5	44.3	46.5	47.3	46.0	43.8	47.0	46.8	45.0
3	49.3	48.0	49.3	49.0	48.5	49.5	48.3	47.0	48.0	47.5	50.3	49.5
4	52.8	53.3	52.5	52.5	51.5	53.5	52.5	52.8	51.3	52.5	53.5	53.8
5	56.3	57.8	57.0	56.5	56.3	57.5	56.3	56.0	54.8	57.3	56.8	57.8
6	58.3	59.5	58.3	58.5	57.8	59.5	58.0	58.8	57.8	58.8	58.3	60.5
7	58.8	60.5	60.0	60.3	60.5	60.8	60.0	60.5	59.0	61.5	60.0	63.0
Mean	**51.5**	**52.7**	**52.8**	**54.0**	**52.1**	**54.5**	**53.5**	**53.5**	**50.3**	**54.9**	**54.3**	**53.9**
sd	**2.5**	**2.1**	**1.8**	**2.8**	**2.6**	**2.0**	**1.3**	**2.2**	**2.4**	**1.6**	**1.4**	**3.0**

Uncorrected data of the average egg weight (g/egg) per treatment class per week.

Category	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
Treatment	1	3-5	6-11	5, 7-11	2, 4	8-12
1	39.0	44.5	49.3	48.9	44.0	48.3
2	46.5	47.1	46.0	45.8	46.6	45.7
3	49.3	48.9	48.6	48.3	48.5	48.5
4	52.8	52.2	52.8	52.3	52.9	52.8
5	56.3	56.6	56.6	56.2	57.1	56.5
6	58.3	58.2	58.8	58.2	59.0	58.8
7	58.8	60.3	60.7	60.3	60.4	60.8
Mean	**51.5**	**52.5**	**53.3**	**52.9**	**52.6**	**53.0**

Appendix 9 Modelled and realised egg-weight (g) per week per pen



Appendix 10 Uncorrected egg-mass data

Uncorrected data of the average egg-mass (g/hen/d) per treatment per week.

Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Week	Control	Control – Crumble	Sand	Sand – Crumble	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
1	2.2	3.1	1.9		1.4		1.5		0.5	0.9		0.7
2	7.4	7.1	8.8	7.4	9.0	8.7	9.9	6.7	6.3	3.9	10.6	6.5
3	24.2	21.1	27.2	30.2	26.7	29.5	21.4	22.3	19.9	22.0	28.9	22.7
4	43.4	40.4	47.0	49.1	43.5	47.6	43.8	39.3	38.8	43.0	46.9	41.9
5	51.6	51.4	56.0	55.2	54.2	55.6	53.3	51.9	50.4	53.8	54.1	55.0
6	56.8	53.9	56.4	56.5	55.5	57.3	54.4	55.5	56.2	55.4	55.3	59.1
7	56.9	58.2	59.1	57.9	60.8	58.7	56.1	59.9	57.7	56.8	55.8	60.4
Mean	**34.6**	**33.6**	**36.6**	**42.7**	**35.9**	**42.9**	**34.3**	**39.3**	**32.8**	**33.7**	**41.9**	**35.2**
Sd	**4.4**	**6.9**	**4.2**	**3.9**	**4.3**	**2.5**	**4.1**	**6.6**	**4.7**	**5.0**	**3.0**	**3.0**

Uncorrected data of the average egg-mass (g/hen/d) per treatment class per week.

Category	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
Treatment	1	3-5	6-11	5, 7-11	2, 4	8-12
1	2,2	1,6	0,9	1,1	3,1	0,7
2	7,4	8,4	7,5	7,7	7,3	6,8
3	24,2	28,0	23,8	23,5	25,7	23,2
4	43,4	46,6	43,0	42,6	44,8	42,0
5	51,6	55,1	53,4	52,9	53,3	53,0
6	56,8	56,1	56,2	55,4	55,2	56,3
7	56,9	59,3	57,9	57,8	58,0	58,1
Mean	**34,6**	**36,4**	**34,7**	**34,4**	**35,3**	**34,3**

Appendix 11 Uncorrected bodyweight data

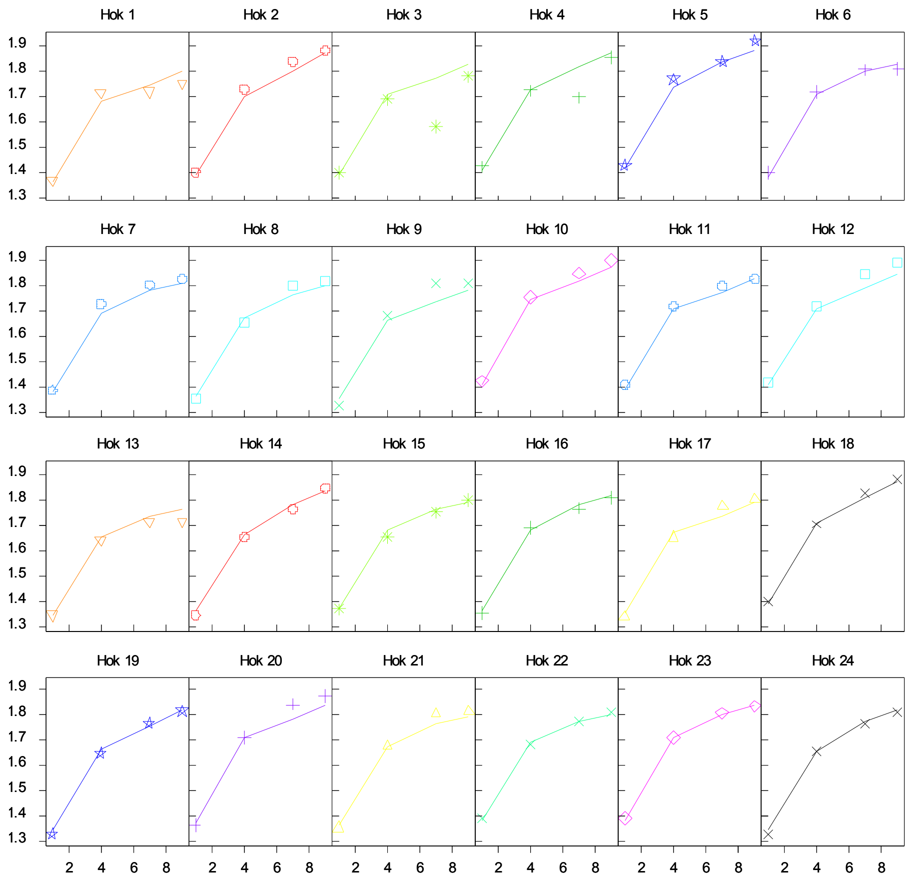
Uncorrected data of the average bodyweight (kg/hen) per treatment per week.

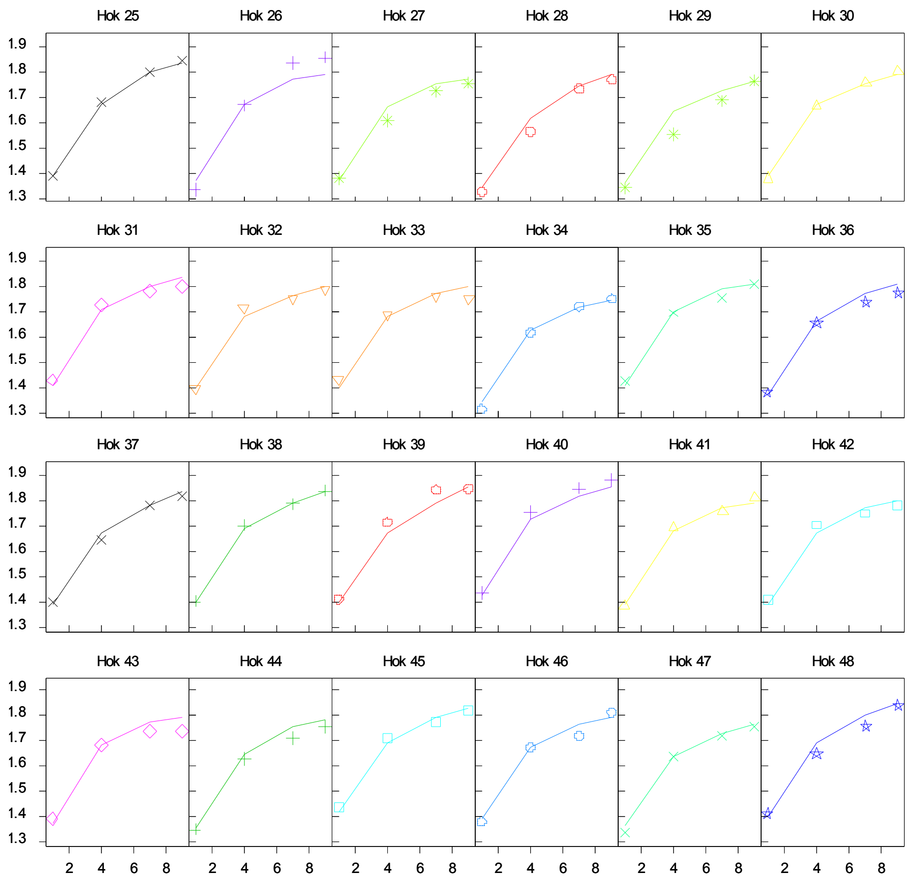
Treatment	1	2	3	4	5	6	7	8	9	10	11	12
Week	Control	Control – Crumble	Sand	Sand – Crumble	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet
1	1.380	1.371	1.382	1.385	1.404	1.409	1.364	1.387	1.372	1.371	1.372	1.382
4	1.671	1.665	1.685	1.681	1.698	1.719	1.672	1.690	1.625	1.673	1.683	1.712
7	1.791	1.794	1.740	1.774	1.792	1.794	1.774	1.735	1.684	1.761	1.760	1.832
9	1.839	1.836	1.814	1.837	1.827	1.817	1.808	1.752	1.775	1.795	1.803	1.854
Mean	**1.670**	**1.667**	**1.655**	**1.669**	**1.680**	**1.684**	**1.654**	**1.641**	**1.614**	**1.650**	**1.654**	**1.695**
sd	**0.029**	**0.059**	**0.043**	**0.054**	**0.038**	**0.047**	**0.016**	**0.028**	**0.052**	**0.030**	**0.044**	**0.030**

Uncorrected data of the average bodyweight (kg/hen) per treatment class per week.

Category	Control	NSP-	NSP+	Coarse grind.	Form crumble	NSP+ Sol.
Treatment	1	3-5	6-11	5, 7-11	2, 4	8-12
1	1.380	1.390	1.379	1.378	1.378	1.377
4	1.671	1.688	1.682	1.673	1.673	1.677
7	1.791	1.768	1.763	1.751	1.784	1.754
9	1.839	1.826	1.800	1.793	1.837	1.796
Mean	**1.670**	**1.668**	**1.656**	**1.649**	**1.668**	**1.651**

Appendix 12 Modelled and realised egg-weight (g) per week per pen





Appendix 13 Effect of individual diet on egg performance per period

Effect of individual diet on feed intake, rate of lay, egg mass, bodyweight (gain) and feed conversion ratio per period

	1	2	3	4	5	6	7	8	9	10	11	12		
Treatment	Control	Control	Sand	Sand	Grit	Oat hulls (fine)	Oat hulls (coarse)	Beet pulp	Arbocell	Soya hulls	Straw	Com. Anti FP diet		
Feed Form	Meal	Crumble	Meal	Crumble	Meal	Meal	Meal	Meal	Meal	Meal	Meal	Meal	P-value	LSD
Feed intake (g/hen/d)[1]														
Period 1	86.69^{ab}	84.25^{a}	97.23^{d}	96.71^{d}	96.75^{d}	97.70^{d}	96.04^{d}	94.04^{cd}	90.27^{bc}	92.21^{bcd}	95.63^{cd}	93.56^{cd}	<0.001	5.730
Period 2	110.07^{ab}	108.97^{a}	119.26^{def}	121.58^{f}	120.92^{ef}	119.15^{def}	114.23^{abcd}	112.60^{abc}	114.21^{abcd}	115.03^{bcd}	117.98^{def}	115.71^{cde}	<0.001	5.344
Period 3	123.25^{ab}	121.05^{a}	135.20^{e}	135.48^{e}	135.24^{e}	130.35^{cde}	128.86^{cd}	130.04^{cd}	133.04^{de}	131.92^{cde}	131.30^{cde}	126.82^{bc}	<0.001	5.156
Rate of lay (%)														
Period 1	5.83	5.83	6.43	5.36	7.02	6.43	7.14	5.12	5.00	2.86	7.50	5.00	0.790	4.583
Period 2	74.2	69.5	81.0	83.9	78.5	81.7	74.0	71.2	69.3	73.9	80.2	73.1	0.124	11.09
Period 3	97.14	96.67	97.50	96.43	98.39	97.05	93.57	96.96	97.50	93.21	93.75	96.79	0.583	5.362
Egg mass (g/hen/d)														
Period 1	2.64	2.62	3.08	2.47	3.25	2.91	3.41	2.34	2.19	1.36	3.54	2.29	0.753	2.138
Period 2	39.69	37.67	43.37	44.83	41.47	44.20	39.50	37.83	36.37	39.60	43.29	39.87	0.134	6.230
Period 3	56.89	58.53	57.73	57.18	58.16	57.76	55.26	57.68	56.95	56.07	55.52	59.74	0.426	3.581
Bodyweight (kg)														
Period 1	1.67	1.67	1.69	1.68	1.70	1.72	1.67	1.69	1.63	1.67	1.68	1.71	0.223	0.05881
Period 2	1.79^{bc}	1.79^{bc}	1.74^{ab}	1.77^{bc}	1.79^{bc}	1.79^{bc}	1.77^{bc}	1.74^{ab}	1.68^{a}	1.76^{b}	1.76^{b}	1.83^{c}	0.005	0.06074
Period 3	1.84^{cd}	1.84^{cd}	1.81^{bcd}	1.84^{cd}	1.83^{cd}	1.82^{bcd}	1.81^{bcd}	1.75^{a}	1.77^{ab}	1.79^{abc}	1.80^{bc}	1.85^{d}	0.013	0.05066
Bodyweight gain (%)														
Period 1	21.09^{b}	21.41^{bc}	21.99^{bc}	21.37^{b}	20.95^{ab}	22.01^{bc}	22.64^{bc}	21.89^{bc}	18.42^{a}	22.06^{bc}	22.67^{bc}	23.91^{c}	0.037	2.531
Period 2	7.23	7.82	3.27	5.57	5.56	4.36	6.10	2.68	3.78	5.31	4.58	7.03	0.284	4.112
Period 3	2.68	2.36	4.33	3.56	1.95	1.29	1.91	1.00	5.53	1.92	2.48	1.21	0.091	2.882
Feed conversion Ratio[2]														
Period 2	2.79	2.98	2.52	2.48	2.67	2.45	2.64	2.83	2.93	2.66	2.48	2.78		
Period 3	2.17	2.14	2.13	2.16	2.11	2.05	2.13	2.05	2.13	2.15	2.15	2.02		

[1] Different superscripts within a row means significantly different ($p<0.05$)
[2] Corrected for level of dilution

Appendix 14 Uncorrected gizzard data

Uncorrected gizzard parameters per treatment (g/kg hen)

Treatment		Full gizzard weight	Gizzard content	Empty gizzard weight	Gizzard score
1	Control	23.7	13.6	14.5	0.38
2	Control – Crumble	22.7	13.2	13.2	0.63
3	Sand	26.6	11.9	14.9	0.50
4	Sand – Crumble	23.0	10.7	13.7	0.88
5	Grit	29.3	13.7	16.8	1.25
6	Oat hulls (fine)	34.8	15.5	20.7	0.63
7	Oat hulls (coarse)	36.0	17.2	22.2	0.88
8	Beet pulp	29.0	13.3	17.1	1.50
9	Arbocell	19.9	10.4	14.0	0.75
10	Soya hulls	26.2	10.5	14.7	0.50
11	Straw	31.9	13.5	18.3	1.00
12	Com. Anti FP diet	23.8	12.6	13.9	0.75

Uncorrected gizzard parameters per treatment category (g/kg hen)

Treatment class	Full gizzard weight	Gizzard content	Empty gizzard weight	Gizzard score
Control	23.7	13.6	14.5	0.38
NSP-	26.3	12.1	15.1	0.88
NSP+	28.8	13.3	17.3	0.86
Coarse grind.	28.0	13.0	16.7	0.90
Form crumble	22.8	12.0	13.5	0.75
NSP+ Sol.	26.2	12.1	15.6	0.90

Appendix 15 Uncorrected eating time data

Treatment		Week	Period 1	Period 2	Period 3	Eating time (%)
1	Control	4	15,76		17,68	16,72
1	Control	7	17,24	27,34	13,96	19,51
1	Control	9		27,15	22,86	25,00
2	Control – Crumble	4	12,83	15,92	21,00	16,58
2	Control – Crumble	7	16,55		20,84	18,69
2	Control – Crumble	9		26,47	25,79	26,13
3	Sand	4	14,45		23,68	19,06
3	Sand	7		24,48		24,48
3	Sand	9	27,64		25,34	26,49
4	Sand – Crumble	4		9,24	24,23	16,73
4	Sand – Crumble	7	19,24		23,70	21,47
4	Sand – Crumble	9	20,61	32,94		26,78
5	Grit	4	13,35	18,30	23,17	18,27
5	Grit	7	21,98	27,09		24,53
5	Grit	9	30,98	23,53	28,31	27,61
6	Oat hulls (fine)	4		20,04	31,09	25,56
6	Oat hulls (fine)	7	26,57	26,71	40,33	31,20
6	Oat hulls (fine)	9	27,80	23,54	26,31	25,88
7	Oat hulls (coarse)	4		17,80	22,46	20,13
7	Oat hulls (coarse)	7	22,62		29,45	26,03
7	Oat hulls (coarse)	9	25,40	36,19	22,45	28,01
8	Beet pulp	4	13,79	23,54	26,41	21,24
8	Beet pulp	7	14,14		21,81	17,97
8	Beet pulp	9		22,45		22,45
9	Arbocell	4		18,56	34,22	26,39
9	Arbocell	7	24,41		26,52	25,47
9	Arbocell	9	23,78	25,68		24,73
10	Soya hulls	4		17,12	27,21	22,16
10	Soya hulls	7	29,69	7,58	18,74	18,67
10	Soya hulls	9	22,71	23,05	23,94	23,23
11	Straw	4	18,97	16,98		17,98
11	Straw	7		25,09	21,96	23,52
11	Straw	9	26,26	30,08	29,52	28,62
12	Com. Anti FP diet	4	22,62	18,94		20,78
12	Com. Anti FP diet	7	18,32	16,89	17,03	17,41
12	Com. Anti FP diet	9	20,16		28,14	24,15