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EFFECT OF FEEDING SILAGES OR CARROTS AS SUPPLEMENTS TO LAYING HENS ON PRODUCTION PERFORMANCE, NUTRIENT DIGESTIBILITY, GUT STRUCTURE, GUT MICROFLORA AND FEATHER PECKING BEHAVIOUR

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EFFECT OF FEEDING SILAGES OR CARROTS AS SUPPLEMENTS TO LAYING HENS ON PRODUCTION PERFORMANCE, NUTRIENT DIGESTIBILITY, GUT STRUCTURE, GUT MICROFLORA AND FEATHER PECKING BEHAVIOUR

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3 1 **Effect of feeding silages or carrots as supplements to laying hens on production**
4
5 2 **performance, nutrient digestibility, gut structure, gut microflora and feather pecking**
6
7 3 **behaviour**
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22 10
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27 11 Short title: FORAGING MATERIAL FOR LAYING HENS
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53 22 **Abstract.** 1. An experiment was carried out to examine the suitability of using maize
54
55 23 silage, barley-peas silage and carrots as foraging materials for egg-laying hens. Production
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3 24 performance, nutrient digestibility, gastrointestinal characteristics, including the
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5 25 composition of the intestinal microflora as well as feather pecking behaviour were the
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7
8 26 outcome variables.
9
10 27 2. The protein content of the foraging material (g/kg DM) was on average 69 g in carrots
11
12 28 94 g in maize silage and 125 g in barley-pea silage. The starch content was highest in the
13
14 29 maize silage (312 g/kg DM), and the content of NSP varied from 196-390 g/kg, being
15
16 30 lowest in carrots. Sugars were just traceable in the silages, whereas carrots contained on
17
18 31 average 496 g/kg DM.
19
20 32 3. Egg production was highest in hens fed either carrots or maize-silage, whereas hens fed
21
22 33 barley-pea silage produced less (219 vs. 208). Although the consumption of foraging
23
24 34 material was high (33%, 35% and 48% of the total feed intake on "as fed" basis for maize
25
26 35 silage, barley-pea silage and carrots, respectively) only a minor effect on AME_n and
27
28 36 apparent digestibility was seen. At 53 weeks of age, hens fed maize silage had AME_n and
29
30 37 apparent digestibility values close to the control group (12.61 and 12.82, respectively),
31
32 38 whereas access to barley-pea silage and carrots resulted in slightly lower values (12.36 and
33
34 39 12.42, respectively). Mortality was reduced dramatically in the three groups given
35
36 40 supplements (0.5-2.5%) compared to the control group (15.2%).
37
38 41 4. Hens receiving silage had greater relative gizzard weights than the control or carrot-fed
39
40 42 groups. At 53 weeks of age, the gizzard-content pH of hens receiving silage was about 0.7-
41
42 43 0.9 units lower than that of the control or carrot-fed hens. Hens fed both types of silage had
43
44 44 higher concentrations of lactic acid (15.6 vs. 3.2 $\mu\text{mol/g}$) and acetic acid (3.6 vs. 6.1
45
46 45 $\mu\text{mol/g}$) in the gizzard contents than the other two groups. The dietary supplements had a
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48 46 minor effect on the composition of the intestinal microflora of the hens.
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4 47 5. Access to all three types of supplements decreased damaging pecking in general (to
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6 48 feathers as well as skin/cloaca), reduced severe feather pecking behaviour and improved
7
8 49 the quality of the plumage at 54 weeks of age.

9
10 50 6. In conclusion, access to different types of foraging material such as silages and carrots
11
12 51 improved animal welfare.

13 14 15 INTRODUCTION

16
17 53 Non cage housing systems for egg production (single or multiple tier systems with or
18
19 54 without access to range area) have expanded markedly in Denmark within the last 15
20
21 55 years, due mainly to changes in consumer preference. In Denmark, the market share of
22
23 56 organic eggs was 14.1% of all eggs in retail in 2005 (Danish Poultry Council, 2006), a
24
25 57 trend which reflects an increased interest and concern related to our environment, animal
26
27 58 welfare and product quality. Unfortunately, it has been demonstrated in many cases that
28
29 59 egg production in alternative housing systems is facing welfare problems in terms of
30
31 60 feather pecking and cannibalism. Outbreaks of feather pecking and cannibalism can be
32
33 61 caused by a number of factors such as genetic background of the high productive strains
34
35 62 used (Kjaer *et al.*, 2001), dietary deficiencies (Ambrosen and Petersen, 1997) or
36
37 63 environmental conditions (Savory, 1995; Kjaer and Sørensen, 2002). The Danish law
38
39 64 requires that hens in organic egg production have access to some high-fibre feed
40
41 65 ingredients such as silages, straw, grass, sugar beets or carrots. In general, feeding with
42
43 66 forage seems to have a positive effect on behaviour, and available foraging material in the
44
45 67 housing system motivates the hens to spend more time foraging and less feather pecking
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47 68 (Blokhuys, 1986; Nørgaard-Nielsen *et al.*, 1993; Aerni *et al.*, 2000).

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49 69 Feeding poultry with whole cereals, oat hulls or wood shavings having a
50
51 70 large particle size and more structure than pelleted feed stimulates the upper part of the
52
53 71 intestinal system and increases gizzard weight and activity (Gabriel *et al.*, 2003; Hetland

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4 72 and Svihus, 2001; Hetland *et al.*, 2003, Engberg *et al.*, 2004). Furthermore, an increased
5
6 73 content of structural components, such as whole grains, is claimed to have a beneficial
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8 74 effect on gastrointestinal health, probably due to increased hydrochloric acid secretion and
9
10 75 a fall in gizzard pH, which inhibits acid-sensitive potentially-pathogenic bacteria like
11
12 76 *Salmonella* from entering the lower intestinal tract (Engberg *et al.*, 2004; Bjerrum *et al.*,
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14 77 2005). Other coarsely-structured feeds may have a comparable effect on the
15
16 78 gastrointestinal tract, as shown for maize silage by Idi *et al.* (2005).

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20 79 The nutritive value of silages to poultry may be minimal, because it has a
21
22 80 high content of dietary fibre (non-starch polysaccharides ~ NSP + lignin) which, due to the
23
24 81 lack of endogenous fibre-degrading enzymes in the intestine (Scott *et al.*, 1982), is poorly
25
26 82 digested by poultry (Longstaff and McNab, 1989; Carré *et al.*, 1990; Steinfeldt *et al.*,
27
28 83 1998; Lazaro *et al.*, 2003). A high intake of soluble NSP can depress performance and the
29
30 84 digestibility of other nutrients in broilers (Choct and Annison, 1992a; Steinfeldt, 2001), in
31
32 85 part because of increased microbial activity (Choct *et al.*, 1996; Smits *et al.*, 1998;
33
34 86 Langhout *et al.*, 1999). In contrast to soluble fibre, the insoluble fibre fraction is not much
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36 87 fermented by the microflora (Choct *et al.*, 1996).

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41 88 Diets with moderate amounts of insoluble fibre can improve starch
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43 89 digestibility in broilers or laying hens (Svihus and Hetland, 2001; Hetland *et al.*, 2002,
44
45 90 2003) and reduce pecking at other birds and mortality from cannibalism in layers (Hartini
46
47 91 *et al.*, 2003). If the use of foraging material is to be recommended in practice in alternative
48
49 92 production systems for laying hens, it is important to know how it may influence different
50
51 93 aspects of production. The purpose of the present study was to examine the effect of using
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53 94 different foraging materials as feed supplements to laying hens on egg production, nutrient
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55 95 digestibility, gastrointestinal characteristics including the composition of the intestinal
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3 96 microflora, as well as aspects of feather pecking behaviour and plumage condition. In the
4
5 97 present investigation maize silage, barley-pea silage and carrots were used as forages.
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10 MATERIAL AND METHODS

11 **Diet, foraging material and treatments**

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15 101 The basal layer diet was formulated to contain the nutrients recommended (NRC, 1994) for
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17 102 commercial layer diets but was based on Danish-grown raw ingredients, with the exception
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19
20 103 of soyabean meal (Table 1.)
21

22 **Table 1**

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24
25 105 The control group received the layer diet without any supplement, whereas
26
27 106 hens in the other three treatments were fed supplemental foraging material, provided as
28
29 107 maize-silage, or barley-pea-silage, or carrots. The supplements were given unprocessed
30
31 108 (carrots as cleaned, uncooked roots), and the daily amounts were slightly increased during
32
33 109 the experimental period in order to achieve an approximate *ad libitum* intake during the
34
35 110 light hours of the day. The layer diet was provided as 3 mm pellets and fed *ad libitum* over
36
37 111 the entire experimental period. The treatments will be referred to as LD (layer diet without
38
39 112 supplements), LD+MS (layer diet + maize silage), LD+BS (layer diet + barley-pea silage)
40
41 113 and LD+C (layer diet + carrots). The experiment was performed over a period of 238 d,
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43
44 114 from the age of 20 to 54 weeks.
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48 **Birds, housing and experimental design**

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50 116 A total of 800 ISA Brown pullets were obtained from a commercial company at 16 weeks
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52 117 of age and placed in 16 identical indoor floor pens with 50 birds/pen, each with a floor area
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54 118 of 8.9 m². The hens were not beak trimmed because this process would probably hamper
55
56 119 the hens ability to fully exploit the foraging material. In addition, beak trimming is not
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59 120 allowed in organic egg production in Denmark (Danish Ministry of Justice, 1998:
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3 121 Bekendtgørelse nr. 210 af 6/4-1998). The lighting programme was 12L:12D at 16 weeks.
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5 122 Day length was gradually increased by 1 h per week to 16L:8D at 19 weeks. The 16L:8D
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7 123 programme was planned to continue until termination of the experiment at 54 weeks of
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9 124 age. However, a 23L:1D programme was introduced in error when the hens were 27 weeks
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11 125 of age. The mistake was discovered when the hens were 39 weeks; thereafter the light
12
13 126 programme was corrected gradually by reducing day length by 1 h per week until a
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15 127 16L:8D programme was reached at 46 weeks and continued for the rest of the experiment.
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18 128 The number of hens was reduced to 43 hens per pen after 5 weeks, when the hens were 23
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20 129 weeks old. The 4 experimental treatments were allocated at random to the 16 floor pens, to
21
22 130 provide 4 replicates. The bedding material was wood shavings. The basal diet was given *ad*
23
24 131 *libitum* in one round feeder (34 cm diameter) and water was supplied by nipple drinkers.
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26 132 Each pen was equipped with 9 single nests in a battery, each 28 cm wide. Adjacent pens
27
28 133 were separated by thin wooden walls 160 cm high and with wire mesh above (total 200
29
30 134 cm), which allowed auditory contact but prevented visual contact between hens from
31
32 135 separate pens and treatments. Supplementation with maize silage or barley-pea silage or
33
34 136 carrots started at 20 weeks of age, with fresh material fed each morning in a wooden box
35
36 137 (height: 40 cm, length: 50 cm, width: 40 cm). Eggs were collected and recorded from nests
37
38 138 every day, and the collection of one day per week was weighed. Feed consumption was
39
40 139 recorded every second week. Egg production and feed consumption were calculated on a
41
42 140 hen-day basis (taking into account the actual number of hens housed per floor pen at the
43
44 141 time of recording). Mortality was noted daily, and body weight was recorded at 25, 39
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46 142 and 54 weeks of age. The experiment complied with the guidelines of the Danish Ministry
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48 143 of Justice with respect to animal experimentation and care of birds under study.
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144 **Digestibility experiments and calculations**

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3 145 At the age of 23 and 53 weeks, respectively, digestibility experiments were performed in
4
5 146 battery cages with raised floors, each of the three batteries contained 12 cages (50x50x50
6
7 147 cm), each with a feeding trough outside and two water cups inside. Two hens were taken at
8
9 148 random from each pen and placed in one cage, representing one replicate. The 4 treatments
10
11 149 were assigned at random, each treatment being represented in each battery and on each tier.
12
13 150 Supplements were given fresh in small portions, once in the morning and once in the
14
15 151 afternoon and after the adaptation period of 7 d, the excreta were collected quantitatively
16
17 152 on three consecutive days. Pelleted feed and supplements were weighed separately.
18
19 153 Excreta were collected three times per day and stored in closed containers at 20°C,
20
21 154 immediately after collection to prevent microbial degradation. In addition, two hens per
22
23 155 replicate were fed with the silages or carrots alone without access to layer diet to give an
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25 156 indication of the DC of organic matter and AME of the supplements.
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32 157 The content of polysaccharide residues was calculated as anhydrosugars, and apparent
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34 158 digestibility coefficients were calculated according to the analysed content of nutrients (g/kg
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36 159 DM) in feed (layer diet plus supplements, analysed separately) and in excreta, taking into
37
38 160 account the amount of feed eaten (g) and excreta voided (g) on a dry matter basis. The AME_n
39
40 161 content was calculated as the difference between gross energy content in feed eaten (layer diet
41
42 162 and supplement, separately) and the gross energy in excreta, and corrected to zero N-retention
43
44 163 using a value of 34 kJ/g N retained (Hill and Anderson, 1958). N-retention was determined as
45
46 164 (N in feed – N in excreta)/g feed intake.
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50 165 **Chemical analyses**

51
52 166 The dry matter (DM) content of the layer diet, foraging material and excreta was determined
53
54 167 by drying at 105°C for 8 h. Protein (N x 6.25) was determined by the Kjeldahl method 984.13
55
56 168 (AOAC, 1990a) using a Kjell-Foss 16200 autoanalyser and energy by a LECO AC 300
57
58 169 automated calorimeter system 789-500 (LECO, St. Joseph, Michigan, USA). Ash was
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3 170 analysed according to method 923.03 (AOAC, 1990b), and fat (hydrochloric acid-fat) was
4
5 171 extracted with diethyl ether after acid-hydrolysis (Stoldt, 1952). Amino acids were analysed
6
7 172 as described by Mason *et al.* (1980). The sugars (glucose, fructose and sucrose), and the
8
9 173 oligosaccharides (raffinose, stachyose and versbascose) were extracted with 50% (v/v)
10
11 174 ethanol at 60°C and quantified by gas-liquid chromatography (GLC) using the method of
12
13 175 Bach Knudsen and Li (1991). Starch was analysed by the enzymatic-colorimetric method of
14
15 176 Bach Knudsen (1997). Total NSP and their constituent sugars were determined as alditol
16
17 177 acetates by gas-liquid chromatography for neutral sugars and by the colorimetric method for
18
19 178 uronic acids using a modification of the Uppsala procedure (Theander *et al.*, 1994) as
20
21 179 described by Back Knudsen (1997). Cellulose was determined as the difference in glucose
22
23 180 content of NSP when the swelling step with 12 M sulphuric acid was included and omitted,
24
25 181 respectively, and the content of cellulose, non-cellulosic (NCP) and soluble NSP was
26
27 182 calculated as described by Bach Knudsen (1997). Klason lignin was measured gravimetrically
28
29 183 as the residue obtained of the treatment with 12 M sulphuric acid (Theander *et al.*, 1994). All
30
31 184 analyses were performed in duplicate.

185 **Gastrointestinal characteristics and intestinal microflora**

186 At 23 and 53 weeks of age, 5 hens from each pen were killed by cervical dislocation and
187 the contents of the gizzard, jejunum, ileum, caeca and rectum were quantitatively collected
188 and pooled by segment before further analyses. Jejunum and ileum were defined as the
189 intestinal segments cranial and caudal to the Meckels diverticulum. The weight of the
190 contents in gizzard, jejunum, ileum and caeca as well the weight of the empty
191 gastrointestinal segments were measured. The pH-value of the contents in all segments was
192 measured with a combined glass/reference electrode (GK 2401C, Radiometer, Denmark),
193 and the dry matter of intestinal contents was analysed after freeze drying of the samples. In
194 gastrointestinal contents, coliform bacteria, lactose-negative enterobacteria, lactic acid

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3 195 bacteria and enterococci were enumerated as described by Engberg *et al.* (2004).
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5 196 Concentrations of short chain fatty acids and lactic acid were analysed (Jensen *et al.*,
6
7 197 1995).
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10 11 198 **Behavioural and clinical recordings** 12

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14 199 Recordings of allo-pecking (pecking of one bird by another) were made at 24, 38 and 53
15
16 200 weeks of age. Every pen was observed for 20 min at each age. All pecks at other chickens
17
18 201 were recorded. Each peck was counted, and recorded in groups (events) called bouts. A
19
20 202 bout was defined as pecks in a continuous series directed to the same chicken and body
21
22 203 part (plumage, beak or feet) and of the same type (see below). The inter-bout interval was
23
24 204 10 s. Pecks were classified: 1) severe feather pecking, 2) gentle feather pecking, 3)
25
26 205 aggressive pecking, 4) beak pecking, 5) object pecking and 6) pecking at dust particles on
27
28 206 dustbathing birds. The two last categories were rarely seen and discarded from further
29
30 207 analyses. The distinction between non-aggressive and aggressive pecks was in most cases
31
32 208 quite clear, aggressive pecks being vigorous, directed towards the head region and forcing
33
34 209 the receiver to react (escape or fight) (Hoffmeyer, 1969; Wennrich, 1975). At 25, 39 and
35
36 210 54 weeks of age a random sample of 15 birds per pen were individually scored for the
37
38 211 condition of plumage and skin, as well as for health status of feet and comb. Body weight
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40 212 was also recorded. Plumage and skin condition were scored individually (Tauson *et al.*,
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42 213 2005), assigning scores of 1, 2, 3 and 4 points for each character. Higher scores means
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44 214 better health. Plumage condition was scored for each of 5 body parts (neck, breast, back,
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46 215 wings and tail). The sum of these 5 scores ('total score', 5 to 20 points) was also used for
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48 216 analyses. Less than 1% of birds had wounds (skin score of body part less than 4) and
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50 217 therefore these data were discarded from further analysis.
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58 218 **Statistical analyses** 59 60

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3 219 A randomised complete block design was used, a single pen representing the experimental
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5 220 unit (replicate). The results are presented as means and standard error of means (SEM)
6
7 221 calculated by standard procedures. Analysis of variance by the general linear model
8
9 222 (GLM) procedure (SAS Institute Inc., 1990) was used to determine the significance of
10
11 223 treatment and block effects on the dependent variables (production, apparent digestibility,
12
13 224 AME_n, intestinal values, feather pecking behaviour and plumage score at 54 weeks of
14
15 225 age). Normality of data was tested by a univariate procedure, and the means of the
16
17 226 variables were tested for variance homogeneity by Bartlett's test. An outlier test based on
18
19 227 externally Studentised residuals was performed. No significant outliers were found in the
20
21 228 data, and no effect of block. The LS-Means were calculated and differences regarded as
22
23 229 significant at $P < 0.05$. With respect to production, apparent digestibility and AME_n,
24
25 230 differences were classified by the Ryan-Einot-Gabriel-Welsch (REGW) multiple range test
26
27 231 (SAS Institute Inc., 1990). The results obtained from measurements in the intestinal
28
29 232 content of gizzard, duodenum and jejunum, ileum, caeca and rectum (pH, dry matter and
30
31 233 bacterial counts) were analysed separately for each segment. In cases in which the overall
32
33 234 effect was significant ($P < 0.05$) means were compared pairwise (pdiff). Data on plumage
34
35 235 condition at 25 and 39 weeks of age were tested using the Wilcoxon signed rank test (non-
36
37 236 normally distributed data).
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238 RESULTS

239 **Chemical analysis of basal diet and foraging material**

240 The silages and carrots were chemically analysed at the beginning of the experiment at 23
241 weeks of age (I) and at the end at 54 weeks of age (II), which represented the periods
242 where the digestibility experiments were performed (Table 2).

243 **Table 2**

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2
3 244 The analyses were performed at these times to examine any possible changes in chemical
4
5 245 composition of the foraging material over time. The silages and carrots used were from the
6
7
8 246 same harvest year (2000). The DM content of the silages was on average 323 g/kg DM
9
10 247 (maize I and II) and 221 g/kg DM (barley-pea I and II), respectively, whereas carrots had a
11
12 248 DM content as low as 84 and 125 g/kg DM (I and II). Protein content varied from 65 to
13
14
15 249 127 g/kg DM, the lowest values measured in carrots. Fat content was generally low,
16
17 250 ranging between 12-32 g/kg DM. Starch content averaged 312 g/kg DM in maize silage
18
19 251 and 126 g/kg DM in barley-pea silage, but was not detectable in carrots. Overall, the
20
21 252 results of the nutrient analyses in samples from the two periods agreed closely.
22
23

24 253 Only traces of sugars were detected in the silages. In carrots, high
25
26 254 concentrations of glucose, fructose and sucrose were measured, constituting 458 g/kg DM
27
28 255 in sample I and 533 g/kg DM in sample II. The highest content of total NSP was found in
29
30 256 the silages, containing average values of 333 g/kg DM in maize-silage and 376 g/kg DM in
31
32 257 barley-pea silage. Cellulose and arabinoxylans (AX), the sum of arabinose and xylose
33
34 258 residues, were the dominant NSP residues, constituting approximately 88% and 77% of the
35
36 259 total NSP in maize- and barley-pea silage respectively. In barley-pea silage the content of
37
38 260 uronic acid averaged 57 g/kg DM. Soluble NSP as a percentage of total NSP averaged 6%
39
40 261 in the maize-silage and 12% in the barley-pea silage. The lignin content was high in the
41
42 262 silages, with dietary fibre ranging between 403-483g/kg DM. In carrots the dominant NSP
43
44 263 residues were uronic acids and glucose monosaccharides, cellulose content averaged 63
45
46 264 g/kg DM, total NSP content was 196 and 203 g/kg DM, and in contrast to the silages,
47
48 265 soluble NSP was a very high proportion of total NSP, constituting more than 50%. The
49
50 266 total dietary fibre content averaged 232g/kg DM. The two silages were similar with respect
51
52 267 to the dietary fibre fraction, but differed with regard to protein and starch. The carrots
53
54 268 contained less protein than the silages.
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3 269 The protein content of the layer diet was close to that calculated (Table 1).
4
5 270 The starch content was 365 g/kg DM and fat was 76 g/kg DM. The ME of the layer diet
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7
8 271 was 11.79 MJ/kg DM, calculated on the basis of the chemical analyses and close to the ME
9
10 272 given in Table 1.

13 273 **Production**

14
15 274 Average egg weight was not influenced by the use of silages or carrots (Table 3). The
16
17 275 number of eggs and total egg mass (kg) per hen was highest in the group given carrots,
18
19 276 whereas hens with access to barley-pea silage (LD+BS) produced fewer eggs per hen than
20
21 277 the other groups given foraging material ($P<0.03$).

24 278 **Table 3**

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26
27 279 Rate of lay (%) was highest for hens fed carrots or maize-silage when compared to the
28
29 280 control group, whereas hens fed barley-pea-silage produced less ($P<0.04$). The
30
31 281 unintended change in the light programme at 27 weeks of age did not influence
32
33 282 production during the remaining part of the experimental period. The consumption
34
35 283 of the layer feed was reduced ($P<0.004$) by supplementation with carrots and barley-pea
36
37 284 silage as compared to the LD group. The intake of maize silage, barley-pea silage and
38
39 285 carrots was 33%, 35% and 48 %, respectively, as a percentage of total feed intake on "as
40
41 286 fed" basis. On a dry matter (DM) basis, the figures were 15%, 11% and 8%. Due to the
42
43 287 lower DM content of the foraging material the total feed consumption in kg per kg egg
44
45 288 produced was higher in the groups given the silages and carrots compared to the LD group
46
47 289 on "as fed" basis ($P<0.0001$). Litter samples were taken at the end of the experiment and
48
49 290 the DM content was 78% (LD), 76% (LD+MS), 71% (LD+BS) and 68% (LD+C), where
50
51 291 the DM content for the last two groups was lower than for the control ($P<0.05$).
52
53 292 Supplemental foraging material reduced mortality dramatically ($P<0.02$), (Table 3).
54
55 293 Approximately 50% of the mortality recorded in the LD group was cannibalism directed
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3 294 against the cloacal region. Body weight was higher in the LD group and in hens fed LD+C
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5 295 at 25 and 39 weeks and at 54 weeks the hens fed LD+C were heavier than all other hens.

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8 296 **Digestibility and AME_n**

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10 297 The coefficients of total tract apparent digestibility (DC) of different dietary constituents
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12 298 and the apparent metabolisable energy, nitrogen corrected (AME_n) are given in Table 4.

14
15 299 **Table 4**

16
17 300 Three weeks after the hens had been introduced to the supplements (23 weeks of age),
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19 301 there was no significant difference between treatments with respect to the DC of organic
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21 302 matter (average 0.749) and fat (average 0.853). The hens digested starch very efficiently in
22
23 303 all groups with DC averaging 0.997, however, the DC of starch was lower for hens fed
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25 304 LD+BS compared to the other groups ($P<0.01$). The DC of total NSP was low, ranging
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27 305 from 0.131 (LD+C) to 0.309 (LD), whereas hens fed with carrots had a significantly lower
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29 306 NSP digestibility as compared to hens fed LD and LD+MS. The N-retention varied from
30
31 307 0.412 (LD+C) to 0.521 (LD+MS), ($P<0.01$). The highest AME_n was seen in hens fed the
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33 308 LD diet and LD+MS, both groups being better than the LD+C ($P<0.01$), reflecting the
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35 309 generally lower DC obtained in hens fed carrots as supplement at this stage of the
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37 310 experiment.

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43 311 At 53 weeks of age, the DC of organic matter was lowest for the group
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45 312 receiving LD+BS. The DC of fat was significantly lower when hens were fed LD+C as
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47 313 compared to LD + MS (0.804 vs 0.861). No significant difference was observed between
48
49 314 groups with respect to DC of starch and total NSP. The overall digestibility of total NSP
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51 315 was low, however, the different residues of NSP were digested to a varying degree (data
52
53 316 not shown). The major NSP residues arabinose, xylose and galactose appeared to be
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55 317 digested to some extent in all groups (average DC arabinose: 0.320, xylose: 0.202 and
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57 318 galactose: 0.248). Uronic acids, being an important NSP-residue in carrots were poorly

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3 319 digested in hens fed the LD+C diet with a DC close to zero. In general, all groups digested
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5 320 the soluble part of NSP to a higher extent compared with the insoluble part, being on
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7 321 average 0.334 (S-NSP) and 0.219 (I-NSP) at 23 weeks of age, and 0.392 (S-NSP) and
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9 322 0.208 (I-NSP) at 53 weeks of age (Table 4). The N-retention was found to be in the range
10
11 323 of 0.363 (LD+C) to 0.419 (both group LD and LD+BS) with no significant difference. The
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13 324 AME_n varied from 12.1 to 12.8 MJ/kg DM and no significant difference between groups
14
15 325 was observed. During the 30 weeks between the two digestibility experiments, the daily
16
17 326 intake of the three supplements increased from 31 (MS), 29 (BS) and 45 (C) g/day to 74,
18
19 327 50 and 120 g/day, respectively. The results indicate that high supplemental intake of
20
21 328 silages or carrots had only minor effects on the apparent digestibility of the dietary
22
23 329 constituents and AME_n. The DM content in excreta (Table 4) was lowest in hens fed
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25 330 LD+C. With respect to the digestibility of the supplements fed without the layer diet (data
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27 331 not shown), on average 55 % of organic matter in the foraging material was digested. The
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29 332 AME_n obtained reached an average value of 11 MJ/kg DM. The results indicate that the
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31 333 supplements to some extent contribute with nutrient and energy to the hens.
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334 **Gastrointestinal characteristics and intestinal microflora**

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41 335 Birds receiving supplements of maize silage or barley pea silage had higher relative
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43 336 gizzard weights as compared to the control and birds fed carrots (Table 5).
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337 **Table 5**

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48 338 This difference was evident after three weeks on the experimental diets ($P < 0.05$) and was
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50 339 even more pronounced at 53 weeks of the experiment ($P < 0.001$). No significant
51
52 340 differences between the dietary treatments were observed at any of the sampling times with
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54 341 respect to the relative weights of the small intestinal segments and the caeca.
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56 342 The relative weight of gizzard contents (Table 5) was likewise higher in birds receiving
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58 343 silage as compared to the other two dietary groups, ($P < 0.01$ and < 0.001 at 23 and 53
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3 344 weeks of age, respectively). There was also a difference between groups regarding the
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5 345 relative weight of contents in the upper small intestine (duodenum/jejunum). At both
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7 346 sampling times, birds fed with LD+MS had the highest, and birds fed solely with LD had
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9 the lowest amounts of small intestinal contents ($P < 0.05$ and < 0.01 at 23 and 53 weeks of
10
11 347 age, respectively). Following intake of barley-pea silage, the relative weight of the contents
12
13 348 in the upper small intestine increased over time to reach values similar to maize silage at
14
15 349 53 week of age. A similar picture was observed considering the relative weight of ileal
16
17 350 contents (Table 5). At 23 weeks, the relative weight of caecal contents was similar in all
18
19 351 dietary groups, whereas at 53 weeks, the amount of caecal digesta tended to be lower ($P =$
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21 352 0.07) in hens receiving supplements of barley pea silage as compared to the other groups.
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23 353 At both sampling times a difference between treatments regarding the percentage of dry
24
25 354 matter in the gizzard contents ($P < 0.01$) was observed (Table 5). The dry matter content
26
27 355 was lowest in hens supplemented with carrots, and increased slightly when fed with barley
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29 356 pea silage. The highest DM contents in gizzard contents was observed in birds receiving
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31 357 maize silage and in birds fed solely LD (Table 5).
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33 358 The pH in the contents of the gizzard (Table 6) was not different at 23 weeks of age,
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35 359 whereas at 53 weeks of age a decrease of the pH about 0.7-0.9 units was found in birds fed
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37 360 with both types of silages as compared to birds supplemented with carrots or birds
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39 361 receiving no foraging material ($P < 0.05$).
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Table 6

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51 364 In the upper part of the small intestine, the pH was lower in birds receiving
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53 365 maize silage and carrots as compared to the other groups ($P < 0.01$). At 23 weeks, the pH
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55 366 of the caecal content was not influenced significantly by the dietary treatment, however, at
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57 367 53 weeks, the caecal pH value was about 0.4 units higher in birds fed the LD as compared
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59 368 to the birds supplemented with the different foraging material ($P < 0.05$).
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3 369 Counts of intestinal bacteria were conducted on two occasions (23 weeks and
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5 370 53 weeks of age) and showed that differences between the dietary groups with respect to
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7 371 bacterial composition became more distinct with the progress of the experiment. Because
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9 372 of the large amount of data, only the results obtained at the last sampling are presented
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11 373 (Table 6). No difference between the diets was observed with respect to the number of
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13 374 anaerobic bacteria in the different gastrointestinal segments. Coliform bacteria and lactose
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15 375 negative enterobacteria in the small intestine were more numerous in hens fed with pellets
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17 376 alone as compared to birds supplemented with forages, but these differences were not
18
19 377 statistically significant.

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22 378 Lactic acid bacteria in the contents of the small intestine tended to be fewer
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24 379 in the group fed with barley pea silage compared to the other groups. The numbers of
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26 380 enterococci in the gizzard and small intestine of hens receiving only LD were in the range
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28 381 of 0.6 (gizzard) up to 2 log units (small intestine) higher than in birds supplemented with
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30 382 forage ($P < 0.05$).

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33 383 The concentration of lactic acid (Table 7) was highest in gizzard contents of
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35 384 birds fed both types of silages as compared to hens fed LD+C and LD ($P < 0.01$).

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41 385 **Table 7**

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43 386 In the upper small intestine the highest lactic acid concentrations were found in
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45 387 small intestinal contents of hens LD+MS followed by LD+BS, LD and LD+C ($P <$
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47 388 0.02). Birds fed with both types of silages had higher concentrations of acetic acid
48
49 389 in the gizzard contents than the other two groups ($P < 0.05$). The amounts of acetic
50
51 390 acid found in the contents of the upper small intestine were very low in all groups
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53 391 and did not exceed 1.5 $\mu\text{mol/g}$ contents. In ileal contents, acetic acid concentration
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55 392 was lower in birds receiving supplements of carrots than in the other dietary
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57 393 groups. In caecal contents, the concentrations of both acetic and propionic acid

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3 394 generally tended to be higher in birds fed with maize silage than in the other
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5 395 dietary groups.

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8 396 **Feather pecking and plumage condition**

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10 397 No effects of treatments were found at 24 and 38 weeks of age. At 53 weeks of age the
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12 398 incidence of feather pecking bouts was significantly higher in the control compared to the
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14 399 groups receiving foraging material (Table 8).

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18 400 **Table 8**

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20 401 The number of feather pecks was higher in the control compared to hens fed carrots and
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22 402 with hens fed barley-pea silage and maize silage intermediate. These differences were
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24 403 caused by more severe feather pecking in the control than in forage treatments. Gentle
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26 404 feather pecking bouts were higher in control and barley than in the others, whereas gentle
27
28 405 feather pecking pecks did not differ significantly amongst treatments. Treatments did not
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30 406 affect aggressive nor beak pecking. Plumage condition deteriorated over time and birds in
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32 407 the control treatment had in general the worst quality, even though this was only
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34 408 statistically significant for the combined score at 54 weeks of age (Table 8). As regards
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36 409 quality of neck, the barley-pea group had a significantly better score at 54 weeks than
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38 410 control hens. Skin quality was in general very good in all treatments and ages (data not
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40 411 shown).

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48 413 **DISCUSSION**

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50 414 The results show beneficial effects of supplemental feeding of silage and carrots. The hens
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52 415 given access to silages or carrots showed great interest in the supplements after few days of
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54 416 introduction, and the intake of layer diet was reduced in the groups given carrots or barley-
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56 417 pea silage compared to the control. The daily intake of both types of silage was close to 60
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58 418 g per hen, and the intake of carrots exceeded 100 g per hen, illustrating that the supplement

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3 419 constituted a large proportion of the total feed intake on “as feed” basis. The daily intake
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5 420 of essential nutrients necessary for optimal egg-production was sufficient, in spite of a
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7 421 reduced intake of layer diet. Hvidsten and Herstad (1972) reported that silage of barley
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9 422 grain or barley meal could be used to supplement a layer diet with good results on egg
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11 423 production and feed utilisation. Tkalcic *et al.* (2000) fed ensiled maize grains mixed with a
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13 424 diet based on soyabean meal, meat meal, wheat meal and limestone in order to study the
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15 425 effect on egg-production. They concluded that groups fed diets with 60% of the dry matter
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17 426 intake from ensiled maize silage grain had better laying performance than the control
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19 427 group fed a complete commercial diet, indicating that inclusion of ensiled maize grains
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21 428 instead of dry maize grains had a positive effect on production, in line with the present
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23 429 experiment.
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29 430 The daily protein intake from the layer diet was 22.2 g (LD), 20.3 g
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31 431 (LD+MS), 18.3 g (LD+BS) and 19.5 g (LD+C) per hen. Protein from the supplements
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33 432 contributed further with 1.8 g (LD+MS), 1.6 g (LD+BS) and 0.8 g (LD+C) daily per hen.
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35 433 Based on the calculated methionine content in the layer diet (Table 1), the daily methionine
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37 434 intake per day per hen from the layer diet ranged from 572 mg (LD) to 472 mg (LD+BS)
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39 435 emphasising that methionine intake was sufficient for egg production, as the recommended
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41 436 requirement is 300 mg/hen /day (NRC, 1994). As earlier reported by Hammershøj and
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43 437 Steinfeldt (2005), the content of methionine in maize-silage and carrots is very low,
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45 438 analysed to be 1.30 and 0.84 g/kg DM, respectively, suggesting that the contribution of
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47 439 foraging material to the total dietary essential amino acid concentration is negligible. A
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49 440 major concern in modern animal husbandry, both with regard to commercial and organic
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51 441 productions, is the excretion of nitrogen and phosphorus to the environment. The N-
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53 442 retention was less efficient when hens were fed with carrots as supplements compared to
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55 443 the other groups. Since no difference in N-retention was found between hens fed LD,
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3 444 LD+MS and LD+BS at any ages, we conclude that the high intake of silages did not
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5 445 increase excretion of nitrogen to the environment.
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8 446 Dietary fibre (NSP+ lignin) in feed is a complex group of components
9
10 447 differing widely in chemical composition, physical properties and physiological activity
11
12 448 (Theander *et al.*, 1989; Bach Knudsen, 1997). The content of dietary fibre was high in the
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14 449 foraging material used in the present experiment, especially in the two silages, where the
15
16 450 insoluble fibre constituted the main part (~ 90% of NSP). In carrots, the soluble fraction
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18 451 makes up the bulk of the total NSP. It is known that high amounts of soluble NSP in diets
19
20 452 can increase intestinal viscosity, often having negative effects in broiler chickens (Bedford
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22 453 and Classen, 1992; Choct and Annison, 1992*b*; Smits *et al.*, 1998; Steinfeldt, 2001).
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24 454 However, adult birds seem to be less sensitive to increased intestinal viscosity created by
25
26 455 soluble NSP in cereal-based diets (Salih *et al.*, 1991; Lázaro *et al.*, 2003). The results from
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28 456 the present digestibility experiment indicate that the hens are able to digest a part of the
29
30 457 total NSP from diets and supplements, in agreement with studies performed with adult
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32 458 hens or cockerels (Longstaff and McNab, 1989; Carré *et al.*, 1990; Steinfeldt *et al.*, 1995;
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34 459 Lázaro *et al.*, 2003). Furthermore, in the present study the soluble part of NSP was
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36 460 digested to a higher extent than the insoluble fraction, in agreement with Carré *et al.*
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38 461 (1990). It is believed that the main part of the soluble NSP from the supplements are
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40 462 fermented during the passage through the intestinal system, especially in the caeca, and
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42 463 may contribute with energy through production of short chain fatty acids. In an experiment
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44 464 with broiler chickens Jørgensen *et al.* (1996), concluded that NSP fermentation contributed
45
46 465 3-4% of the metabolisable energy intake. Longstaff and McNab (1989) fed adult cockerels
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48 466 with carrots (freeze-dried and tube-fed) and overall average digestibility of soluble uronic
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50 467 acids to be 49.9%, whereas the corresponding figure for insoluble uronic acids was minus
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52 468 111%. It was concluded that polysaccharide digestibility is very difficult to quantify, due
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3 469 to differences in polysaccharide solubility, when different fibre sources pass through the
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6 470 intestinal system.

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8 471 The large amount of supplements eaten by the hens in the present experiment
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10 472 had only minor effects on AME_n and total tract apparent digestibility of the measured
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12 473 nutrients. (Table 4). In some recent studies the inclusion of different insoluble fibre
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14 474 sources (oat hulls, wood shavings, cellulose) in poultry diets had positive effects on starch
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16 475 digestibility in both broilers and laying hens (Hetland and Svihus, 2001; Svihus and
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18 476 Hetland, 2001; Hetland *et al.*, 2003).

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22 477 Hens fed with carrots had a higher final body weight than the other groups,
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24 478 suggesting that large amounts of easily-fermented components as sugars and soluble NSP
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26 479 contribute some energy to the hens, which confirm the results of Lázaro *et al.* (2003). In
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28 480 the present study, hens fed with both types of silage developed larger gizzards than hens
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30 481 receiving carrots or no supplementation, due to increased mechanical stimulation by the
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32 482 increased amounts of dietary fibre retained in the gizzard and to a coarser feed structure
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34 483 (Engberg *et al.*, 2002, 2004; Hetland *et al.*, 2003; Idi *et al.*, 2005). In addition, the pH of
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36 484 the gizzard contents was lower in silage-fed birds, suggesting an increased secretion of
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38 485 hydrochloric acid as a response to the coarse structure of the silage (Engberg, *et al.*, 2004;
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40 486 Idi *et al.*, 2005). The relative weight of contents increased both in the gizzard and in the
41
42 487 upper part of the small intestine following intake of the silages, which might indicate a
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44 488 prolonged passage time in these segments of the digestive tract. Hetland *et al.* (2004)
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46 489 propose that accumulation of insoluble fibres in the gizzard results in a slower passage rate
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48 490 of especially the fibre fraction. A full gizzard is likely to make the birds feel more satiated
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50 491 resulting in birds appearing more calm, which, in turn, may contribute to a lower feather
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52 492 pecking pressure.
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3 493 The composition of the microflora in the digestive tract of the hens was
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5 494 influenced only marginally by the dietary treatments. Coliform bacteria and lactose
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7 495 negative bacteria tended to decrease in small intestinal contents of forage fed birds
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10 496 compared to non-supplemented hens (Table 6). These results are in accordance with earlier
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12 497 findings in broilers, where a coarser feed structure, such as feeding whole wheat, reduced
13
14 498 the counts of these gram-negative bacteria compared to pellet feeding (Engberg *et al.*,
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16 499 2004, Bjerrum *et al.*, 2005). This may be explained by a lower gizzard pH and longer
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18 500 retention time of feed in the gizzard, providing a barrier for acid labile bacteria, including
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20 501 pathogens like *E. coli* and *Salmonella* (Bjerrum *et al.*, 2005).
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24 502 With respect to the lactic acid producing bacteria, only the enterococci were
25
26 503 significantly influenced in the entire digestive tract, with the highest counts in hens fed the
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28 504 control diet without forage (Table 6). However, the increase of enterococcus counts in
29
30 505 control hens was not reflected by the lactic acid concentration, which was highest in the
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32 506 upper digestive tract (gizzard and duodenum jejunum) of hens fed both types of silages.
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34 507 This might be explained by the contribution of lactic acid in addition to the acetic acid
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36 508 already present in both types of silage.
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40 509 The lower pH in the caecal contents of hens given foraging material,
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42 510 compared to the controls, may indicate that forage provides some carbohydrate, which
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44 511 escapes enzymatic hydrolysis in the small intestine and is fermented by the caecal
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46 512 microflora. Although not significant, higher concentrations of acetic, propionic and butyric
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48 513 acid in caecal contents of forage-fed hens (Table 7) may point in this direction. Whether
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50 514 the increased caecal fermentation followed by a pH decrease has a significant beneficial
51
52 515 influence on gut health, or following absorption of short chain fatty acids contributes to the
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54 516 energy supply of the bird, is a matter of speculation (Jozefiak *et al.*, 2004).
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3 517 Feeding supplements dramatically reduced mortality in the groups given
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5 518 foraging material (0.5-2.5% vs. 15% in the control). Approximately 50% of the mortality
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7 519 recorded in the LD group was identified as cannibalism directed against the cloacal region.
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9 520 Layer diets deficient in protein or methionine and cystine can increase feather pecking and
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11 521 cannibalism (Ambrosen and Petersen, 1997). However, in the present experiment the layer
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13 522 diet contained sufficient essential nutrients to cover requirements, meaning that deficiency
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15 523 in the layer diet cannot explain the high incidence of this kind of cannibalism. Rather it
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17 524 seems that access to supplemental foraging material decreased damaging pecking in
18
19 525 general (to feathers as well as skin/cloaca). This reduction in feather pecking was also seen
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21 526 with pheasant chickens given access to green clover, beech branches or range area
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23 527 (Hoffmeyer, 1969; Kjaer, 2004). In a number of studies with laying hens, access to
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25 528 different kinds of foraging material or dietary insoluble fibre resulted in reduced feather
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27 529 pecking and improved plumage condition (Blokhuys, 1986; Nørgaard-Nielsen *et al.*, 1993;
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29 530 Wechsler and Huber-Eicher, 1998; Aerni *et al.*, 2000; Köhler *et al.*, 2001). In addition, El-
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31 531 Lethy (2000) found improved immune response in groups of laying hens with access to
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33 532 foraging material (long-cut straw) compared to controls fed diets without foraging
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35 533 material, which might indicate lower stress. This corresponds well with the fact that
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37 534 divergent selection on feather pecking (Kjaer *et al.*, 2001) seems to affect a range of
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39 535 immune variables (Buitenhuis *et al.*, 2006). The type of feather pecking in this study was
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41 536 predominantly of the severe kind causing damage to the plumage and even feathers pulled
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43 537 out. Therefore it was quite surprising that so few hens had skin damage. Much pecking was
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45 538 directed to the cloacal region and, in many cases, this led to cannibalism and death of the
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47 539 hen prior to the records of pecking damages at 25, 39 and 54 weeks of age. Hughes and
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49 540 Duncan (1972) suggested that there was a distinction between cannibalistic pecking at the
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51 541 cloacal region (vent pecking) and at other parts of the body. All three types of forage
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3 542 reduced severe feather pecking behaviour and increased the quality of the plumage,
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5 543 whereas the effect on gentle, non damaging feather pecking was less clear. The
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8 544 significantly higher total feed consumption of the hens fed silages or carrots could indicate
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10 545 that more time was spent on feeding compared to the control LD, suggesting less time was
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12 546 spent feather pecking in these groups..

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14
15 547 In conclusion, access to three types of foraging material, silages and carrots,
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17 548 had beneficial effects on feather pecking behaviour and mortality. In addition, egg-
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19 549 production was improved indicating that high fibre sources, like the silages and carrots,
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21 550 have some nutritional value. Caution must be taken with regard to the use of carrots,
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23 551 because a high intake increases the water content of the excreta, which in turn may result
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25 552 in wet litter increasing the risk of infection with bacteria and parasites. However, moderate
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27 553 amounts of carrots can be recommended. With regard to production, the use of maize
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29 554 silage as supplement was overall a better choice than the barley-pea silage. The very high
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31 555 content of mainly insoluble NSP, including cellulose, in barley-pea silage was probably the
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33 556 reason for the limited feed intake. The results also showed that the influence of forage
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35 557 supplementation on gastrointestinal characteristics depends on the type of foraging
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37 558 material. In contrast to carrots, silages are fermented feeds and provide large amounts of
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39 559 fibre that stimulate gizzard function. Both silage and carrots seem to stimulate caecal
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41 560 fermentation. On the basis of the present results, the provision of foraging material to
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43 561 laying hens can be recommended, and may benefit some aspects of animal welfare.
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Table 1. *Composition of the layer diet (g/kg).*

Ingredients	Diet
Wheat	383
Barley	160
Oat	100
Soyabean meal	136
Fish meal	20
Meat-and-bone-meal	37
Animal fat	27
Soyabean oil	20
Calcium carbonate	70
Dicalcium phosphate	5
Sodium chloride	1
Sodium bicarbonate	2.5
Alfalfa meal	32
DL-Methionine (40%)	4
Vitamin and mineral premix ¹	2.5
Calculated content:	
ME, MJ per kg DM	11.5
Protein (Nx6.25, g/kg)	174
Lysine (g/kg)	8.3
Methionine (g/kg)	4.4
Methionine + cystine (g/kg)	7.2
Calcium (g/kg)	33.5
Total phosphorus (g/kg)	5.4

¹The vitamin and mineral premix provided per kg of diet: Vitamin A 4.1 mg; Vitamin D₃ 0.08 mg; Vitamin E 30 mg; Vitamin K₃ 2.5 mg; Vitamin B₁; 1 mg; Vitamin B₂, 5 mg; Vitamin B₆, 2.5 mg; D-pantothenic acid 9 mg; Niacin 30 mg; Betaine anhydrate 338 mg; Folic acid 1 mg; Biotin 0.05 mg; Vitamin B₁₂ 0.02 mg; Fe 80 mg; Zn 120 mg; Mn 100 mg; Cu 6 mg; I 0.5; Se 0.3 mg.

Table 2. Chemical composition of layer diet, maize¹- and barley/pea silage¹ and carrots¹ (g/kg DM).

Constituents	Layer diet	Maize silage	Barley/pea silage	Carrots
Dry matter	914.4	317.1-328.8	212.1-230.4	83.7-125.2
Ash	126.6	42.4-37.8	73.3-73.2	63.4-53.8
Protein (Nx6.25)	186.9	98.8-89.4	122.5-126.9	72.8-65.0
HCL-fat	75.9	32.4	29.2-28.3	11.6-16.4
Gross energy (MJ/kg DM)	181.0	19.0-18.7	18.3-18.5	16.1-16.7
Starch	364.9	304.8-319.2	123.5-125.6	t
Sugars				
Glucose	0.4	t	t	150.0-155.5
Fructose	1.0	t	0.5	157.5-142.5
Sucrose	15.6	t	t	150.0-234.5
Raffinose	2.2	t	t	t
Stachyose	6.4	t	t	t
Verbascose	t	t	t	t
Cellulose	33	171-166	201-180	60-66
NCP ²				
Rhamnose	1	t	3-1	4-5
Fucose	t	t	t	1
Arabinose	23	22-21	16	20-11
Xylose	38	11-98	86-77	3
Mannose	4	3	7	4
Galactose	10	8	9	31-16
Glucose	17	13-12	12	3-4
Uronic acid	9	16	56-58	70-94
NSP ³	133(29) ⁴	342(13)-323(28)	390(47)-361(42)	196(112)-203(112)
Lignin	23	75-80	93-103	30-35
DF (NSP+lignin)	156	417-403	483-464	226-238

¹Values given represent analyses from the supplement samples taken at hen age 23 (I) and 54 (II) weeks.

²Non-cellulosic polysaccharides.

³Non-starch polysaccharides (NCP+cellulose).

⁴Values in parentheses are the soluble fraction of NCP.

t=trace.

Table 3. Production, body weight and mortality of laying hens fed a layer diet with or without supplements of maize silage, barley pea silage or carrots.

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM ¹	P-value
Egg production, per hen						
Number of eggs	214 ^{ab}	218 ^a	208 ^b	219 ^a	1.61	0.04
Egg mass, kg	13.2 ^{ab}	13.3 ^{ab}	12.8 ^b	13.6 ^a	0.10	0.03
Egg weight, g	61.5	61.1	61.5	61.9	0.16	0.36
Rate of lay, %	89.9 ^{ab}	91.4 ^a	87.2 ^b	92.0 ^a	0.67	0.04
Feed consumption, per hen						
Layer diet, kg	31.0 ^a	28.2 ^{ab}	25.5 ^b	27.2 ^b	0.63	0.004
Layer diet, g/day	130.1 ^a	118.5 ^{ab}	107.3 ^b	114.1 ^b	2.63	0.004
Silage/carrots, kg	-	14.1 ^b	13.8 ^b	25.6 ^a	1.66	0.0001
Silage/carrots, g/day	-	59.3 ^b	58.1 ^b	107.6 ^a	6.99	0.0001
LD + silage/carrots, g/day	130.1 ^a	177.7 ^b	165.4 ^b	221.7 ^a	8.64	0.0001
Silage/carrots, % of total feed intake	-	33.4 ^b	35.1 ^b	48.5 ^a	2.06	0.0001
Feed consumption, kg per kg egg						
Layer diet	2.35 ^a	2.12 ^{ab}	2.00 ^b	2.00 ^b	0.05	0.02
Silage/carrots	-	1.06 ^b	1.08 ^b	1.88 ^a	0.12	0.0001
LD + silage/carrots	2.35 ^a	3.18 ^b	3.08 ^b	3.88 ^a	0.15	0.0001
Body weight, g						
25 weeks	1750	1742	1718	1726	18.1	0.59
39 weeks	1889 ^a	1796 ^b	1795 ^b	1915 ^a	23.4	0.0001
54 weeks	1813 ^b	1787 ^b	1805 ^b	1917 ^a	24.8	0.001
Mortality, % of hens housed	15.3 ^a	1.5 ^b	2.5 ^b	0.5 ^b	2.10	0.02

Means in each row followed by different superscript letters ^a ^b differ significantly.

¹Standard error of mean.

Table 4. Apparent metabolisable energy (MJ/kg DM), coefficients of total tract apparent digestibility and nitrogen retention in laying hens fed a layer diet with or without supplements of maize silage, barley pea silage or carrots.

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM ⁴	P-value
23 weeks of age						
Organic matter	0.763	0.760	0.758	0.734	0.01	0.10
Fat	0.872	0.853	0.847	0.833	0.01	0.31
Starch	0.999 ^a	0.998 ^a	0.992 ^b	0.997 ^a	0.01	0.01
Total NSP ¹	0.309 ^a	0.276 ^{ab}	0.288 ^a	0.131 ^b	0.02	0.03
S-NSP ²	0.414	0.429	0.353	0.381	0.02	0.87
I-NSP ³	0.280 ^a	0.245 ^a	0.273 ^a	0.041 ^b	0.02	0.03
N-retention	0.472 ^{ab}	0.521 ^a	0.472 ^{ab}	0.412 ^b	0.02	0.005
AME _n	13.39 ^a	13.41 ^a	13.14 ^{ab}	12.78 ^b	0.09	0.04
DM in excreta	22.39	17.86	19.88	19.14	0.69	0.11
53 weeks of age						
Organic matter	0.721 ^a	0.703 ^{ab}	0.689 ^b	0.706 ^{ab}	0.01	0.03
Fat	0.848 ^{ab}	0.861 ^a	0.848 ^{ab}	0.804 ^b	0.01	0.03
Starch	0.993	0.994	0.983	0.985	0.01	0.08
Total NSP ¹	0.220	0.239	0.264	0.244	0.01	0.70
S-NSP ²	0.270	0.497	0.543	0.258	0.04	0.34
I-NSP ³	0.206	0.185	0.201	0.240	0.02	0.60
N-retention	0.419	0.400	0.419	0.363	0.02	0.74
AME _n	12.82	12.61	12.36	12.42	0.08	0.19
DM in excreta	22.31	20.06	21.06	17.00	0.82	0.11

Means in each row followed by different superscript letters ^{a, b} differ significantly.

¹Non-starch polysaccharides (NCP+cellulose).

²Soluble NSP.

³Insoluble NSP.

⁴Standard error of mean.

Table 5. *Relative weights of digestive tract segments and their contents and dry matter content in gastrointestinal contents of hens fed with or without supplements of maize silage, barley pea silage or carrots at 23 and 53 weeks of age.*

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM ¹	P-value
<i>Relative segment weight, g/kg BW</i>						
23 weeks						
Gizzard	20.62 ^b	24.72 ^a	24.87 ^a	22.51 ^{ab}	1.06	0.04
Duodenum/jejunum	20.14	20.86	19.93	19.97	0.60	0.68
Ileum	7.56	8.53	8.60	8.67	0.52	0.42
Caeca	4.51	4.50	4.57	4.73	0.38	0.97
53 weeks						
Gizzard	16.3 ^b	30.5 ^a	33.0 ^a	19.0 ^b	1.21	0.001
Duodenum/jejunum	16.3	16.1	15.2	15.7	0.64	0.67
Ileum	6.50	7.98	7.35	7.05	0.44	0.17
Caeca	4.67	4.14	4.11	4.30	0.38	0.71
<i>Relative weight of contents, g/kg BW</i>						
23 weeks						
Gizzard	8.35 ^b	11.69 ^a	11.27 ^a	9.89 ^{ab}	0.60	0.01
Duodenum/jejunum	7.20 ^c	9.69 ^a	7.64 ^{bc}	9.26 ^{ab}	0.63	0.04
Ileum	5.64 ^b	6.71 ^{ab}	5.74 ^b	7.54 ^a	0.41	0.02
Caeca	3.26	3.24	3.64	3.40	0.40	0.89
53 weeks						
Gizzard	8.2 ^b	14.0 ^a	15.9 ^a	8.3 ^b	0.67	0.001
Duodenum/jejunum	9.8 ^c	14.9 ^a	13.5 ^{ab}	11.2 ^{bc}	0.76	0.004
Ileum	5.50	7.59	6.55	6.58	0.65	0.21
Caeca	3.80	3.18	2.21	3.78	0.43	0.07
<i>Dry matter content, %</i>						
23 weeks						
Gizzard	34.13 ^a	34.02 ^a	29.24 ^b	24.19 ^c	1.59	0.002
Duodenum/jejunum	19.00 ^a	18.72 ^a	18.39 ^a	15.81 ^b	0.70	0.03
Ileum	22.88	20.87	21.83	19.47	0.82	0.07
Caeca	22.79	22.53	23.68	21.53	0.95	0.48
Colon/rectum	25.36	24.11	23.80	23.60	0.75	0.38
53 weeks						
Gizzard	33.56 ^a	29.46 ^b	23.96 ^c	21.71 ^c	1.09	0.001
Duodenum/jejunum	21.29 ^a	18.66 ^b	18.54 ^b	19.20 ^b	0.49	0.01
Ileum	29.76	19.88	20.17	19.87	3.69	0.21
Caeca	28.56	26.14	25.02	24.16	1.31	0.15
Colon/rectum	22.44	20.98	19.23	20.32	0.91	0.14

Means in each row followed by different superscript letters ^{a b c} differ significantly.

¹Standard error of mean.

Table 6. Counts of total anaerobic bacteria, coliform bacteria, lactose negative enterobacteria, lactic acid bacteria, enterococci (log cfu/g digesta) and pH in the digestive tract of hens fed with or without supplements of maize silage, barley pea silage or carrots.

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM ¹	P-value
Anaerobic bacteria						
Gizzard	7.68	7.15	7.54	7.54	0.25	0.49
Duodenum/jejunum	8.52	8.06	8.23	7.97	0.26	0.50
Ileum	8.59	8.51	8.77	8.52	0.14	0.52
Caeca	10.06	9.79	9.95	10.21	0.13	0.21
Colon/rectum	9.15	8.76	8.96	8.84	0.18	0.48
Coliform bacteria						
Gizzard	4.54	3.72	4.22	4.14	0.32	0.38
Duodenum/jejunum	5.73	4.28	5.13	4.90	0.44	0.19
Ileum	7.29	7.07	6.59	6.42	0.27	0.17
Caeca	7.39	7.15	7.28	7.31	0.17	0.78
Colon/rectum	7.08	7.48	7.24	7.10	0.27	0.71
Lactose negative enterobacteria						
Gizzard	3.76	3.43	3.47	3.46	0.18	0.54
Duodenum/jejunum	4.67 ^a	3.06 ^b	3.85 ^a	3.85 ^a	0.34	0.04
Ileum	6.40	5.76	5.46	5.82	0.26	0.19
Caeca	6.06	5.92	5.52	6.08	0.28	0.50
Colon/rectum	6.18	5.91	5.65	6.08	0.25	0.47
Lactic acid bacteria						
Gizzard	7.63	7.49	7.49	7.69	0.41	0.98
Duodenum/jejunum	8.47	8.38	7.99	8.43	0.20	0.32
Ileum	8.96	8.73	8.46	8.79	0.16	0.23
Caeca	9.53	9.43	9.56	9.68	0.10	0.40
Colon/rectum	8.93	8.84	8.60	9.15	0.13	0.06
Enterococci						
Gizzard	5.64 ^a	3.89 ^b	4.04 ^b	5.05 ^a	0.27	0.002
Duodenum/jejunum	6.85 ^a	4.70 ^c	4.70 ^c	5.74 ^b	0.27	0.001
Ileum	7.72 ^a	6.49 ^b	6.01 ^b	6.55 ^b	0.32	0.02
Caeca	7.96	7.43	6.97	7.95	0.25	0.05
Colon/rectum	7.41	6.85	6.82	7.16	0.29	0.44
pH						
Gizzard	4.82 ^a	3.91 ^b	3.90 ^b	4.64 ^a	0.21	0.02
Duodenum/jejunum	6.27 ^a	5.92 ^b	6.22 ^a	6.08 ^{ab}	0.06	0.01
Ileum	7.48	7.44	7.57	7.17	0.18	0.47
Caeca	6.53 ^a	6.18 ^b	6.14 ^b	6.14 ^b	0.10	0.04
Colon/rectum	7.19	7.14	7.21	7.17	0.26	0.99

Means in each row followed by different superscript letters ^a^b differ significantly.

¹Standard error of mean.

Table 7. Concentrations of lactic - and acetic acid in the digestive tract and caecal concentrations of butyric and propionic acid ($\mu\text{mol/g}$ digesta) of hens fed with or without supplements of either maize silage, barley pea silage or carrots.

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM	P-value
Lactic acid						
Gizzard	4.7 ^b	16.9 ^a	14.3 ^a	1.6 ^b	2.81	0.01
Duodenum/jejunum	16.4 ^b	25.0 ^a	19.6 ^{ab}	13.5 ^b	2.08	0.01
Ileum	13.9	22.3	12.8	17.5	3.83	0.34
Colon/rectum	13.5	16.6	14.1	17.0	3.65	0.84
Acetic acid						
Gizzard	3.5 ^b	5.9 ^a	6.2 ^a	3.6 ^b	0.71	0.03
Duodenum/jejunum	1.5	0.2	1.3	0.7	0.65	0.41
Ileum	9.7 ^a	11.5 ^a	9.7 ^a	6.8 ^b	0.82	0.01
Colon/rectum	26.1	24.5	24.0	25.0	4.43	0.99
Caeca						
Acetic acid	70.0	91.5	77.0	74.3	7.30	0.24
Propionic acid	25.0	32.0	27.0	27.3	2.67	0.35
Butyric acid	13.6	17.1	16.5	18.8	2.06	0.39

Means in each row followed by different superscript letters^{a,b} differ significantly.

¹Standard error of mean.

Table 8. *Allo-pecking at 53 week of age (LSmeans of bouts/pecks per bird per hour) and plumage condition at 54 weeks of age of hens fed with or without supplements of either maize silage, barley pea silage or carrots.*

	Layer diet (LD)	Layer diet + maize silage (LD+MS)	Layer diet + barley/pea silage (LD+BS)	Layer diet + carrots (LD+C)	SEM ³
Feather pecking					
-Total, bouts	0.92 ^a	0.21 ^b	0.44 ^b	0.20 ^b	0.09
-Total, pecks	1.58 ^a	0.57 ^{ab}	0.95 ^{ab}	0.36 ^b	0.15
-Severe, bouts	0.56 ^a	0.01 ^b	0.03 ^b	0.07 ^b	0.08
-Severe, pecks	0.60 ^a	0.03 ^b	0.04 ^b	0.09 ^b	0.08
-Gentle, bouts	0.36 ^a	0.20 ^b	0.42 ^a	0.13 ^b	0.04
-Gentle, pecks	0.98	0.54	0.91	0.27	0.15
Aggressive pecking					
-Bouts	0.21	0.18	0.19	0.23	0.02
-Pecks	0.22	0.21	0.21	0.24	0.02
Beak pecking					
-Bouts	0.25	0.23	0.10	0.17	0.04
-Pecks	0.98	0.78	0.32	0.51	0.17
Plumage condition ¹					
-Total score ²	13.9 ^b	18.3 ^a	19.2 ^a	16.3 ^{ab}	1.24
Separate body parts					
-Neck	3.2	3.8	3.9	3.6	0.19
-Breast	2.4	3.1	3.5	3.1	0.26
-Back	2.4	3.8	4.0	3.0	0.38
-Wings	2.4	3.8	3.9	3.6	0.21
-Tail	2.6	3.8	3.9	3.1	0.33

Means in each row followed by different superscript letters ^a^b differ significantly ($P < 0.05$).

¹Maximum of 4 points for perfect plumage, minimum of 1 point for a very poor plumage.

²Total score is the sum of body part scores, max. 20 and min. 5 points.

³Standard error of mean.