agriculture

Article

Particle Size Distribution of Organic Complete Diets for Laying Hens during Feed Offering

Dietrich Nunnenkamp [1], Eyleen Bierschenk [1], Heiner Westendarp [2] and Petra Wolf [1,*]

[1] Department of Nutritional Physiology and Animal Nutrition, University of Rostock, 18051 Rostock, Germany; dietrich.nunnenkamp@uni-rostock.de (D.N.); eyleen.bierschenk@bio-eichenmuehle.de (E.B.)
[2] Department of Animal Nutrition, University of Osnabrück, 49076 Osnabrück, Germany; h.westendarp@hs-osnabrueck.de
* Correspondence: petra.wolf@uni-rostock.de; Tel.: +49-381-4983320

Abstract: Complete diets for laying hens are usually offered in meal form. This form initially promotes the laying hens' natural feed intake behavior and allows them to satisfy their pecking behavior. At the same time, it can also cause difficulties, because it consists of different particles and is not a homogeneous unit. A homogeneous mixture is essential to ensure that each laying hen in the flock can meet its nutritional needs. If feed exhibits a wide particle size distribution, this can promote feed segregation during transport and selective feed intake behavior of laying hens. These two processes sometimes lead to significant differences between the composition of the feed produced and the composition of the feed that is finally ingested by the laying hens. Multi-stage sampling can be used to investigate progressing differences in feed composition. In this study, samples of different complete diets for laying hens (n = 76) were collected from ten organic farms in Germany to examine their particle size distributions (dry sieve analysis). Samples were taken at four different locations (V1 = loading, V2 = silo, V3 = at the beginning of the feed chain, V4 = at the end of the feed chain) in each farm. There was a tendency for V1 and V2 to be characterized by high proportions of particles between 1400 and 3150 µm (V1 = 61.2%, V2 = 43.5%). V3 and V4 consisted mainly of particles of size 500–800 µm and 200–400 µm, respectively. The lowest proportions across all variants were in the range above 3150 µm (V1 = 2.20%, V2 = 1.30%, V3 = 1.00%, V4 = 0.400%) and between 400 and 500 µm (V1 = 2.50%, V2 = 4.50%, V3 = 5.70%, V4 = 6.60%). The mean value comparison of the proportions of sieve mesh sizes from 200 to 1000 µm resulted in: V1 < V2 < V3 < V4; and of sieve mesh sizes between 1400 and 2000 µm in: V1 > V2 > V3 > V4. This observation can be explained by segregation of the feed during transport and a selective feeding behavior of the laying hens. However, trends were discontinuous and varied between the farms. Deviations from the guideline values were found in particular for particle sizes in the range of 1000 to 1400 µm.

Keywords: laying hens; organic; particle size; sieve analysis

check for updates

Citation: Nunnenkamp, D.; Bierschenk, E.; Westendarp, H.; Wolf, P. Particle Size Distribution of Organic Complete Diets for Laying Hens during Feed Offering. *Agriculture* **2022**, *12*, 272. https://doi.org/10.3390/agriculture12020272

Academic Editor: Javier Álvarez-Rodríguez

Received: 25 January 2022
Accepted: 12 February 2022
Published: 15 February 2022

1. Introduction

Compound feed for laying hens in organic farms exists in diverse physical forms. The administration of pelleted feed contradicts the fact that the risk of luxury consumption [1–3] and lack of employment [1,4–6] can increase. A lack of employment is seen, among other things, as a trigger for behavioral disorders such as feather eating, feather pecking or cannibalism [2,3,5–8]. The processing of pellets into granulated feed or crumbly feed can counteract this, but often results in hard and sharp-edged particles that can be problematic for the animals [8]. In addition, processing with pressure and heat causes, on the one hand, higher costs for the energy consumption [9–14] and, on the other hand, nutrient losses [12,13], especially for heat-labile ones. For these reasons, feeding mash diets is generally recommended [2,3,8,14]. However, this form of feed could promote feed segregation and a selective feeding behavior due to its wide range of particle sizes [15]. Feed segregation means that the composition of the feed changes on its way from production to feeding pan and leads to an inhomogeneous distribution of particles and nutrients [15,16]. Critical spots of feed segregation are loading and transport [12,17], storage [16–19], and feed delivery through either auger or drag-chain delivery systems [15,20]. Feed selection is the animal-related preferred intake of certain feed particles, which can have several causes. Layers mainly react to tactile and visual stimuli [12,21,22]; however, their sense of smell and taste may often be undervalued [23–26]. The birds are able to select feed particles nutrient-specific, which is called 'nutritional wisdom'. Nevertheless, this ability seems to be limited by other influencing factors [27]. In terms of particle size, laying hens show a preference from coarse to fine [22,26,28–31]. The finest particles are taken up at last or even avoided and can therefore have a negative effect on feed intake if they are abundant [30,32]. Generally, large particles (>1180 µm) are mostly corn ingredients and contain primarily carbohydrates, NFE, and calories. Dietary nutrients such as vitamins, minerals, and amino acids from protein sources are usually contained in the small particles (<1180 µm) [15]. On the one hand, this can be explained by the structure of the feed, as hens are less able to pick up finer particles [2,8], but on the other hand also by other influences. For example, mineral additives and vitamins generally exhibit poor palatability in addition of their fine particulate structure [32]. For this reason, they are particularly exposed to demixing processes.

Since most of the available literature concerning this topic refers to conventional farms, the question remains to what extent, firstly, feed segregation and, secondly, feed selection takes place in commercial organic farms. Because there are more restrictions (e.g., non-GMO) and fewer permitted feed components in organic farming, inhomogeneities in feed intake can easily lead to an inadequate supply of nutrients and behavioral disorders [2,8]. The aim of the present work was to investigate the particle size distributions of organic diets for laying hens by means of a multistage sampling and analysis.

2. Materials and Methods

2.1. Experimental Design

The feed samples that served as the basis for these investigations came from ten commercial organic farms in Germany. These farms were selected with the aim of providing a realistic picture of local organic farming. Therefore, samples from research institutes were deliberately not included. To preserve the anonymity of the farms, their names were abbreviated with the initial letter of the farm's location. In case of duplication, chronological numbering was applied. The sizes of the ten selected farms varied from 6000 to almost 14,000 laying hens. On average, around 11,000 animals were kept per farm. Thus, the farm size was very close to the current nationwide average of 2016 with 11,652 hens per organic farm [33]. The youngest flock was 22 weeks old at the time of sampling, and the oldest flock was 75 weeks old (average age: 47 weeks). Laying performance averaged 83.2%, while feed and water consumption averaged 128 g/d and 207 g/d, respectively. Depending on the operational possibilities, there were one to two runs, each with one to two repetitions. A total of 76 samples were evaluated. For each run, a new loading sample (V1) was taken. Analyzes were performed in the laboratory of the Faculty of Agricultural and Environmental Sciences at the University of Rostock.

To produce the diets, all the ingredients except the premix (minerals) were initially added to the mixer. After the initial mixing, grinding took place with a crushing roller mill. Finally, the premix was added, and the entire feed was mixed once more. A total of six different formulations of feed were fed (Table 1). In all diets, the proportion of starch-rich feed (maize, wheat, triticale, barley) was around half (50.2%, 45.0%, 52.1%, 51.9%, 45.0%, 49.1%), with corn being the most widely used component at 20 to 28 percent. Of the protein-rich ingredients (soybean and cake, sunflower cake, corn gluten, field beans, peas, lupins, alfalfa green meal, fish meal, sweet whey powder), the soybean and sunflower products accounted for the largest share, thus together they were at 20.2 to 30.1%. Furthermore, the use of conventional corn gluten (4.30%, 4.30%, 4.20%, 3.00%, 4.30%, 4.30%) was characteristic of current laying hen feed; just below the permissible 5% limit. Further protein supply was realized differently depending on the mixture by other legumes (field beans, peas, lupins), sweet whey powder or fish meal. Calcium carbonate (8.20%, 8.40%, 8.90%, 8.60%, 8.40%, 8.60%) served as the main Ca supplier, while a large part of the phosphorus requirement in all experimental diets was provided by monocalcium phosphate (0.500–0.800%).

Table 1. Nutrient composition of experimental diets.

Ingredient (%)	**Diet**					
	1	**2**	**3**	**4**	**5**	**6**
Corn	20.0	28.0	20.0	25.9	28.0	20.0
Wheat	10.2	7.00	17.1	16.0	7.00	14.0
Triticale	20.0	5.00	15.0	5.00	5.00	11.7
Barley		5.00		5.00	5.00	3.40
Corn gluten	4.30	4.30	4.20	3.00	4.30	4.30
Broad beans	2.40					0.600
Peas	3.00	4.30	2.00	5.00	4.30	
Soybeans, toasted		12.0		3.00	12.0	
Soybean cake, toasted	10.8	2.70	13.2	8.50	2.70	13.1
Sunflower cake	14.1	15.0	7.00	13.1	15.0	17.0
Lupines	2.20	2.00				
Alfalfa-meal		2.60	6.10	4.00	2.60	2.60
Soybean oil						0.900
Soybean oil/Sunflower oil	1.10		1.10			
Fish meal			2.70			
Beer yeast		0.040		0.030	0.040	
Sweet whey powder						1.00
Sugar cane molasses		2.00	1.00	1.00	2.00	0.800
Calcium carbonate	8.20	8.40	8.90	8.60	8.40	8.60
Mono calcium phosphate	0.500	0.700	0.600	0.800	0.700	0.800
Oyster shells	2.00					
	Calculated nutrient content, %					
Crude protein	16.8	17.0	17.0	17.0	17.0	17.5
Crude fat	6.00	6.00	6.00	6.00	6.00	5.50
Crude fibre	6.20	6.70	6.30	6.70	6.70	7.00
Ash	13.5	13.0	12.8	13.0	13.0	12.8
Methionine	0.310	0.320	0.330	0.320	0.320	0.330
Lysine	0.740	0.750	0.750	0.750	0.750	0.770
Calcium	4.00	3.50	3.50	3.50	3.50	3.50
Phosphorus	0.550	0.600	0.550	0.600	0.600	0.650
Sodium	0.150	0.170	0.180	0.170	0.170	0.180
ME (MJ/kg)	10.8	10.9	10.9	10.9	10.9	10.5

In 9 of 10 farms, one diet was maintained for all runs and replicates in each farm. Only in Farm Z were two different diets (No. 5, 6) used in two runs. Overall, Diet 2 was fed most frequently (4 times). Diets 3 and 6 were fed twice each, whereas Diets 1, 4 and 5 were provided only once (Table 2).

Table 2. Diets used on the farms.

Name of Farm	**D**	**G**	**K**	**N**	**T**	**V**	**W1**	**W2**	**W3**	**Z**
No. of Experimental Diet	3	2	4	6	2	3	2	2	1	5, 6

2.2. Feed Sampling and Analysis

Feed samples were taken from four different points (Figure 1):

1. Loading (V1):

The loading samples were taken from the storage bins at the feed manufacturer immediately before loading trucks.

2. Silo (V2):

In all farms, feed was stored in silos after delivery. The V2 sample was collected from the hopper opening of the silo during feeding.

3. Feed chain (beginning/end; V3/V4):

Sampling at the feed chains in the barn took place immediately after the first feeding of the day. V3 was the place where the animals had access to the feed for the first time. V4 was the end of the feed chain before it was filled again. In all farms, these two sampling points were in the same section due to circulation.

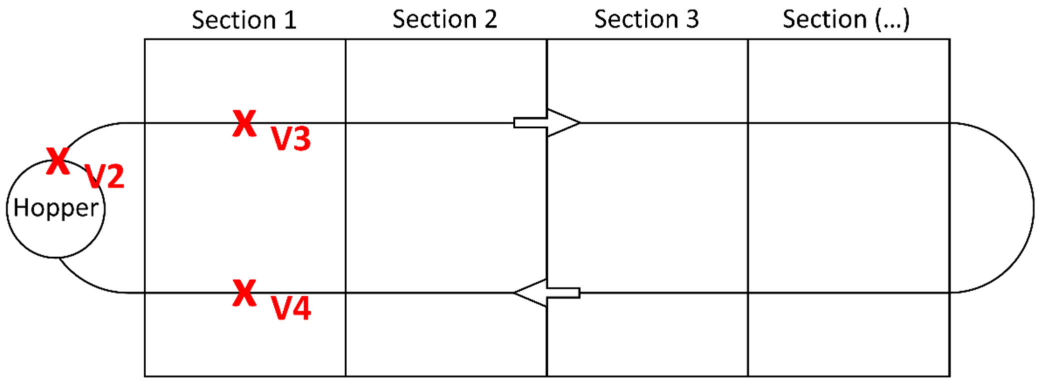

Figure 1. Layout of the 3 sampling points in the hen houses. V2 = silo, V3 = beginning of the feed chain, V4 = end of the feed chain.

Dry sieve analyses were carried out according to the VDLUFA association methods. For this purpose, samples of approximately 200 g were poured onto the top sieve of the EML 200 Premium Remote sieve tower (HAVER & BOECKER, Oelde, Germany). The sieve tower consisted of sieves with mesh sizes of 200, 400, 500, 800, 1000, 1400, 2000 and 3150 µm (Table 3). These were arranged in a graduated manner so that the feed passed through progressively finer mesh sizes. The column was placed on a mechanical shaker. The samples were shaken for 10 min at an amplitude of 2.00 mm. Finally, the amounts of feed remaining on the sieves were weighed and their proportions of the total mass were calculated.

Table 3. Design of the sieve tower used and corresponding guideline values.

Layer	Sieve Mash Width (µm)	Guideline Values (%) [8,34]
Sieve 1	3150	2.00
Sieve 2	2000	8.00
Sieve 3	1400	15.0
Sieve 4	1000	35.0
Sieve 5	800	12.0
Sieve 6	500	10.0
Sieve 7	400	9.00
Sieve 8	200	5.00
Pan	<200	4.00

2.3. Statistical Analyses

Microsoft Excel® (Version 2019, Microsoft Corporation, Redmond, WA, USA) was used for collection and processing of data and furthermore for descriptive statistical analyses.

3. Results and Discussion

3.1. General Comments

First, it should be noted that this study was a field-scale study. It must be assumed that different conditions prevailed on the ten farms despite uniform organic farming practices. Furthermore, different feed mixtures with different compositions were used. In some cases, the number of runs and repetitions also differed between the farms. This was due to the operational conditions and possibilities, which were deliberately not to be interfered with. The results therefore only permit limited statements to be made across farms. However, this disadvantage in the evaluation was subordinated to the aim of this work, which was to investigate organic laying hen feed under practical conditions.

In two farms, only three samples were taken instead of four, so variant 3 was omitted. The reason for this was that in both houses the first section, where the V3 sample would otherwise have been taken, was directly adjacent to the silos. Accordingly, a differentiation between V2 and V3 would have had little significance due to the local proximity of the two sampling points. One farm in this study was without a loading sample (V1) because it was later found to be unusable, and resampling was not possible due to the time lag between it and the other samples.

3.2. Particle Size Distributions of the Diets—Observations and Trends

Particle size distributions were determined based on dry sieve analysis data. Guideline values [8,34] were used to classify the results. The following diagram shows the averaged values including standard errors of the mean over all ten farms (Figure 2).

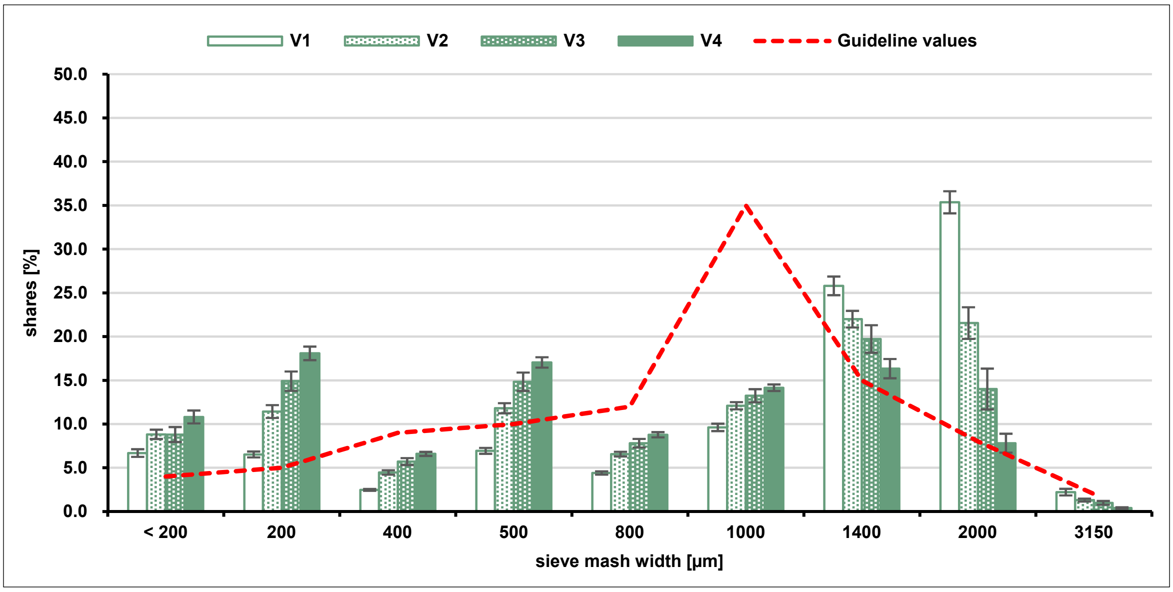

Figure 2. Averaged particle size distribution and guideline values [8,34]. Mean values ± standard error of the mean (SEM) across all farms (V1 = 13 samples, V2 = 23 samples, V3 = 21 samples, V4 = 19 samples), regardless of diet, run, and replicate.

Variants 1 and 2 were defined by particularly high proportions (V1 = 30.6%, V2 = 21.8%) on sieves 2 and 3 (2000 and 1400 µm), whereby this trend was more apparent with V1 than with V2. In contrast to the other variants, in V1 these two sieve fractions were the largest in all cases. Variants 3 and 4 were characterized mainly by high relative proportions (V3 = 29.7%, V4 = 35.1%) on sieves 6 and 8 (500 and 200 µm). Although their shares tended to be lower on sieve 3 in relation to V1 and V2, the values there still averaged 19.7% (V3) and 16.3% (V4). The lowest percentages across all variants were on sieves 1 (V1 = 2.20%, V2 = 1.30%, V3 = 1.00%, V4 = 0.400%) and 7 (V1 = 2.50%, V2 = 4.50%, V3 = 5.70%, V4 = 6.60%). Additionally, it is remarkable that the particle size distribution of the feed not only changed over the variants, but that these changes even tended to show progressions. The comparison of the mean values of the variants on the individual sieve levels showed that there were recurring sequences among the variants:

V1 < V2 < V3 < V4 (sieve mash size: 200–1000 μm)
V1 > V2 > V3 > V4 (sieve mash size: 1400–2000 μm)

From loading (V1) to the end of the feed chain (V4), there was a tendency for a relative decrease in coarse particles (>1400 μm) to be offset by a relative increase in fine particles (<1400 μm). Similar effects are known from literature in relation to feed segregation [12,16–19] and feed selection [15,22,26,28–31]. In contrast to the results here, other authors found only feed selection without feed segregation [15]. The fine particles are components of both the original straight feed and the premix. Due to its poorer palatability, this fine portion is ingested to a lesser extent. This means that the hens are sometimes inadequately supplied with minerals. This situation is further aggravated by the selective feed intake behavior. The coarser particles, which the hens prefer to pick up, are primarily components that are larger and thus satisfy the pecking instinct on the one hand, and on the other hand stand out from the rest of the feed in terms of color. These are primarily cereals (e.g., corn fragments), which have energy contents that exceed requirements and deficient mineral contents (e.g., calcium) as well [14,15]. As a result, imbalances or even deficits can occur despite mixed feeds that cover energy and requirements. It must be expected that, especially in diets for organic laying hens, problems may come to a head because overall nutrient density is lower than in conventional farms [2,8].

Although the progression of the particle size distribution was very uniform on average across all four variants, it must be taken into account that the trends between variants varied greatly from farm to farm. The largest range between farms was found at all four sampling points on sieve 2 (V1 = 11.3, V2 = 23.3, V3 = 21.6, V4 = 13.1). At V1, Farm G achieved the highest value (42.8%) and Farm K the lowest (31.5%), while at V4 it was Farm Z (7.10%) and Farm D (1.70%). The lowest ranges between farms were found on sieve 1 (V1 = 3.70, V2 = 1.90, V3 = 1.90, V4 = 0.900). Accordingly, feed segregation and feed selection may have had influences in different combinations and to different degrees on individual farms. Feed selection between V1 and V2 can be excluded because the animals did not have access to feed there. If feed segregation is really to be identified as the main cause for the observed trends in particle size distribution, the question arises, where exactly the segregated feed particles remained and how long they remained there. For example, small-scale feed segregation within the feed chains has been reported [15]. It is also conceivable that the effects would be reversed after a large part of the feed had been used up. There also may have been other influencing factors. It could be, for example, that a structural change was caused during feed transport. Thus, the feeding technique can lead to further grinding processes and thus to shifts in the particle size distribution. Moreover, it is also conceivable that fine particles remained permanently in the bottom of the feed chain, which were not ingested by the layers, but which came up during the sampling.

Overall, the examination of the particle size distributions of the layer farms showed that V1 was particularly rich in particles in the range between 1400 and 3150 μm. V4 was mainly found on sieves 6 and 8, while V2 and V3 were found to be in between, indicating a trend from coarse to fine and vice versa. It was assumed that both feed segregation and feed selection had taken place, which may be associated with negative consequences.

3.3. Particle Size Distribution of the Diets—Comparison to the Guideline Values

Deviations from the guideline values in the particle size distribution of laying hen feed, especially with increased fine contents at the detriment of the coarse contents, can be associated with a variety of negative effects. These are impairment of feed intake [2,8], beak deformities [35], underdevelopment of the gizzard, overload of the small intestine, and greater exposure due to feed dust [8,36]. The absorption of larger particles leads to a slightly reduced digestibility of starch in the small intestine. Thus, larger amounts of starch enter the large intestine, where there is an increase in lactic acid content. The resulting decrease in pH leads to a reduction in salmonella incidence [37]. On the other hand, if the hens are offered a lack of alternatives, then there is a risk of glandular gastric dilatation [38,39]. In Figure 1, the guideline values are shown in addition to the averaged particle size distribution. The largest undercutting of the guideline value was found for all farms and across all four variants in the particle size range from 1000 to 1400 µm (sieve 4). Since the average deviations from production to the feed chain were almost constant at 25.4% (V1), 23.0% (V2), 21.8% (V3), and 20.9% (V4), it must be assumed that these particle fractions were not sufficiently homogeneously mixed into the complete feed. Notable exceedances of the guideline values occurred at V1 and V2 (sieves 2 and 3) and at V3 and V4 (sieves 6 and 8). The guideline values were at 8.00% for sieve 2 (V1 = 35.4%, V2 = 21.5%, V3 = 14.0%, V4 = 7.80%), at 15.0% for sieve 3 (V1 = 25.8%, V2 = 22.0%, V3 = 19.7%, V4 = 16.3%), at 12.0% for sieve 6 (V1 = 6.90%, V2 = 11.8%, V3 = 14.8%, V4 = 17.0%) and at 5.00% for sieve 8 (V1 = 6.50%, V2 = 11.4%, V3 = 14.9%, V4 = 18.1%). It is interesting to note that the difference to the guideline values on sieves 2 and 3 decreased in the course of V1, V2, V3 and V4. The difference in percentage points was 27.4 and 10.8 (V1), 13.5 and 7.00 (V2), 6.00 and 4.70 (V3) and 0.200 and 1.30 (V4). This observation indicates that, consciously or unconsciously, feeds were produced that had higher coarse particle contents than the stated guideline values specified. This could possibly provide a buffer to counteract the negative effects of feed segregation and feed selection. With regard to the progression from V3 to V4, it should additionally be considered that the ingestion of these particles by the animals may have been relatively high. An opposite trend was noticed on sieves 6 and 8. Here, the averaged differences in percentage points tended to be smaller for V1 (3.10, 1.50) and V2 (1.80, 6.40) than for V3 (4.80, 9.90) and V4 (7.00, 13.1). Consequently, the guideline values were still complied with at the time of loading (V1) but were subsequently (V2, V3, V4) increasingly exceeded. In particular, the relative increase from V3 to V4 suggests that the animals consumed fines to a lesser extend despite the increased amount of fines in the diet. An analysis of the fine particles could provide information on the extent to which this could cause deficiency symptoms. Although V4 deviated on average the lowest number of percentage points from the guideline values (V1 = 9.50, V2 = 7.50, V3 = 6.70, V4 = 6.30), it contained too high a proportion of fines (sieve 6 = 17.0%, sieve 8 = 18.1%, pan = 10.8%). The question remains open as to whether deviations from the guideline values can generally be evaluated equally on all sieves, or whether deviations above or below the guideline values may be more significant on selected sieves. Moreover, it must be assumed that such changes in particle size distribution also imply changes in nutrient supply. Therefore, in the worst case, an unbalanced structural supply could be accompanied by an unbalanced nutrient supply.

It can be summarized that there were deviations from the guide values at all four sampling points. There was a tendency for V1 and V2 to be above the guideline values for the fine particles (sieve 8, Pan) and for V3 and V4 to be above the guide values for the coarse particles (sieves 2 and 3). None of the variants reached the target guideline value of 35.0% on sieve 4. It can be assumed that feeds with too high coarse particles are produced during the manufacturing process, but that the animals nevertheless receive feeds with high fine particles at the end of the feed chain. It must be worried that both the structure supply and the nutrient supply of the hens were not optimal, and the risk of the mentioned negative consequences was high.

4. Conclusions

In this study, dry sieve analysis was used to investigate the particle size distribution of commercial organic layer diets. On the one hand, it was examined whether the guideline values were met and, on the other hand, whether trends in the particle size distribution could be found.

The results showed that the guideline values were only partially met at all four sampling locations. Furthermore, progressive changes in the particle size distribution could be assumed. There was a tendency for coarse particles to be in excess during production and fine particles at the end of the feed chain. This observation was consistent with results from previous studies, which indicated that coarse particles were preferentially ingested and fine particles, such as mineral nutrients, were avoided. It is known that this can lead to consequences such as behavioral disorders and digestive problems. Finally, it must be assumed that the feed composition is characterized by strong heterogeneity and that the laying hens are not supplied according to their needs. This is contrary to the actual goal of organic farming. Since the problem cannot be solved by other feed forms, such as pellet feed, granulated feed, or crumbly feed [1,4–6,8], the solution approach must be sought in more uniform grinding and thereby maximum homogeneity.

Author Contributions: Conceptualization, E.B. and P.W.; methodology, E.B., P.W. and D.N.; software, P.W. and D.N.; validation, P.W. and D.N.; formal analysis, P.W., H.W. and D.N.; investigation, E.B. and D.N.; resources, P.W.; data curation, D.N.; writing—original draft preparation, D.N., P.W. and H.W.; writing—review and editing, D.N., P.W. and H.W.; visualization, D.N.; supervision, P.W. and H.W.; project administration, P.W.; funding acquisition, P.W. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Vtlariño, M.; Picard, M.L.; Melcion, J.P.; Faure, J.M. Behavioural adaptation of laying hens to dilution of diets under mash and pellet form. *Br. Poult. Sci.* **1996**, *37*, 895–907. [CrossRef]
2. Dänicke, S.; Jeroch, H. Fütterung des Geflügels. In *Ernährung Landwirtschaftlicher Nutztiere*, 2nd ed.; Jeroch, H., Drochner, W., Simon, O., Eds.; Eugen Ulmer KG: Stuttgart, Germany, 2008; pp. 486–540.
3. Eder, K.; Roth, F.X. Geflügelfütterung. In *Tierernährung*, 14th ed.; Kirchgeßner, M., Ed.; DLG-Verlag GmbH: Frankfurt am Main, Germany, 2014; pp. 579–623.
4. Yo, T.; Siegel, P.B.; Guérin, H.; Picard, M. Self-selection of dietary protein and energy by broilers grown under a tropical climate: Effect of feed particle size on the feed choice. *Poult. Sci.* **1997**, *76*, 1467–1473. [CrossRef]
5. Aerni, V.; El-Lethey, H.; Wechsler, B. Effect of foraging material and food form on feather pecking in laying hens. *Br. Poult. Sci.* **2000**, *41*, 16–21. [CrossRef]
6. Savory, C.J.; Hetherington, J.D. Effects of plastic anti-pecking devices on food intake and behaviour of laying hens fed on pellets or mash. *Br. Poult. Sci.* **1997**, *38*, 125–131. [CrossRef]
7. Blokhuis, H.J.; Arkes, J.G. The development and causation of feather pecking in the domestic fowl. *Appl. Anim. Behav. Sci.* **1984**, *12*, 145–157. [CrossRef]
8. Jeroch, H. Fütterung des Lege-, Reproduktions- und Mastgeflügels. In *Geflügelernährung*, 2nd ed.; Jeroch, H., Simon, A., Zentek, J., Eds.; Eugen Ulmer KG: Stuttgart, Germany, 2019; pp. 237–502.
9. Banerjee, G.C. Animal Husbandry. In *Animal Husbandry*, 6th ed.; Prinzlani, M., Ed.; Oxford and IBN Publishers: Oxford, UK, 1987.
10. Jahan, M.S.; Asaduzzaman, M.; Sarkar, A.K. Performance of broiler fed on mash, pellet and crumble. *Int. J. Poult. Sci.* **2006**, *5*, 265–270. [CrossRef]
11. El-Serwy, A.A.; Shoeib, M.S.; Fathey, I.A. Performance of broiler chicks fed mash or pelleted diets containing corn-with-cobs meal with or without enzyme supple-mentation. *J. Anim. Poult. Prod.* **2012**, *3*, 137–155. [CrossRef]
12. Blair, R. *Nutrition and Feeding of Organic Poultry*, 2nd ed.; CAB International: Boston, MA, USA, 2018.
13. Coehlo, M.B. Vitamin stability in premixes and feeds: A practical approach. In Proceedings of the BASF Technical Symposium, Indianapolis, IN, USA, 25 May 1994; pp. 99–126.
14. Schreiter, R.; Damme, K. *Legehennenfütterung—Einsatz Heimischer Futtermittel und Fütterung Schnabelunkupierter Legehennen*; Bayerische Landesanstalt für Landwirtschaft (LfL): Freising-Weihenstephan, Germany, 2017.
15. Tang, P.; Patterson, P.H.; Puri, V.M. Effect of feed segregation on the commercial hen and egg quality. *J. Appl. Poult. Res.* **2006**, *15*, 564–573. [CrossRef]
16. Swierkowski, M. Technische Maßnahmen zur Vermeidung von Entmischungen in Silos. *Agrartechnik* **1985**, *35*, 551–552.
17. Shinohara, K.; Golman, B.; Nakata, T. Size segregation of multicomponent particles during the filling of a hopper. *Adv. Powder Technol.* **2001**, *12*, 33–43. [CrossRef]

18. Böhrnsen, J.U. Dynamisches Verhalten von Schüttgütern beim Entleeren aus Silos. Ph.D. Thesis, Technische Universität Braunschweig, Braunschweig, Germany, 12 December 2001.
19. Cellai, D.; Cregan, V.; Curtis, M.; Fowler, A.; Hinch, J.; Hocking, G.; Mcguinness, M.; Murnane, J.; O'brien, S.B.G.; Smith, N. Particle Size Segregation in Granular Flow in Silos. June 2012. Available online: http://www.mat.ucm.es/momat/2012SmithEtAl-ReportStudyGroup-Limerick.pdf (accessed on 6 October 2021).
20. Zeigler, M.P.; Manbeck, H.B.; Roush, W.B. Sources of variance in feed distribution systems. *Trans. ASAE* **1997**, *40*, 435–444. [CrossRef]
21. Zentek, J.; Jeroch, H. Einfluss der Ernährung auf die Tiergesundheit und fütterungsassoziierte Gesundheitsstörungen. In *Geflügelernährung*, 2nd ed.; Jeroch, H., Simon, A., Zentek, J., Eds.; Eugen Ulmer KG: Stuttgart, Germany, 2019; pp. 64–108.
22. Stangl, G.I. Die Nährstoffe und ihr Stoffwechsel. In *Tierernährung*, 14th ed.; Kirchgeßner, M., Ed.; DLG-Verlag GmbH: Frankfurt am Main, Germany, 2014; pp. 47–134.
23. Gentle, M.J. Taste preference in the chicken (*Gallus domesticus* L.). *Br. Poult. Sci.* **1972**, *13*, 141–155. [CrossRef]
24. Kare, M.R.; Scott, M.L. Nutritional value and feed acceptability. *Poult. Sci.* **1962**, *41*, 276–278. [CrossRef]
25. Choi, Y.H.; Asakura, K.; Okumura, J.; Furuse, M. Repulsive effect and palatability of dietary phenylalanine in laying hens. *Asian-Australas. J. Anim. Sci.* **1996**, *9*, 159–164. [CrossRef]
26. El-Boushy, A.R.Y.; Van Der Poel, A.F.B. Palatability and feed intake regulations. In *Handbook of Poultry Feed from Waste: Processing and Use*, 2nd ed.; El-Boushy, A.R.Y., Van der Poel, A.F.B., Eds.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2000; pp. 348–397.
27. Forbes, J.M.; Shariatmadari, F. Diet selection for protein by poultry. *World's Poult. Sci. J.* **1994**, *50*, 7–24. [CrossRef]
28. Schiffman, H.R. Texture preference and acuity in the domestic chick. *J. Comp. Physiol.* **1969**, *67*, 462–464. [CrossRef]
29. Portella, F.J.; Caston, L.J.; Leeson, S. Apparent feed particle size prefe-rence by laying hens. *Can. J. Anim. Sci.* **1988**, *68*, 915–922. [CrossRef]
30. Leeson, S.; Summers, J.D. Feeding programs for laying hens. In *Commercial Poultry Nutrition*, 3rd ed.; Leeson, S., Summers, J.D., Eds.; University Books: Guelph, ON, Canada, 2005; pp. 163–227.
31. Nir, I.; Melcion, J.P.; Picard, M. Effect of particle size of sorghum grains on feed intake and performance of young broilers. *Poult. Sci.* **1990**, *69*, 2177–2184. [CrossRef]
32. Pousga, S.; Boly, H.; Ogle, B. Choice feeding of poultry: A review. *Livest. Res. Rural. Dev.* **2005**, *17*. Available online: http://www.lrrd.cipav.org.co/lrrd17/4/pous17045.htm (accessed on 4 October 2021).
33. DESTATIS. 41323-0002: Betriebe mit Legehennenhaltung, Erzeugte Eier, Legeleistung: Deutschland, Monate, Haltungsformen. Available online: https://www-genesis.destatis.de/genesis//online?operation=table&code=41323-0002&bypass=true&levelindex=0&levelid=1633862953026#abreadcrumb (accessed on 10 October 2021).
34. Kamphues, J.; Wolf, P.; Coenen, M.; Eder, K.; Iben, C.; Kienzle, E.; Liese-Gang, A.; Männer, K.; Zebeli, Q.; Zentek, J. *Supplemente zur Tierernährung für Studium und Praxis*, 12th ed.; M. & H. Schaper: Hannover, Germany, 2014.
35. Pohlenz, J. Verdauungsapparat. In *Pathologie der Haustiere. Teil 1: Organveränderungen*; Schulz, L.-C., Ed.; Gustav Fischer Verlag: Jena, Germany, 1991; pp. 214–344.
36. Amerah, A.M.; Ravindran, V.; Lentle, R.G.; Thomas, D.G. Feed particle size: Implications on the digestion and performance of poultry. *World's Poult. Sci. J.* **2007**, *63*, 439–455. [CrossRef]
37. Ratert, C.; Sander, S.J.; Verspohl, J.; Beyerbach, M.; Kamphues, J. Effects of the Physical Form of Diets on the Outcome of an Artificial Salmonella Infection in Broilers. *Avian Dis.* **2015**, *59*, 74–78. [CrossRef]
38. El-Wahab, A.; Kriewitz, J.P.; Hankel, J.; Chuppava, B.; Ratert, C.; Taube, V.; Visscher, C.; Kamphues, J. The effects of feed particle size and floor type on the growth performance, GIT development, and pododermatitis in broiler chickens. *Animals* **2020**, *10*, 1256. [CrossRef]
39. Gievre, A.G.; Kaldhusdal, M.; Eriksen, G.S. Gizzard erosion and ulceration syndrome in chickens and turkeys: A review of causal or predisposing factors. *Avian Pathol.* **2013**, *42*, 297–303. [CrossRef]