Higher precision level at individual laying performance tests in noncage housing systems

W. Icken,*[1] S. Thurner,† A. Heinrich,† A. Kaiser,‡ D. Cavero,* G. Wendl,† R. Fries,‡ M. Schmutz,* and R. Preisinger*

*Lohmann Tierzucht GmbH, Am Seedeich 9-11, 27472 Cuxhaven, Germany; †Institute for Agricultural Engineering and Animal Husbandry, Bavarian State Research Center for Agriculture, Vöttinger Straße, 36, 85353 Freising, Germany; and ‡Chair of Animal Breeding, Technische Universität München, Liesel-Beckmann-Str. 1, 85354 Freising, Germany

ABSTRACT With the Weihenstephan funnel nest box, 12 laying hen flocks were tested for their individual laying performance, egg quality, and nesting behavior in a noncage environment. During the whole observation period of 8 yr, a transponder-based data recording system was continuously improved and resulted in a recording accuracy of 97%. At peak production, heritabilities for the number of eggs laid are in some flocks higher than expected. With improved data accuracy, heritability estimates on individual egg weights are more stable. Heritabilities for nesting behavior traits range between a low to moderate level, providing very useful information for laying hen selection to help improve traits that cannot be recorded in cages. Over the years, the benefits of the Weihenstephan funnel nest box for laying hen breeders have grown. This is due to higher data recording accuracies and extended testing capacities, which result in more reliable genetic parameters.

Key words: data recording, performance test, layer

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INTRODUCTION

Phenotypic performance tests are the basis of a breeding program, and their extension and reliability determine the rate of genetic progress. It is therefore irrelevant whether traditional phenotype-based selection strategies, marker-assisted, or genomic selection is used. Any selection strategy requires a high accuracy of individually observed phenotypes as described by Dekkers (2010). Preisinger (2012) illustrated the huge impact of one selected male in the breeding program of layers. In regard to the standard 4-way cross and the sex ratio of 1 male to 10 females, genetic gain of one pure line male affects 16,200,000 commercial layers. This effect is the result of different multiplication stages from pure lines via grandparents and parent stocks to commercial layers. One advantage of this breeding structure is that selection decisions are based on a relatively small nucleus of 4 pure lines for each commercial layer line. However, the accuracy of selection is, according to Dekkers (2010), determined by the amount of information that is available to estimate an individual's breeding value as each single pure line layer is tested in a comprehensive way. In their studies, Besbes et al. (2002) and Wolc et al. (2012) showed a high variety of selection traits that covers feed efficiency, egg quality, longevity, and behavior. Results of precise data recording and recurrent selection for many years were summarized by McKay (2009). Based on Hy-Line and industry data, he emphasized that the efficiency of egg production has improved by at least 2 to 3 eggs annually. Since the late 1930s, egg number to the age of 60 wk has been improved by more than one egg per year, and at the same time, feed conversion ratio by 0.01 per year. Simultaneously, selection for survival rate and disease resistance results in 0.18% better livability up to 80 wk of age.

For further genetic improvement in relevant egg production traits, it is important to consider changes in the global structure of the egg industry. In accordance to Besbes et al. (2002), the big challenge for breeding companies is to provide commercial layers that are able to express their full genetic potential under a large variety of field conditions such as high density cages, deep litter, and free-range systems. Due to these varying field conditions, the testing environment of pure lines should also be adapted to minimize the negative effect of genotype-environment interactions and maximize genetic progress. Therefore, breeding companies have

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[1]Corresponding author: icken@ltz.de

Table 1. Number of tested hens in the Weihenstephan funnel nest box

Flock	Origin[1]	Observation time	Recording period (d)	Number of hens housed	Number of control hens[2]	Number of available nests	Number of analyzed hens
1	LB	12/2004–12/2005	355	366	29	48	272
2	LB	03/2006–07/2006	150	353	30	48	226
3	LB	08/2006–01/2007	153	266	10	48	228
4	LSL	02/2007–07/2007	138	287	5	48	206
5	LB	08/2007–01/2008	150	251	10	48	232
6	LB	03/2008–10/2008	214	295	15	48	243
7	LB	11/2008–05/2009	175	264	22	48	240
8	LB	06/2009–01/2010	177	574	24	72	516
9	LB	01/2010–09/2010	191	633	30	72	548
10	LB	09/2010–03/2011	138	630	41	72	454
11	LB plus	03/2011–08/2011	116	519	261	72	239
12a,b	LB, LT	10/2011–04/2012	163	498	40	72	447

[1]LB: Lohmann Brown, LSL: Lohmann Selected Leghorn, LB plus: Lohmann Brown plus, LT: Lohmann Tradition.

[2]With exception of flock 4, layers with white-shelled eggs.

extended their laying hen testing stations to noncage layer houses as well for individual performance testing as reported by Bal (2012) and Icken and Preisinger (2009). The real challenge of these individual testing methods in group housing systems is a high accuracy of hen to egg assignment, which is the most important and crucial prerequisite to use these transponder-based systems in commercial layer breeding. Therefore, the objective of this study is to pursue the continuous increase in accuracy in individual laying performance tests in noncage housing systems.

MATERIALS AND METHODS

Since 2005, 12 breeding flocks of brown and white layers have been tested in an aviary system, hen specifically, for laying performance, egg quality, and nesting behavior traits. The so-called Weihenstephan funnel nest box (**FNB**) is a single nest that was especially developed for breeding purposes. The functionality of this FNB has already been published, and further details are described in Thurner et al. (2005) and Icken and Preisinger (2009). The project started in 2005 with 48 FNB and 24 additional FNB were installed in 2009 at the experimental station Thalhausen. The new nests are equipped with a double tilting floor that identifies the presence of 2 hens inside the nest box, which means that the correct hen to egg assignment is no longer ensured. The new double tilting function guarantees that double nest occupations, which do sometimes occur, can be identified and the data set will be corrected accordingly. In August 2011, the first 48 single-tilted FNB were replaced by double tilted FNB. From flock number 1 to 7, the total number of FNB used was 48, and for all subsequent flocks, 72 nest boxes were available. Correspondingly, the number of tested hens increased (Table 1) and is a result of the following: hens housed minus control hens minus hen reductions as in the cases of flocks 2, 4, 6, and 8 to 11. These were done as a consequence of too many double nest occupations. Therefore, the nest to hen ratio varies for these flocks (Table 2). Control hens were only used to calculate the accuracy of the hen to egg assignment in the system but were not used for genetic analysis.

The data accuracies calculated are based on regular checks of the sequence of eggs with different eggshell color. Kaiser et al. (2012) described the verification procedure as follows: (1) The identification of each white egg/brown egg in the egg collecting tube corresponds to the respective laying process data provided by the FNB. (2) The hen registered for this barcode number is in fact a white layer/brown layer. (3) Whenever a white egg/brown egg was noted in the writing protocol, a white/brown layer was registered in the laying process data.

With the exception of the first flock, all hens were tested in a semiannual rhythm. Data recording started after transferring the birds with 17 wk of age to the layer house. Up to 50% of production, in between 22 to 23 wk of age, the trap doors at the entrance of the FNB were left open to make the hens familiar with the nests. During this period of 5 to 6 wk, no data were recorded. Recording of egg number and egg quality data started when egg production was higher than 50% production and all FNB were functioning correctly. Egg numbers were collected daily and aggregating in laying periods of 28 d each. Specifically developed software allowed the transponder-based identification of hens in the FNB as well as oviposition times. Software for data registration was continuously improved. Three different software versions were used (Table 2). Software version I was used for the first 48 FNB. Because these nests did not have the double tilted floor, double nest occupations could only be detected when 2 different transponders were read in the same nest box within a short time span. All FNB with a double tilt floor give an additional signal for double nest occupations, which is analyzed in software version II. After closing the nests, the sequence of brown and white eggs in the egg collecting tube is noted manually. This sequence is synchronized with the automatically recorded hen information in software version III.

Routinely, egg weight measurements were done for at least 10 d per flock, once at the beginning and again at

Table 2. Management figures as double nest occupations, floor eggs, and data accuracy for each tested flock

Flock	Software	Available nests with single tilting function	Available nests with double tilting function	Number of hens housed	Nest to hen ratio	Double nest occupations (%)	Floor eggs (%)	Data recording accuracy (%)
1	I	48	0	366	1:7.6	4	5	96
2	I	48	0	353	1:7.4	14	3	91
2				253[1]	1:5.3	2	1	96
3	I	48	0	266	1:5.5	2	30	96
4	I	48	0	287	1:6.0	32	19	61
4				212[1]	1:4.4	11	14	92
5	I	48	0	251	1:5.2	4	19	96
6	II	48	0	295	1:6.1	9	2	93
6				260[1]	1:5.4	<1	<1	97
7	II	48	0	264	1:5.5	<1	<1	96
8	II	48	24	574	1:8.0	7	3	89
8				538[1]	1:7.4	3	2	95
9	II	48	24	633	1:8.8	7	8	92
9				584[1]	1:8.1	2	8	94
10	II	48	24	630	1:8.8	8	3	92
10				556[1]	1:7.7	1	3	96
11	II	48	24	519	1:7.2	11	10	92
11				445[1]	1:6.2	4	3	96
12a,b	III	0	72	498	1:6.9	3	<1	97

[1]After reduction of flock size.

the stage of peak production. All single eggs that were correctly assigned to the hen were weighed, and heritabilities were estimated for each day. This was done to verify data recording indirectly. Egg weight is, according to literature, highly heritable. Therefore, there should not be 1 d with a heritability estimate of less than 0.05.

All tested layers were pedigreed birds. For the estimation of heritabilities, a 4-generation pedigree was used. The minimum number of sires per flock was 20. These were mated with more than 100 dams. The calculated number of daughters per sire exceeds 10 layers, with the exception of flock 4, in which 5 progeny per sire were tested.

The variance and covariance components were estimated by the software VCE 4 (Groeneveld, 1998) using the restricted maximum likelihood method. To analyze laying performance, egg numbers of each hen were summarized for laying periods, which consisted of 28 subsequent days. Heritabilities for the egg weight were analyzed on a daily basis. The fixed effect of hatch was included into the model as in the case of flocks 9 and 10, as siblings of consecutive hatches were tested across flocks. All flocks were kept under identical housing and management conditions.

The model used for the egg number and egg weight parameters is as follows.

Model 1:

$$Y_{ijk} = \mu + H_i + a_j + e_{ijk},$$

where Y_{ijk} = individual observation for the corresponding trait per bird j, μ = overall mean, H_i = fixed effect of hatch i, a_j = additive genetic effect of bird j, and e_{ijk} = random error.

Heritability estimations for the oviposition time and duration of stay in a nest were based on model 2. In this case, the repeatability model includes the fixed effect of each single day within the respective 28-d laying period.

Model 2:

$$Y_{ijklm} = \mu + D_i + H_j + pe_k + a_l + e_{ijklm},$$

where Y_{ijklm} = individual observation for the corresponding trait per bird l, within period, μ = overall mean, D_i = fixed effect day i, H_j = fixed effect of hatch j, pe_k = permanent environmental effect k, a_l = additive genetic effect of bird l, and e_{ijklm} = random error.

RESULTS AND DISCUSSION

Double Nest Occupation

In the vast majority of cases, the separation mechanisms in terms of traps at the nest entrance of the FNB ensures that only one hen uses the nest at the same time, and only in rare cases, more than one hen enters the same nest at the same time. This phenomenon is described as double nest occupation and occurred with an incidence of up to 32% in the exceptional case of flock 4 (Table 2). The percentage of double nest occupations is strongly influenced by the number of hens per nest box. A challenging nest to hen ratio of more than 4 layers to one single nest increases the pressure to one nest at the main laying time and raises the risk for floor eggs. The best examples for minimizing the occurrence of double nest occupations as well as the percentage of floor eggs is to adjust the hen to nest ratio by a reduction in flock size as done in flocks 2, 4, 6, and 8 to 11. A reduction in nest to hen ratio (e.g., from 1:7.4 to 1:5.3 in flock 2) minimizes the double nest occupancy rate from 14 to 2% or as in the case of flock 6, from 9% to less than 1% for an average reduction of less than one hen per

Table 3. Heritabilities and corresponding SE (in parentheses) for egg number at beginning of lay (laying period 1–2) and peak production (laying period 3–5) for the corresponding flock

Flock	Number of analyzed hens	Heritabilities (h^2) for egg number	
		Laying period 1–2	Laying period 3–5
1	272	0.16 (0.12)	0.13 (0.12)
2	226	0.10 (0.13)	0.46 (0.21)
3	228	0.15 (0.13)	0.63 (0.19)
4	206	0.31 (0.15)	0.29 (0.12)
5	232	0.38 (0.11)	0.12 (0.11)
6	243	0.31 (0.15)	0.56 (0.13)
7	240	0.57 (0.08)	0.06 (0.05)
8	516	0.39 (0.11)	0.13 (0.06)
9	548	0.49 (0.11)	0.27 (0.11)
10	454	0.22 (0.02)	0.08 (0.02)
11	239	0.20 (0.09)	0.09 (0.01)
12a	220	0.11 (0.09)	0.22 (0.14)
12b	227	0.10 (0.09)	0.14 (0.08)

nest to a ratio of 1:5.4 (Table 2). As long as the data of 2 eggs are correctly captured, double nest occupations are irrelevant for individual laying performance tests. However, these cases are problematic for hen-specific egg quality tests. If double nest occupations are identified, these eggs will be eliminated from the data set for egg quality studies. However, nonidentified double nest occupations cannot be corrected and result in wrong data sets for the selection of laying hens.

Data Accuracy

The reliability of each breeding value is based on the kind and extent of information sources as well as the estimated heritability for the selection trait. In view of these complex interrelations, Sanders et al. (2006) estimated the impact of wrong sire information on the response to selection in an Angeln dairy cattle population. The level of heritability as well as the progeny size and the reliability were taken into consideration while summarizing that 7% wrong sire information was more harmful than 10% missing sire information in terms of selection response. The negative effect of wrong sire information on the response to selection can be compared with a wrong egg to hen data assignment in laying performance tests, especially for egg quality measurements. Data accuracies of individual laying performance tests in group housing systems vary from 89 to 97% for the Weihenstephan FNB, taking flock 4 as an outlier with 61% data accuracy before flock reduction (Table 2).

At the onset of laying, most of the tested flocks were higher in hen number than in the ongoing production cycle. The exact extent of reduction in hens housed can be seen for each flock (Table 2) and was caused by very high double nest occupations. In some flocks (e.g., flocks 1, 8, 10, and 12), data recording works well with higher nest to hen ratios than recommended. However, the data recording accuracy in all flocks was improved by a reduction of layers. A big difference between the number of hens housed was obvious for the white layer flock (flock 4). Here, data recording accuracy was improved by more than 30% after reducing hen to nest ratio from 1:6.0 to 1:4.4. All other flocks were brown layers. From Icken et al. (2012), it is known that the behavior of brown and white layers is different. White layers lay their eggs in a shorter time frame during the day and, additionally, stay for a longer time in the nest, unlike brown layers. Together, both characteristics result in a higher occupancy rate of the FNB during the main laying time and, therefore, a higher double nest occupation at identical nest to hen ratios.

In spite of general similar conditions and same breeds, each flock behaved differently, which is presented by varying double nest occupation rates and accuracies.

Genetic Parameters

Estimates of Besbes et al. (1992) showed that egg production traits are less heritable than egg characteristics or BW. In their study, univariate restricted maximum likelihood method estimates of heritabilities varied for egg number in the first three 28-d laying periods for 2 pure lines between 0.09 to 0.27. Egg weight and BW were highly heritable with estimates of $h^2 = 0.44$

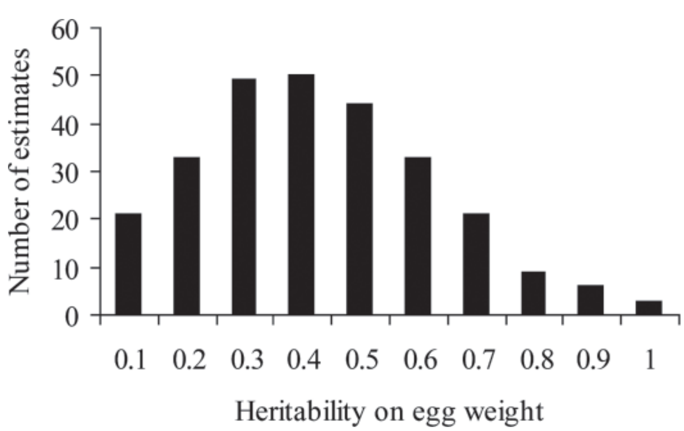

Figure 1. Distribution of the heritability estimates for egg weight on a daily basis for all flocks.

Table 4. Variation in heritability for single day recording on hen specific egg weight

Flock	Number of analyzed hens	Recording days (n)	Heritability (h^2) for egg weight	
			Variation in h^2	Days with $h^2 < 0.10$
1	272	31	0.00 to 0.53	5
2	226	31	0.00 to 0.53	10
3	228	16	0.00 to 1.00	1
4	206	15	0.20 to 0.76	0
5	232	15	0.00 to 0.83	2
6	243	21	0.03 to 0.92	2
7	240	34	0.00 to 0.74	1
8	516	16	0.00 to 0.51	4
9	548	18	0.10 to 0.53	0
10	454	20	0.26 to 0.93	0
11	239	20	0.06 to 0.50	2
12a	220	20	0.19 to 0.68	0
12b	227	20	0.23 to 1.00	0

to $h^2 = 0.51$, which is in conformity with the analysis of Wolc et al. (2011).

Egg Production. In this study, heritabilities for egg production are high in some flocks compared with figures from literature. This might reflect the fact that in this study, egg production is defined in a different way because only the eggs that were laid in a nest were taken into account. In line with Savaş et al. (1998), Mielenz et al. (2003), and Wolc et al. (2011), heritability estimates for the onset of egg production in most flocks are higher than for egg number at peak production (Table 3). These higher heritabilities are well founded by higher variation in egg number at the beginning of lay (Savaş et al., 1998). At peak production, egg numbers are already close to the biological limit, which has been determined as one egg per day or, respectively, 100% laying performance. Only after peak production toward the end of production, the genetic variance of laying performance increases again, and with that, the heritability estimates as well.

Egg Weight. Each single egg of the whole flock was weighed and analyzed on a daily basis. These egg weights have been used as an indicator trait for the correct allocation of the eggs. Heritabilities are estimated with model 1. Minimum and maximum estimates for the respective observation periods are shown in Table 4. Additionally, a distribution of all heritability estimates is shown in Figure 1. This very high variation in heritability estimates for the trait weight of a single egg measured on consecutive days is questionable regarding several published studies, which confirm egg weight as being a highly heritable trait (Besbes et al., 1992). With one exception, a heritability of less than 0.10 was estimated for a minimum of 1 d in flock 1 to 8. Such low heritability estimates for egg weight in layers were not even once estimated in the studies of Besbes et al. (1992), Mielenz et al. (2003), and Wolc et al. (2011). Estimates close to 0 are characterized by a high environmental variance, which might be a sign of an incorrect egg to hen assignment. As it can be seen in Table 4, the incidence of such low heritabilities decreased with ongoing flock number, which is again evidence that enhanced data accuracy also corresponds to increased accuracy values (Table 2). For 2 d, heritability estimates are also below 0.10 in flock 11. In spite of the availability of 72 FNB in flock 11, only 239 brown layers were used for genetic analysis. This is due to the high number of control birds. Almost double the amount of analyzed layers was provided by flocks 8 to 10, resulting in a more comprehensive pedigree struc-

Table 5. Heritabilities and SE (in parentheses) for the oviposition time separated by 28-d laying periods for each tested flock

Flock	28-d laying period				
	1	2	3	4	5
1	0.00 (0.00)	0.12 (0.06)	0.06 (0.04)	0.25 (0.08)	0.25 (0.10)
2	0.18 (0.09)	0.66 (0.02)	0.54 (0.17)	0.53 (0.02)	0.50 (0.14)
3	0.07 (0.04)	0.00 (0.03)	0.09 (0.02)	0.00 (0.02)	0.01 (0.02)
4	0.07 (0.04)	0.23 (0.07)	0.23 (0.07)	0.43 (0.09)	0.44 (0.09)
5	0.12 (0.08)	0.36 (0.10)	0.32 (0.08)	0.21 (0.07)	0.15 (0.07)
6	0.35 (0.09)	0.39 (0.10)	0.44 (0.09)	0.22 (0.08)	0.05 (0.04)
7	0.37 (0.08)	0.43 (0.10)	0.34 (0.08)	0.23 (0.08)	0.25 (0.09)
8	0.09 (0.02)	0.06 (0.03)	0.12 (0.05)	0.09 (0.04)	0.02 (0.03)
9	0.34 (0.11)	0.54 (0.12)	0.46 (0.10)	0.41 (0.10)	0.38 (0.09)
10	0.22 (0.05)	0.08 (0.04)	0.04 (0.04)	0.26 (0.06)	0.42 (0.08)
11	0.33 (0.07)	0.31 (0.06)	0.44 (0.09)	0.51 (0.10)	
12a	0.43 (0.09)	0.35 (0.11)	0.26 (0.10)	0.50 (0.15)	0.45 (0.09)
12b	0.27 (0.07)	0.30 (0.01)	0.39 (0.10)	0.31 (0.08)	0.24 (0.07)

ture. With about 25 sires for almost all brown layer flocks tested, the number of analyzed daughters per sire varied in terms of increasing test capacities from 10 to 25, which led to an improved estimation of variance components. Therefore, 2 different effects: higher data accuracy and enhanced pedigree structure can be noted as indicators for increased and more conformed heritability estimates over the years.

Behavior Traits. Multiple measurements on the same trait, exact oviposition time as well as the duration of stay in the FNB, enable heritability estimations based on model 2. In comparison with single records, as done for egg weight (Table 4), there is a gain in the accuracy of prediction with repeated records, which is dependent on the value of repeatability and the number of records. In accordance to Mrode (1996), this gain in accuracy results mainly from the reduction in temporary environmental variance (within individual variance) as the number of records increases. The maximum number of records is 28 in this case. The overall observation period is divided into 28-d laying periods, and every single hen visits the nest mainly once for oviposition on each day.

The heritabilities on both nesting behavior traits, oviposition time (Table 5), and duration of stay in nest (Table 6) range between a low to moderate level without any distinction between brown and white layers. Repeatability within and between flocks is high for brown layers. A comparison of 11 brown layer flocks in their average duration of stay in a nest shows no significant difference. However, white and brown layers significantly differ in nesting behavior. Average values have already been published and can be read in Icken et al. (2012). Lillpers (1991) also investigated the exact oviposition time of layers and estimated moderate to high heritabilities for the same trait (0.38 to 0.78). Furthermore, Lillpers (1991) indicated that the heritability for mean oviposition time is higher than for egg number, which is not clearly shown in this study; however, oviposition time has been included as multiple trait in a repeatability model. Similar results on genetic parameters are estimated for the duration of stay (Table 6).

Despite the described deficiencies in captured data basis of some flocks, investigations of 12 completed flocks provided very useful information for laying hen selection. The automatic nest box system helps to improve nesting behavior traits that cannot be recorded with traditional laying performance tests in single bird cages. Furthermore, basic knowledge about laying hens' behavior can be obtained from this system and can be used to give better management recommendations in the field.

Oviposition times as well as the duration of stay in a nest are not only helpful traits in terms of management requirements as described by Icken et al. (2012). Even in economic aspects, these nesting behavior traits are of great interest. The number of nest capacities needed depends on nest occupancy rates during the day and determines the amount of salable nest eggs, which is again responsible for economic success. Together with the laying performance captured in the FNB, selection simultaneously guarantees breeding progress in nest acceptance and egg number. This is a big advantage, especially for increasing noncage laying hen systems. In the past, it was not possible to record essential single hen data in group housing systems where the behavior is not biased. In a trap nest system, humans determine when the hen is released from the nest box. The hen has no chance to pick or visit different boxes before laying her first egg. Though not only in reference to upcoming behavior criteria, but also concerning potential genotype-environment interactions, the performance test described opens up new opportunities for laying hen selection.

In conclusion, the FNB was successfully further developed during the last 8 yr. Advanced technical details, such as the double tilted nest floor or the new software configuration, ensure higher data accuracies. Together with extended nest capacities, these improvements lead to more reliable genetic parameters and therefore place laying hen breeding programs on a broader scale.

Table 6. Heritabilities and SE (in parentheses) for the duration of stay in a nest separated by 28-d laying periods for each tested flock

	28-d laying period				
Flock	1	2	3	4	5
1	0.25 (0.10)	0.27 (0.07)	0.38 (0.11)	0.37 (0.09)	0.31 (0.10)
2	0.10 (0.06)	0.40 (0.12)	0.45 (0.02)	0.44 (0.02)	0.40 (0.02)
3	0.15 (0.04)	0.36 (0.03)	0.29 (0.03)	0.28 (0.02)	0.42 (0.02)
4	0.20 (0.08)	0.16 (0.04)	0.11 (0.03)	0.27 (0.06)	0.20 (0.05)
5	0.00 (0.00)	0.31 (0.10)	0.00 (0.00)	0.32 (0.09)	0.43 (0.12)
6	0.20 (0.06)	0.13 (0.05)	0.16 (0.06)	0.20 (0.06)	0.12 (0.06)
7	0.32 (0.07)	0.34 (0.09)	0.33 (0.09)	0.29 (0.08)	0.25 (0.11)
8	0.38 (0.06)	0.36 (0.05)	0.40 (0.06)	0.38 (0.07)	0.30 (0.06)
9	0.33 (0.09)	0.30 (0.06)	0.32 (0.08)	0.32 (0.07)	0.31 (0.07)
10	0.21 (0.04)	0.29 (0.06)	0.36 (0.08)	0.50 (0.08)	0.56 (0.07)
11	0.39 (0.09)	0.32 (0.09)	0.29 (0.08)	0.35 (0.08)	
12a	0.41 (0.08)	0.39 (0.09)	0.32 (0.10)	0.30 (0.09)	0.25 (0.08)
12b	0.19 (0.05)	0.16 (0.05)	0.19 (0.05)	0.14 (0.05)	0.11 (0.05)

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