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NONRUMINANT NUTRITION

The Application of Taguchi Method to Optimize Pellet Quality in Broiler Feeds

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ABSTRACT. The aim of this experiment was to optimize pellet quality by changing different levels of moisture, production rate, grain particle size and conditioning temperature using Taguchi method. In this experiment A 4^3 fractional factorial arrangement using Taguchi method was conducted in broiler starter, Grower and finisher feeds with three production rates (3.5, 4 and 4.5 ton h^{-1}), three steam conditioning temperatures (65, 75 and 85°C), three particle sizes that were achieved by grinding the whole grains in the hammer mill to pass through 6, 6.5 and 7.0 mm sieves respectively, and three moisture content (0, 2.5 and 5%) that were added to the broiler feed in the mixer. During the production process, sampling was done and then PDI and hardness were evaluated in grower and finisher feeds). Results of this experiment showed a significant effect of processing parameters on PDI and hardness. In Conclusion the major finding of this experiment was that the Taguchi method can be used to find the best combination of factors for optimal pellet quality by testing only a fraction of the treatments of the full factorial design.

Keywords: processing parameters; PDI; hardness; feed physical quality; broiler; pellet.

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Introduction

Broiler growth and feed efficiency are improved by pelleting feed. These performance improvements are attributed to decreased feed wastage, reduced selective feeding, decreased ingredient segregation, less time and energy expended for eating, destruction of pathogenic organisms, thermal modification of starch and protein and improved feed palatability. Poor quality of obtained crumble or pellets will result in a reduction of the feed intake and poorer biological performance.

On the farm, attention should be given to managing feed distribution to minimize physical deterioration in crumble and pellets (Ross Broiler Management Handbook, 2014). The main aim of the pelleting process is to agglomeration small particles into larger particles by use of a mechanical pressure process in combination with moisture, heat (Cutlip et al., 2008). This combination results in thermo mechanical changes in feed constituents and an improvement in feed form. Offering feed to birds in pellet increases the economy by improved animal performance and decreasing the feed conversion ratio (Wamsley & Moritz, 2013).

The need to achieve high physical quality and to reduce potential levels of feed-borne pathogens such as Salmonella has led to the application of relatively high conditioning temperatures during conventional hydrothermal processes, a practice that does not favor high nutrient utilization and stability of heat sensitive feed additives (Kiarie & Mills, 2019). Recently, feed additives significantly reduced the *S. enteritidis* population in both ileum and cecum (Moharreri, Vakili, Oskoueian, & Rajabzadeh, 2022).It is essential to optimize pellet quality by changing different levels of pelleting process. Paying attention to form and feed particle size is vital in improving production efficiency, nutrient utilization and reducing the burden of environmental pollution.In laying hens, some trace minerals and extracts in egg contents were retained differently due to feed (Niknia, Vakili, & Tahmasbi, 2022; Vakili, Toroghian, & Torshizi., 2022; Khoshbin, Vakili, & Tahmasbi, 2023). According to Hafeez et al. (2015), in contrast to combinations of fine feed particles with mash and expandate forms, the retention of a few trace elements in egg contents (iron and zinc, respectively) was increased when the coarse particle size was combined with both the mash and expandate forms.

A successful experiment mainly depends on a proper design. The traditional method of process optimization of factors with interaction effects involves the study of these factors at different levels, which is costly, and labor and time intensive. A full factorial design is extensively used in agricultural and poultry science for the optimization of such factors and their interaction effects. The advantage of a full factorial design is that it is possible to calculate the main effects and all the possible multi-factor interactions of the factors, but the number of factors and their levels that can be tested is limited (Antony, 2003).

Therefore, other statistical tools with a lower number of runs may replace full factorial designs. The Taguchi method is an easy statistical tool, which enables a maximum number of main effects to be estimated with a minimum number of experimental runs (Chung, Chen, & Hsieh, 2007; Roy, 2010). The objective of the current study was to determine the effect of pelleting process based on manufacturing technique on pellet feed quality.

Material and methods

Experimental design and data collection

Factor Levels and Orthogonal Array

In the present work, four process parameters including production rate, temperature, humidity, and particle size varied at three levels were considered. The range of different factors and their levels used for this study are shown in Table 1.

Table 1. The L9 (3^4) Taguchi orthogonal array of the experimental design.

L9(3^4)	A	B	C	D
Trial No.	Production rate	Particle size	Moisture	Steam conditioning temperature
1	3.5	coarse	0	65
2	3.5	medium	2.5	75
3	3.5	fine	5	85
4	4	coarse	0	65
5	4	medium	2.5	75
6	4	fine	5	85
7	4.5	coarse	0	65
8	4.5	medium	2.5	75
9	4.5	fine	5	85

A modified orthogonal array of L9 is found to be appropriate and hence it was chosen. The orthogonal array of L9 (9 treatments) was selected based on the number of parameters and their levels via Minitab 16.1 software (Minitab Inc., State College, PA). Taguchi's L9 orthogonal array was used as shown in Table 1. The composition of the diets and the amount of their nutrients are indicated in Table 2. Ross 308 nutrition guideline was used to formulate the diets (Ross Broiler Management Handbook, 2014).

Table 2. Composition of grower and finisher experimental diets.

Ingredients	Grower (11-24 d of age)	Finisher (25-42 d of age)
Corn	51. 2	52.5
Soybean meal	29.3	26.8
Meat meal	2	1.5
Canola meal	5	4
Soybean oil	2.1	3
Di-calcium phosphorus	1.72	1.72
Calcium carbonate	1.33	1.33
Wheat	8	10
Mineral supplement	0.25	0.25
Vitamin supplement	0.25	0.25
Iodized salt	0.25	0.25
DL-Methionine	0.34	0.44
L-lysine	0.26	0.27
Total	100	100
Calculated Analysis		
Metabolizable energy	3123	3207
Crude protein (%)	20.12	18.77
Crude fat (%)	6.1	3.81
Linoleic Acid (%)	2.13	2.13
Calcium (%)	1.00	1.00
Available phosphorous (%)	0.47	0.47
Na (%)	0.11	0.11
Lysine (%)	1.37	1.37
Methionine + Cysteine (%)	1.028	1.128

The data collection was made in Zardaneh-Dizbad Co in the Nishabour, Iran (pellet mill made in Bulgaria, model 520/178). A 4^3 fractional factorial arrangement with 9 treatments was conducted in grower and finisher feeds with three production rate 220, 320 and 420 pellet feeder speeds (3.5, 4 and 4.5 ton h^{-1}), three steam temperatures conditioning (65, 75 and 85°C), three particle sizes that were achieved by grinding the whole grains in the hammer mill to pass through 6, 6.5 and 7.0 mm sieves respectively, and three moisture content (0, 2.5 and 5%) that were added to broiler feed in the mixer.

During the production process, sampling was done at the end-point of production line. Pellet durability and pellet hardness determine with Holmen pellet tester (model NHP100) and Stable Micro Systems Texture Analyser (model XTplus100), respectively. The obtained pellet quality (PDI and hardness) values were converted to signal to noise (S/N) ratios that were used to find the optimal level of each factor. In this work, the optimized response variables were PDI and hardness, in which both should be increased as much as possible. Hence, the optimum parameter levels were those that gave maximum S/N values of the PDI and hardness.

Results and discussion

A Taguchi robust design method was used to identify the optimal condition and optimize pellet quality. The S/N and the main effects of each parameter for PDI quality in grower and finisher diets are shown in figures 1 and 2 respectively. Figure 3 shows the S/N and main effects of each parameter for hardness quality in grower and finisher diets. In both PDI and hardness, a greater S/N value corresponds to better pellet quality. Therefore, the optimal pellet quality is the combination of the level of each factor with the greatest S/N value. Results of this experiment showed a significant effect of processing parameters on PDI and hardness.

According to Itani and Svihus (2019) study, whilst pelleting molds mash diets to macro particles in the form of pellets, it simultaneously reduces the size of the micro-particles that constitute the intact pellet. A reduction in particle size due to pelleting has also been reported by Péron, Bastianelli, Oury, Gomez, and Carré (2005).

Trials have shown that every 10% increase in fines (< 1 mm) results in a reduction of 40 g body weight at 35 days and therefore, the aim should be to minimize the amount of fine particles (< 1 mm) in the feed (Ross Broiler Management Handbook, 2014).

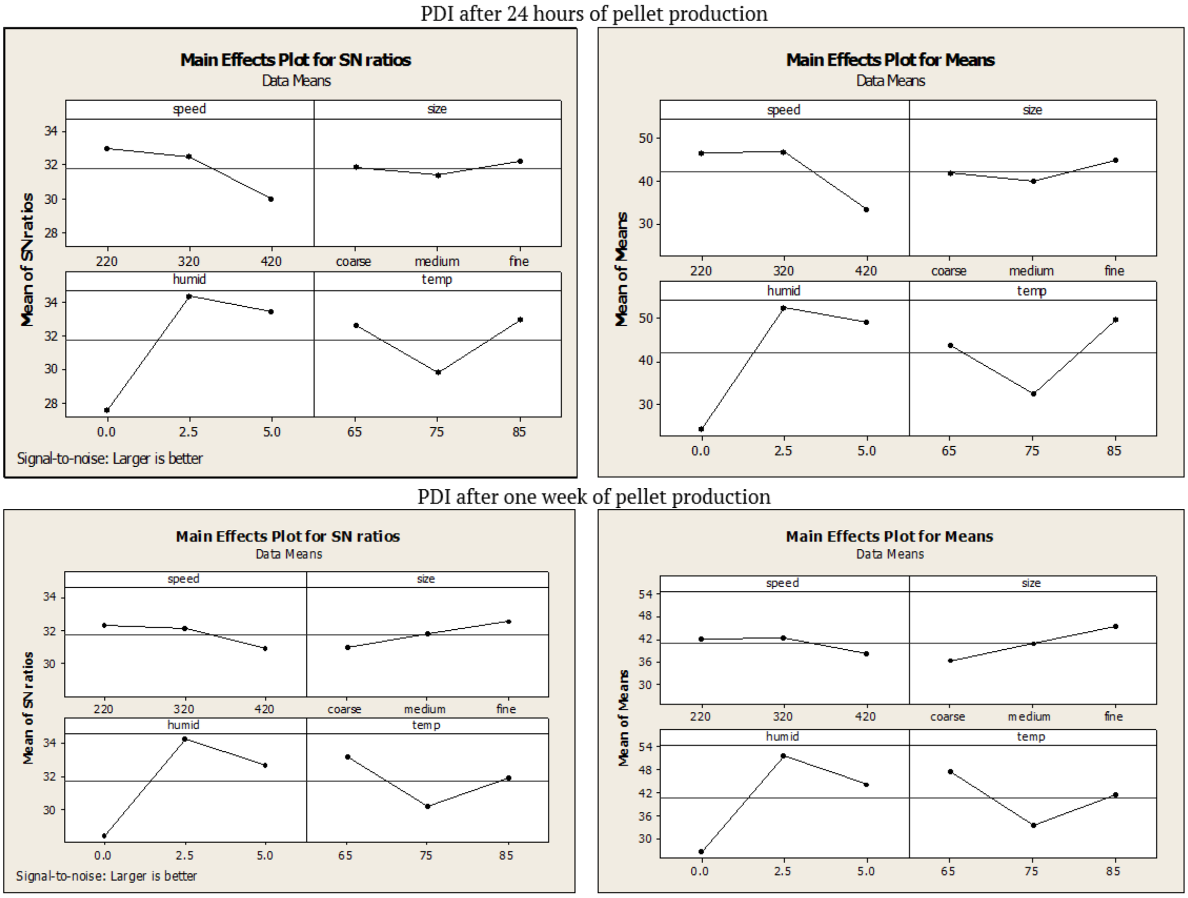

Figure 1. The means and S/N ratio graphs for optimization of PDI in grower diets.

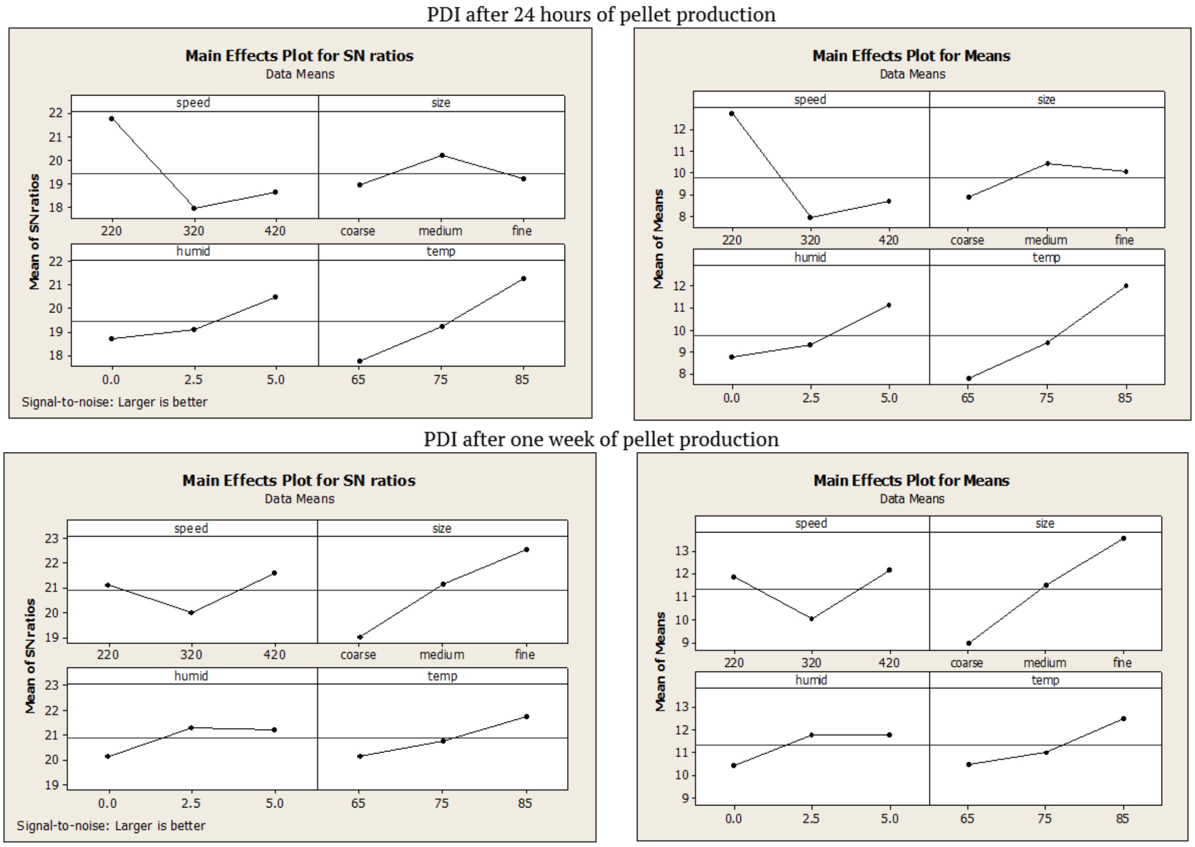

Figure 2. The means and S/N ratio graphs for optimization of PDI in finisher diets.

Amerah, Ravindran, Lentle, and Thomas (2007) showed that feed form had a greater influence on performance parameters than did particle size. Figure 1 shows that pellet durability was decreased by accelerating the production rate in grower feed. Although adding the humidity increased PDI, the addition of 2.5% moisture was better than 5%. Moritz et al. (2001) reported that by adding moisture to the mash in a mixer, feed durability was increased. In our study the PDI raised by increasing the conditioning temperature after 24 hours of pellet production. The conventional pelleting process, increasing conditioning temperature can be performed by increasing the steam flow rate. More steam means more heat and moisture, the two primary perquisites needed for feed particle adhesion, thus improving pellet quality (Abdollahi, Ravindran, Wester, Ravindran, & Thomas, 2011).

So according with Taguchi results, the best combination was the first level of production speed (220 rpm speed feeder), the third level of particle size (fine), the second level of addition of water (2.5%) and the third level of conditioner temperature (85°C) to improve PDI, respectively after 24 hours of pellet production in grower diets. These results are in agreement with Frederick et al and Buchanan and Moritz (2009) findings and rejected the Buchanan, Lilly and Moritz (2010a and b) results. The physical quality of the pellets durability and hardness) was improved by increasing conditioning temperature from 69 to 78 and 86C° (Buchanan and Moritz, 2009).

In the finisher feed, the PDI increased by decreasing the production rate (Figure 2). Medium particle size had greater PDI. Adding the humidity increases the PDI, and adding 5% moisture to the mixer had the best PDI. The raising temperature increased pellet durability after one week of pellet production in finisher diets. So based on the Taguchi method, The best combination of finisher was the first level of production speed (220 rpm speed feeder), the second level of particle size (medium sieve), the second level of humidity addition (5%) and the third level of conditioner temperature (85°C) to improve pellet durability index, respectively.

Finisher pellet durability obtained one week after production showed almost the same trend (Figure 2). Only the best level of production speed, was the third level (feeder speed 420 rpm). Smaller feed particle size through fine grinding increases surface area, provides more contact points with adjoining particles, leads to faster penetration of heat and moisture to the core of particles, and results in better binding characteristics and higher quality pellets (Behnke, 2001; Dozier, 2003; Löwe, 2005).

Pellet hardness

Results of pellet hardness in grower and finisher feeds are shown in Figure 3. According to the Figures 3 the average S/N performance for optimizing pellet hardness index in grower has been shown that increasing pellet hardness decreased production speed. The smaller particle size, had greater hardness. Adding the humidity reduced pellet hardness. Also increases the temperature reduced pellet hardness. So according to the Taguchi method, the best combination was the first level of production speed (220 rpm speed feeder), the first level of particle size (fine), the first level of water addition (zero percent) and the second level of conditioner temperature (75°C), to improve the hardness index in grower.

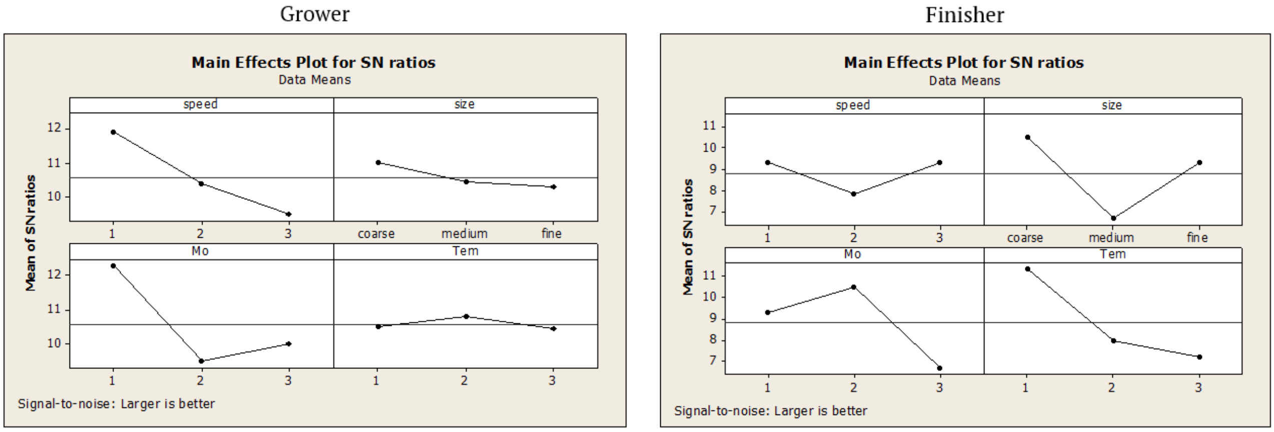

Figure 3. The means and S/N ratio graphs for optimization of Hardness in grower and finisher diets; Speed 1=220, 2=320 and 3=420. Mo= Moisture; 1=0, 2=2.5 and 3=5. Tem= Temperature; 1=65, 2=75 and 3=85°C

In finisher, the best combination was obtained by the first level of production speed (220 rpm speed feeder), the first level of particle size (fine), the second level of water addition (2.5%) and the first level of conditioner temperature (65°C), to improve the hardness index.

Currently, there are no industry standards for manufacturing pellets. Each mill may operate using different diet formulations, ingredient particle sizes, steam pressures, conditioning temperatures, and production rates (Buchanan & Moritz, 2009). For example, in a survey conducted by Buchanan and Moritz (2009), commercial feed mills in the eastern United States used conditioning temperatures ranging from 68 to 91°C (155 to 195°F), die length-to die hole diameter ratios (LDR) ranging from 6.5 to 13.1, and production rates ranging from 907 to 14,882 metric tons/wk. (1,000 to 16,400 tons wk^{-1}).

Variation in all these factors may affect the amount of heat and moisture that feed will accrue through the pelleting process. As a result, thermo mechanical changes in nutrients, such as starch gelatinization and protein denaturation, are widely variable. Inconsistency in manufacturing technique, coupled with constantly changing diet formulations, makes predicting and optimizing pellet quality difficult.

The results of our experiment showed that the TM is an easy statistical tool that can be used for optimization of pellet quality; using this method optimization is possible for each manufacture and helps the feed producers to achieve to the good pellet quality base on their specific conditions.

This method is a robust design approach and extensively applied for evaluation and optimization of products. Recent studies showed that this method has also been successfully applied to biotechnology (Khoudoli, Porter, Blow, & Swedlow, 2004; Lee, 2010), agricultural sciences (Barghbani, Rezaei, & Javanshir, 2012; Mahalakshmi & Ganesan, 2009; Moslemi & Khondabi, 2011) and cell culture (Kallel et al., 2002).

Sedghi, Golian, Esmaeilipour, and Van Krimpen (2014) evaluated the applicability of the TM to optimize *in vitro* intrinsic phytase activity (IPA) of rye, wheat and barley under different culture conditions. They also compared the results of the TM with those obtained by full factorial analysis. The comparison between the TM and full factorial results showed that the TM may be a sufficient and resource saving alternative to the full factorial design for optimization of several factors in poultry science.

The results of our study also showed that TM can be applied for optimization of pellet quality by testing multiple factors at the same time. This study serves as another example for the application of the Taguchi methodology for optimization of biological processes (Figure 4). This result would further facilitate to reduce the cost of the large scale experiments in poultry nutrition.

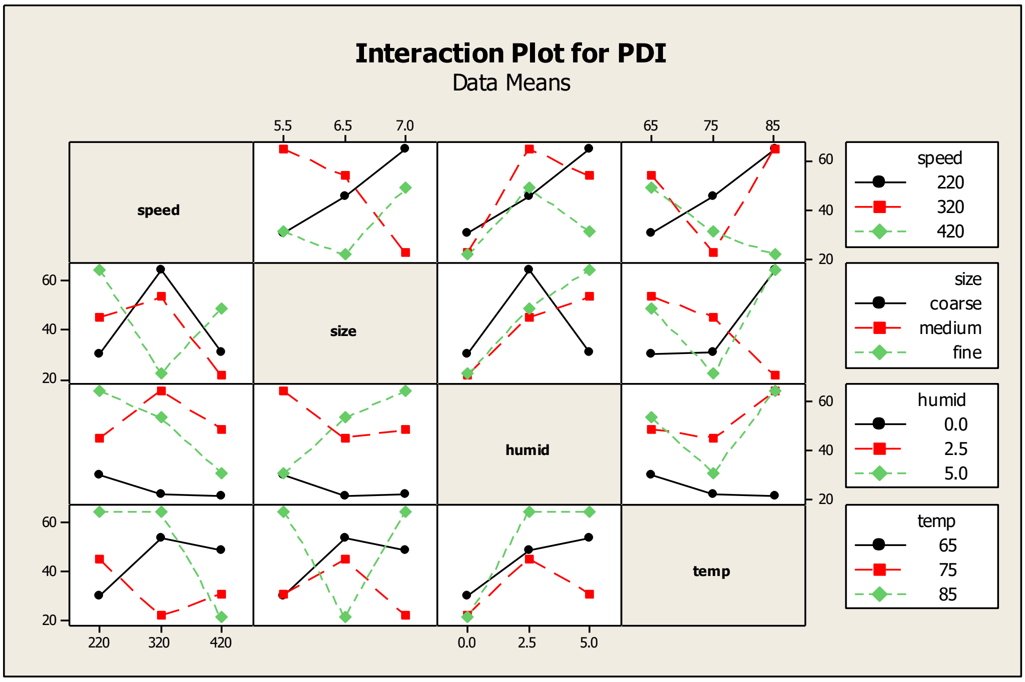

Figure 4. Interaction plots created by Taguchi method.

Conclusion

In Conclusion the major finding of this study was that the Taguchi method can be used to find the best combination of factors for optimal pellet quality by testing only a fraction of the treatments of the full factorial design.

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