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Development of edible environmental enrichment objects for weaned pigs

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ABSTRACT

Studies on environmental enrichment for weaned pigs have predominantly focused on stimulating exploration through "nonedible toys." The research on edible enrichment objects is very limited. For this reason, the aim of this study was to develop and characterize edible environmental enrichment objects (EOs) for weaned pigs and to determine behavioral and weight gain responses of pigs. Two types of EOs were evaluated, a cookie form (EO-C) and a donut-shape (EO-D). The EOs were formulated with dried whey (40% w/v) and sodium alginate (2% w/v) in distilled water. Blends were homogenized, molded, refrigerated, gelled, and dried. The EOs were characterized by dimensions, color, mechanical properties, and proximal chemical analysis. To study the interaction of pigs with EOs, 30 hybrid pigs, weaned at 21 days of age, were distributed into 3 groups (5 pairs of pigs per group): (1) control: pigs without EOs, (2) EO-D group, and (3) EO-C group. The interaction time was video-recorded for 3 days for 3 hours per day and then analyzed with the Observer XT 2011 program. The live weight of pigs and the total consumption of the EOs were also determined. The EOs were yellow in color and had different dimensions, with larger sizes for EO-D (height: 2.5 mm, width: 7.6 cm, and weight: 42 g). The EOs were composed mainly of carbohydrates (67-73%) and proteins (10-11%). The pigs consumed the EOs in high percentages, between 75 and 100% for EO-D and 38 and 60% for EO-C. There were no differences in consumption between EOs. The consumption of the EOs did not have an effect on live weight of the pigs; the final weights in the groups were as follows: 7.4 ± 0.2 kg (control group), 7.6 ± 0.2 kg (EO-C group), and 7.3 ± 0.4 kg (EO-D group). The results of the interaction showed that the pigs interacted with both EOs, that on day 2 they spent more time interacting with EO-D, and that the interaction time through the days was reduced for EO-D and remained constant for EO-C. The interactions of the pigs with the EOs included sniffing, manipulation with nose or extremities, licking, and nibbling or consumption of EOs.

Introduction

Abrupt weaning is a common practice that stresses and negatively affects welfare and productivity of animals raised in intensive farming systems (Dong and Pluske, 2007). Several reasons may trigger a stress response, such as placing pigs away from their mother and siblings, relocation in grow-out pens, mixing with unfamiliar animals, as well as changes in their environment and feeding conditions (Campbell et al., 2013). Some of the negative consequences reported for stressed animals are an increased frequency of aggressive behaviors toward other animals (Hicks et al., 1998; Schrøder-Petersen and Simonsen, 2001), decreased food consumption due to neophobia and adaptation to new diets (Figueroa et al., 2013), greater susceptibility to disease (Jensen et al., 1996; Hicks et al., 1998), and decreased growth rates (Campbell et al., 2013).

Thus, one of the priorities at weaning is to stimulate food consumption, as evidence shows that this factor closely relates to disease incidence, mortality, and productivity losses in pig farming (Dong and Pluske, 2007). In this regard, using dairy products (e.g., dried whey) as ingredients in transition diets can aid to achieve greater food consumption, as they not only contribute to animal nutrition but also confer greater palatability to these diets due to their high lactose and protein contents (Burnell et al., 1988).

The incorporation of environmental enrichment objects is a management practice that has been commonly used during the

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weaning period to stimulate desired behaviors, such as exploration and foraging, while also diminishing unwelcome behaviors, such as exploration and aggression directed toward pen mates (Van de Weerd et al., 2003; Van de Weerd and Day, 2009). Overall, studies on environmental enrichment in pigs have focused on stimulating exploration by means of plastics and rubber toys, ropes, straw, metal chains and bars, sticks, among others (Scott et al., 2009; Van de Weerd and Day, 2009; Colpoys et al., 2018). However, Van de Weerd et al. (2003) explained that this kind of objects must be edible, scented, chewable, deformable, and destructible, as these properties motivate animals to explore, forage, and manipulate objects. These traits act synergistically to attract the attention of animals, and when those objects are also replaceable and edible, they prolong the attention span of animals.

Notwithstanding, few researchers have studied edible objects used as environmental enrichment objects that also provide a nutritional reward. Most of these objects have been derived from vegetables that were placed within pens using a number of different presentations, such as beets, fresh coconut halves and carrots hanging on strings, loose cabbage, lavender straws filled up with whole peanuts, alfalfa hay served from dispensers, ice blocks, sugar/mineral blocks, and food buckets (Van de Weerd et al., 2003; Studnitz et al., 2007). In this regard, the food industry could use emerging technologies to manufacture environmental enrichment objects based on edible products, such as dried whey and sodium alginate. The latter is a hydrocolloid polysaccharide that is extracted from brown algae and is widely used within the food industry due to its gelation properties, which allow for the development of three-dimensional structures (Hamed et al., 2015).

Consequently, this work intended to develop and characterize edible enrichment objects (EOs) that could be used for environmental enrichment purposes and then test how weaned pigs interact with these objects and its effect on weight gain.

Materials and methods

Manufacturing process of EOs

Two types of EO were manufactured, one (EO-C) shaped as a cookie (Figure 1A) and another (EO-D) shaped as a donut (Figure 1B). EO-C was prepared based on a solution of sodium alginate (Sigma-Aldrich) at 2% w/v in distilled water plus dried whey (Prinal S.A, Chile) at 40% w/v. These blends were homogenized using a mechanical agitator and poured into silicone molds (20 mL capacity), which were refrigerated at 5°C for 48 h. Then, EOs were demolded and immersed in a gelling solution ($CaCl_2$ at 5% w/v in distilled water), for 30 min. Next, EOs were drained, deposited in aluminum trays, and dried-up in an oven at 50°C for 24 h. The same manufacturing process was used to prepare both EO-D and EO-C, but a 4% w/v glycerol solution (Droguería Michelson S.A) was added to EO-D to achieve a softer texture to this blend. From the resulting EO-D blend, 90 mL was poured into donut-shaped silicon molds.

Characterization of EOs

Digital photography (Sony DSC-HX1, Sony Corporation, Japan) was used to record the appearance of EOs. In addition, EOs were characterized in regards to color, dimensions, weight, deformation, and strength. Color was measured using a colorimeter (Konica-Minolta CR-300, Japan), their dimensions (height and width) by using a digital Vernier Caliper, their weight by using a digital scale, and their deformation and strength by measuring their fracture resistance using an Instron testing machine (QC-SPA, TSS, England) with a probe of 1 mm thickness, at a speed of 1.5 cm/min.

In addition, these EOs were characterized nutritionally by performing a proximate chemical analysis (AOAC, 1996), which determined their humidity (method 945.15), crude protein (Kjeldahl method 945.18), ether extract (method 945.16), crude fiber (method

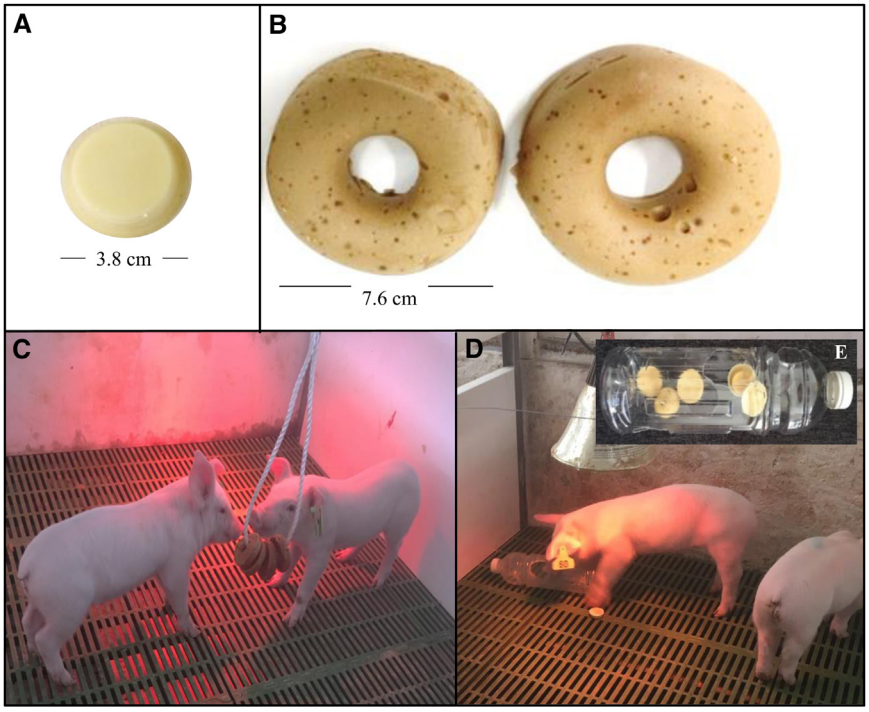

Figure 1. Appearance and dimensions of edible environmental enrichment objects in the form of cookies (A) and donuts (B). Disposal of edible environmental enrichment objects in the pens; hanging on ropes for donuts (C) and inside plastic bottles for cookies (D and E).

962.09), ash (method 920.153), and nitrogen-free extract (calculated by difference).

Study in pigs

The EOs were prepared, characterized, and then offered to weaned pigs to determine whether the animals found them attractive. The pigs' responses were assessed by observing their interactions with these objects during the 3-day trial period.

Animals

The Institutional Committee on Animal Care and Use from the University of Chile (17064-VET-UCH) approved the experimental design proposed for this study, which was performed in the facilities of the Center for Research, Technological Innovation and Training for the National Pig Industry (CICAP) at the Pontifical Catholic University of Chile. This center is located in the province of Pirque, in the Metropolitan Region of Chile.

A total of 30 hybrids, male, 21-day-old weaned pigs of similar live weight (±0.8 kg) were housed in pairs within 15 pens. The animals were allowed 24 hours to adapt to their new environment before beginning the experiment. Twice a day, animals were fed a diet formulated according to their calculated nutritional requirements (NRC, 2012). Water was provided *ad libitum*.

Experimental design

Pigs were randomly assigned in pairs to one of three experimental groups: (1) a control group (C) that comprised 5 pairs of pigs not exposed to any kind of environmental enrichment; (2) an EO-D group where 5 pairs of pigs were provided with objects shaped as donuts (Figure 1C) that were hanging from a string (4 of these EOs were hanging at eyesight level in the center of the pen); (3) an EO-C group comprising 5 pairs of pigs provided with 5 objects shaped as a cookie and enclosed in a 1.5 L bottle with 4 holes (Figure 1D and E). The objects were delivered daily.

The characteristics of the pens are shown in Figure 1C and 1D. The pens have a size of 180 cm x 130 cm, and the floor is slated of polyurethane. The pigs did not have access to straw, bedding, or any other materials.

The purpose behind assigning animals to the control group was to determine whether the consumption of EOs could trigger a live weight gain in animals due to its nutritional composition. Consequently, all animals were weighed individually at the beginning and end of the experimental period. Total consumption of EOs by pigs was calculated based on the weight difference between the amount offered and collected in each day. This analysis was performed to quantify the acceptability of these EOs, but no comparisons were drawn among types of EOs as the amount offered to pigs differed for each EO type.

Interaction of animals with EOs

A total of 8 infrared video cameras (IR Outdoor Cameras 700tvl 1/3 cmos Sony; SENKO S.A. Japan) were installed the day before the beginning of the experimental period, placing one camera in every two pens. Using this equipment, pigs were recorded on video between 10.00 to 13.00 hr for 3 consecutive days, as this time frame has been deemed the period of highest activity for pigs (Olsen et al., 2000).

All the cameras streamed video into a digital video recording system (DVR 08 channels HDMI 1 audio fullD1, China), and these recordings were analyzed by one person using the Observer XT 2011 software (Noldus software, version 11, Noldus Information Technology, The Netherlands). The analysis involved using scan sampling with instantaneous time sampling performed every three minutes. Each interaction of the animals with the EOs was registered and defined as any behavior that indicated interest in these objects; these behaviors are defined according to Van de Weerd et al. (2003) in Table 1. In addition, interactions with bottles containing EO-C were deemed equivalent to a direct interaction with the object and quantified accordingly.

Table 1
Description of the behaviors registered considered as interaction of pigs with the EOs

Behavior	Description
Sniffing	Pig uses its nose to smell the object, nose-EO contact
Manipulation of EO	The EO is displaced from one place to another by using the snout or forelegs
Licking	Pig makes contact with the object with the tongue, no ingestion occurs
Nibbling	Pig nibbles (almost bites) the EO
Eating	Chewing and ingestion of the EO

EO, enrichment object.

Statistical analysis

First, our data were subjected to a Shapiro-Wilk test to determine normality. Then, ANOVA and Tukey tests ($P < 0.05$) were used to analyze both the EO object characteristics and variations in the pigs' live weight. As for the total consumption of EOs, group differences were analyzed using a Friedman test ($P < 0.05$). In addition, the data for the interaction of pigs with EOs between days for each group were analyzed using repeated-measures ANOVA and Tukey tests ($P < 0.05$), whereas the data for interaction time of pigs with EOs between groups for each day were analyzed using a two-sample t test ($P < 0.05$). All the aforementioned analyses were calculated using the Stadistix version 8 software package.

Results and discussion

Characterization of EOs

Three-dimensional matrices were used to shape the EOs, which were demolded intact and easily. Figure 1 shows the visual

Table 2
Properties of edible environmental enrichment objects in the form of cookies (EO-C) or donuts (EO-D) for pigs

Properties	EO-C	EO-D
Color		
L	59.7 ± 9.1[a]	43.8 ± 6.1[b]
a	10.2 ± 2.7[a]	8.5 ± 1.2[b]
b	41.2 ± 8.4[a]	33.2 ± 3.0[b]
Chrome	42.5 ± 8.5[a]	34.2 ± 3.1[b]
Hue angle	75.8 ± 3.9[a]	70.6 ± 1.6[b]
Physical		
High (mm)	1.1 ± 0.2[a]	2.5 ± 0.1[b]
Wide (mm)	3.8 ± 0.6[a]	7.6 ± 0.2[b]
Weight (g)	9.4 ± 0.9[a]	42.4 ± 1.7[b]
Mechanical		
Deformation (mm)	0.8 ± 0.3[a]	9.9 ± 1.9[b]
Strength resistance (mm)	5.2 ± 1.8[a]	0.6 ± 0.4[b]
Nutritional		
Moisture (%)	4.8 ± 0[a]	12.0 ± 0.2[b]
Crude protein (%)	11.8 ± 0.1[a]	10.6 ± 0.3[b]
Ether extract (%)	0.3 ± 0	0.4 ± 0.1
Crude fiber (%)	0.9 ± 0.1	0.8 ± 0.1
Ash (%)	9.2 ± 0	8.9 ± 0.2
Nitrogen-free extract (%)	73.1 ± 0.1[a]	67.5 ± 0.7[b]

EO, enrichment object.
Different letters indicate significant differences in mean values ($P < 0.05$).

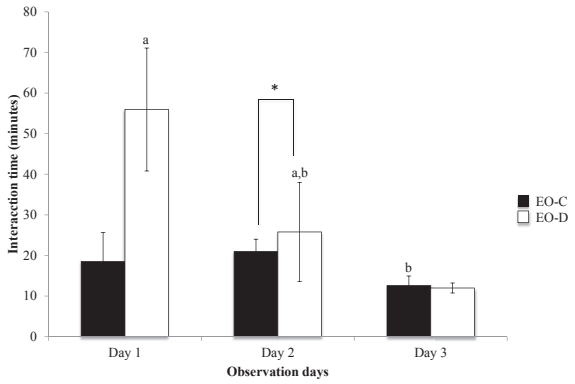

Figure 2. Interaction time of the pigs with different types of edible environmental enrichment objects (EOs) in the form of cookies (EO-C) or donuts (EO-D). Different letters indicate differences for the same EO between study days. *Indicates differences between EO for the same day of study. The data are expressed as mean ± SEM.

characteristics of these objects. In particular, EOs had smooth surfaces, without fissures, but the surface of EO-C was clearly more homogeneous than that from EO-D. This can be explained by the fact that EO-D formulation included glycerol and the fact that heterogeneity increases along with the number of ingredients in any mixture (Fundueanu et al., 1999). As for their color, both types of EOs were yellow due to the presence of dried whey, which was the major component of both formulations.

Table 2 lists the differences in color parameters between EOs, such as the darker shade found in EO-D because of including glycerol in their formulation.

EOs showed not only different shapes due to their molds but also different sizes, with EO-D being bigger and heavier than EO-C to the point of weighing five times more. The donut shape made it easier to hang the objects on a string inside each pen (Figure 1C).

The addition of glycerol to the EO-D formulation also resulted in softer objects, which showed greater deformability and lower fracture resistance due to glycerol's plasticization effect (Thomazine et al., 2005).

Regarding the nutritional properties of these objects, they differed mostly in humidity, owing to the well-known hygroscopic characteristics of glycerol that allow it to capture water from the environment (Park et al., 1994). Meanwhile, differences in content of crude protein and nitrogen-free extract were less important but EO-C showed higher values than its counterpart due to the substitution of other ingredients by glycerol in the formulation.

The edible objects were developed to satisfy the concept of "edible toys." However, they could also be used as food supplements for the weaning stage due to the addition of high concentrations of dried whey to their formulation. In fact, their chemical composition resembles dried whey, as expected. Specifically, current scientific literature reports that the nutritional contributions of dried whey for pig diets reach up to 12% of crude protein and 3,190 Kcal/kg of metabolizable energy (Batal et al., 2011).

Consumption of EOs and live weight of pigs

In this work, we did not compare daily consumption of EO-C against EO-D because each group was offered different amounts. However, an interesting finding was that both types of EOs were consumed steadily throughout the experimental period, in spite of the fact that these objects were offered to pigs during the weaning stage, which is one of the most stressful periods of their lives (Oostindjer et al., 2011; Campbell et al., 2013). In fact, 100% of EO-C and 60% of EO-D were consumed by the end of the first day (Figure 1). Such a high degree of acceptability by pigs can be explained by the use of dried whey, which is very palatable for pigs (Dong and Pluske, 2007). Also, the EOs allowing that pigs to develop exploration behaviors that ultimately rewarded them with food (Young et al., 1994; Vermeer et al., 2017; Qin et al., 2018). Nonetheless, providing these to pigs did not significantly impact live weight gains as animals began the study within a range of 6.9-7.1 kg and finished it weighing in 7.4 ± 0.2 kg, 7.6 ± 0.2 kg, and 7.3 ± 0.4 kg for groups control, EO-C, and EO-D, respectively. This finding agrees with those from other studies that have also explored the use of edible EOs and reported that these objects showed no effect over the production parameters in pigs of similar age (Beattie et al., 2000) or older pigs (Bulens et al., 2016). Meanwhile, few studies have assessed the effect of edible EO over production parameters and most of them reported no effect over live weight (Nannoni et al., 2016; Olsson et al., 2016; Vermeer et al., 2017).

Interaction of pigs with EOs

Figure 2 presents the results for the interaction time of pigs with EOs, observing a high variability of these values. Overall,

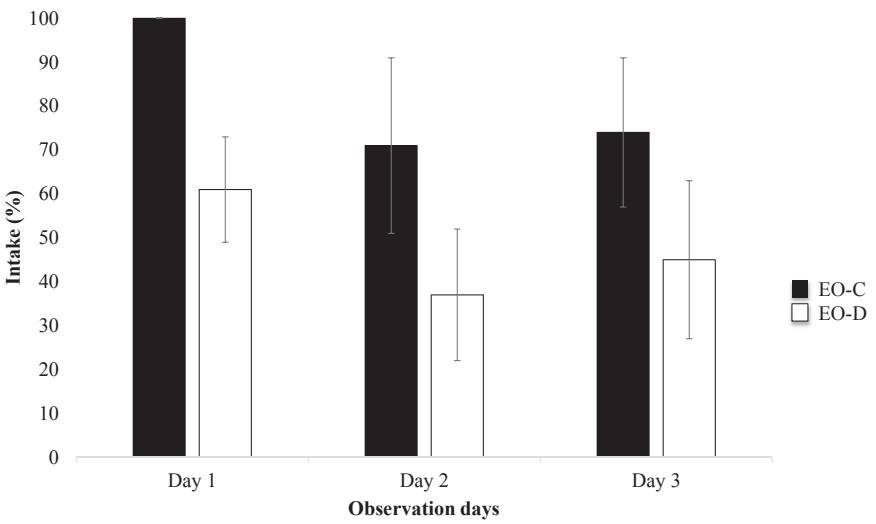

Figure 3. Intake of edible environmental enrichment objects (EOs) in the form of cookies (EO-C) or donuts (EO-D) by pigs (mean ± SEM).

pigs dedicated more time to interact with EO-D, although significant differences between both types of objects were only observed for day 2. This finding resembles evidence from other studies, where researchers reported great variability for interaction times with EOs. For instance, Young et al. (1994) reported high individual variability among pigs for interaction time with a food-dispensing ball ("Edinburgh Foodball"). Similarly, Nannoni et al. (2016) observed strong individual differences for interaction time with EOs in a group of weaned pigs. These findings may explain the numerical difference on day 1 between groups without it being significant, as the high variability could result from some pigs feeling more attracted to these objects than other pigs due to their different personality traits (Melotti et al., 2011). In addition, some studies have reported observing that age influences how pigs use EOs as animals interact more with them during the grow-out stage than immediately after weaning (Docking et al., 2008).

Pigs interacted with EOs in several ways, such as sniffing them, manipulating them using their noses or legs, licking and nibbling them, or simply eating them (some of these behaviors can be observed in the supplementary video).

Although interactions of pigs with EO-C remained relatively constant as the experiment progressed, in the case of EO-D, the interactions became shorter as days went by, to the point that a significant difference was clearly noticeable between days 1 and 3 (Figure 3). Such a difference might be due to the fact that EOs-C were smaller and delivered to pigs in smaller quantities, and hence, pigs ate them quickly and resulted in a lesser chance of animals becoming accustomed to these objects. Contrarily, as EO-D were bigger and more abundant, interactions lasted longer and novelty wore off. Similar studies have reported that this habituation factor manifests over the first few days. For instance, Dawson and Edwards (2015) found that pigs became accustomed to flavored strings after four days of being exposed to these objects. Later on, Docking et al. (2008) assessed 10 objects for the purpose of environmental enrichment and found that habituation to every object was evident within the course of 5 days. However, extending the experimental period up to at least 15 days might be advisable when planning future studies on this topic. This recommendation stems from the work of Horback et al. (2016), who reported an increase on the time spent by pigs in interactions with EOs between days 1 and 3, followed by a reduction between days 3 and 5, only to rise again from days 5 to 14.

Also worth noting is the fact that EO-C were delivered to pigs enclosed in a plastic bottle, thus requiring them to play with the bottle. This might stimulate exploration to a greater extent. Exploratory behavior has been associated to longer attention spans in animals (Van de Weerd et al., 2003; Van de Weerd and Day, 2009).

Conclusions

In this work, our research group was able to develop edible environmental enrichment objects on the basis of dried whey and sodium alginate and shape them as either cookie-like or donut-like toys. These objects were comprised primarily of a mixture of carbohydrates and proteins that, although they were eaten by the pigs, did not result in an increase of live weight. Pigs felt attracted to these objects and interacted with them but over the course of the study showed a reduced interest in the EO-D type of object. Looking at possible future applications of this experience, edible objects could effectively be used not only for environmental enrichment purposes but also as a strategic method of nutritional supplementation during weaning and a tool that may help to reduce undesired animal behaviors.

These objects can be manufactured industrially by extrusion technology and could be used in commercial farms during the first days of the weaning period.

Acknowledgments

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Ethical considerations

The experiments have been approved by the Institutional Committee on Animal Care and Use from the University of Chile (certificate 17064-VET-UCH).

Conflict of interest

The authors declare that they have no competing interests.

Authorship statement

The idea for the paper was conceived by C.V. and T.T. The experiments were designed by C.V. and T.T. The experiments were performed by E.D., O.C., and J.L. The data were analyzed by C.V., J.L., and T.T. The paper was written by C.V., J.L., E.D., and T.T.

Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jveb.2019.06.010.

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