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RESEARCH ARTICLE

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# Alternatives to corn for baiting wild pigs

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## Abstract

We examined dietary preferences of wild pigs to discern possible bait alternatives to corn. Captive trials were conducted during spring and fall 2021 in the Wild Pig Research Facility at Kerr Wildlife Management Area, Hunt, Texas, USA. We conducted 2-choice tests by allowing wild pigs to feed *ad libitum* on soybeans, split peas, mealworms, and peanuts (spring 2021), and oats, acorns, earthworms, and peanuts (fall 2021), always with corn available as a second choice for reference. In each trial, we used proportion of test bait eaten versus total bait eaten, and relative access to both food sources as indices of bait preference. We found that a higher proportion of corn was consumed than that of any test bait in the spring, but not in the fall. However, we found that earthworms were consumed more than any other test bait in the fall. We also found that corn was accessed more than test baits in the spring, but not more than earthworms or peanuts in the fall. Greater consumption of earthworms relative to other baits, and access rates comparable to corn indicated that earthworms could be an effective alternative bait to corn. Our work suggests that alternative baits may be equally or more effective for attracting wild pigs than corn.

KEYWORDS

acorns, attractants, consumption, corn, earthworms, feral swine, wild boar

Wild pig (*Sus scrofa*) populations in the U.S. have increased in range over the last several decades with resident populations being reported in 18 states in 1982 and 35 states in 2016 (Corn and Jordan 2017). Range expansion has been accompanied by an increase in wild pig abundance as population size has almost tripled from 2.4 million to 6.9 million in the same timeframe (Lewis et al. 2019). Increases in range and abundance have resulted in growing economic impacts. Annual costs accrued through wild pig damage and management (e.g., trapping, aerial gunning, exclusion fencing) in the U.S. are estimated at USD$1.5 billion (Pimentel 2007). A central cause of the economic cost associated with wild pigs is their generalist diet, reflected in the reported depredation of wild pigs to over 20 different crop types (Anderson et al. 2016, McKee et al. 2020), livestock (Seward et al. 2004), and a variety of native plant and animal species (Barrios-Garcia and Ballari 2012).

Baits are commonly used to attract wild pigs to expedite population reduction efforts (West et al. 2009, Massei et al. 2011). In some cases, control efforts using bait have reduced wild pig populations by over 80% (Choquenot et al. 1993), and bait can increase the efficacy of trapping, hunting, and pharmaceutical or toxicant deployment for reducing wild pig populations (Choquenot et al. 1996, State of Hawaii 2007, West et al. 2009, Lavelle et al. 2017, Kinsey 2020). Additionally, bait additives such as natural extracts or synthetic flavors have increased visitation or consumption by target species (Campbell and Long 2007, Ahmed et al. 2017). The most common bait to attract wild pigs throughout the U.S. and other countries is whole-kernel corn (*Zea mays*; West et al. 2009, Massei et al. 2011). Whole-kernel corn (hereafter, corn) is inexpensive, abundant, and has been used in successful trapping campaigns in a variety of regions (Garcelon et al. 2005, McCann and Garcelon 2008, Williams et al. 2011). Further, corn has been reported as the most heavily targeted crop in the U.S. (Anderson et al. 2016). While previous studies confirm that corn is an attractive bait for wild pigs, the efficacy of corn to attract wild pigs can vary by season (Hone 1983). Corn may become less attractive as alternative food resources in an area become more abundant (Barrett and Birmingham 1994). Additionally, corn attracts a variety of other species (Snow et al. 2021), resulting in decreased efficacy for wild pigs or endangerment of nontarget species. Finding alternative baits to corn may help wildlife managers increase and target wild pig visitation to bait sites, especially during seasons when corn is less effective. Moreover, flavors or scents from such baits may be extracted or synthesized and used as additives to enhance other baits such as toxicants (Campbell and Long 2007).

There are a variety of potential food resources that may be attractive to wild pigs as baits given the generalist behaviors of wild pigs (Barrios-Garcia and Ballari 2012, Ballari and Barrios-García 2014). The extensive crop damage documented by Anderson et al. (2016) and McKee et al. (2020) demonstrated that wild pigs will readily target agricultural plants when available. Peanuts (*Arachis hypogaea*), oat groats (*Avena sativa*), and soybeans (*Glycine max*) are readily available at farm and ranch suppliers, and all are listed as crops damaged by wild pigs (Carlisle et al. 2021). Split peas are a good source of protein and amino acids and are increasingly used in domestic pig diets (Anderson et al. 2002). Acorns and other seasonal nuts have been described as a staple of wild pig diet across the world (Barrett and Birmingham 1994, Massei et al. 1996, Calenge et al. 2004). Wild pigs have been shown to consume soil invertebrates (Hafez et al. 1962, Giffin 1978), and one recent study found evidence of earthworm consumption in over 83% of wild pig fecal samples collected over a year (Anderson et al. 2018).

Information about wild pig feeding behavior could help explain what factors influence interannual variation in trap visitation, and it could reveal bait types or sources of bait additives that may be effective for attracting wild pigs when corn is less effective. Our objectives were to compare wild pig consumption of corn and a variety of other baits to determine if (a) there was a bait more attractive to wild pigs than corn that could be used by wildlife managers to bait wild pigs, (b) if seasonal food resources that have historically been thought to reduce wild pig visitation to bait sites are preferred over corn by wild pigs, and (c) if wild pig access to novel baits increases over time. Our goal was to identify potential bait alternatives that could be reliably used for control of wild pigs when an alternative to corn is needed.

## STUDY AREA

Our study was conducted in spring and fall of 2021 at the Texas Parks and Wildlife Wild Pig Research Facility, located on the Kerr Wildlife Management Area in Hunt, Texas, USA. Wild pigs used in the study were trapped within 160 km of the study location. Climate in the study area is characterized as semiarid with hot summers and mild winters, and average annual precipitation is 530 mm (Bomar 1983). Average nightly temperature during the spring trials ranged from 12.7°C to 28.7°C, and average nightly temperature during the fall trials ranged from 6.5°C to 23.0°C. The study area lies within the Edwards Plateau ecoregion of Texas and can be characterized by an oak-juniper savannah vegetation community (Gould 1975). The region consists of private lands managed for cattle ranching and hunting. Here, wild pigs have access to deer feeders filled with corn or protein pellets, as corn is used as bait from September through February and supplemented with protein pellets from March through August. Wild pigs are routinely hunted and trapped throughout the area, often at deer feeder locations.

## MATERIALS AND METHODS

### Study design

A total of 120 wild pigs were used in the study. We used 58 females and 2 males per season and each wild pig was used in only 2 consecutive trials. We prioritized females because of their potential to drive population growth, thus we ensured our results were relative to female preferences. The males were included to increase sampling to our target of 60 when we were short of females. Weights of wild pigs ranged from 11.5–71 kg. Average wild pig mass was 31.8 kg (SD = 8.56) in the spring trials and 36.3 kg (SD = 14.1) in the fall. Wild pigs were trapped using corral traps baited with corn and were kept in a 2-ha communal pen prior to the beginning of the study. Individual wild pigs spent 2–44 weeks in the communal pen and were fed a blend that consisted of 3 parts protein pellets (Purina Antler Advantage 20% crude protein, Purina, St. Louis, MO, USA) and 2 parts corn. Water was also provided *ad libitum* from a trough in each pen. Pigs were gathered from the communal pen at the beginning of each trial by staff who coaxed them through gated alleys to the working facility where they were mechanically restrained in chutes, processed, and randomly sorted into trial pens. Each wild pig was injected with 2, 5-ml dosages of Lutalyse (Zoetis, Kalamzaoo, MI, USA) 2 weeks before the start of the spring and fall trials, respectively, to induce parturition and control pregnancy related nutritional demands among individuals.

We conducted our testing during 2 seasons: 6–26 April (spring) and 29 November–19 December (fall). During each season we conducted 4 replicates of 2-choice tests for each test bait. Baits tested in the spring were roasted soybeans, split peas, dried mealworms, and whole peanuts. In the fall, we tested oat groats, acorns, earthworms, and whole peanuts. Pen space limited the number of baits which could be tested concurrently. Thus, we prioritized seasonally limited baits (e.g., acorns and earthworms) to the season in which they are most available to free-ranging wild pigs. We also prioritized baits with relatively high spring preference (i.e., peanuts) to include in fall. Wild pigs were allowed to feed freely during 2-choice tests which lasted for 5 days. Each 2-choice test consisted of a test bait paired with the reference bait (i.e., corn). The test baits were offered in 9 pens following a systematic rotation, so that no wild pig was exposed to the same test bait twice. The tenth pen contained only corn in each trough and was used for detecting whether location bias affected trough choice. Water was also provided *ad libitum* from a trough in each pen. Each bait was tested, with corn present, 9 times in a season. We balanced sampling for each season by rotating which bait was tested 3 times (i.e., rather than twice) in each of the replicates. During each season we placed 30 wild pigs randomly distributed in groups of 3 animals across 10 pens. At the end of each 5-day trial, we removed wild pigs from the pens and removed the remaining test bait and corn from each trough and systematically replaced with another test bait, alternating which of the troughs in each pen received corn. Wild pigs were returned to the same pen for their second replicate. After the second replicate, we humanely euthanized the animals using carbon dioxide in a specifically designed euthanasia chamber for wild pigs (Kinsey et al. 2016) in accordance with AVMA guidelines (Leary et al. 2020). We replaced the 30 pigs from replicates 1 and 2 and conducted replicates 3 and 4 in the same fashion. Pens were 7.2 m × 7.2 m × 1.8 m and were made of galvanized wire mesh reinforced with steel pipe, and contained 2 troughs (1.8 m × 0.3 m × 0.1 m, 0.05 $m^3$ in volume) placed side-by-side in the center of the pen, overlapping by approximately 15 cm so that wild pigs could easily select bait from either trough (Figure 1). In each replicate, 9 of these pens contained a trough filled with a prescribed amount of corn and a different trough filled with a prescribed amount of one test bait (Table 1), and one pen contained 2 troughs filled with prescribed amounts of corn. Corn and test bait were prescribed at 6% of group body weight but were limited at trough capacity. Each trough contained between 16–46 kg of bait, depending on the type of bait. We attempted to offer test baits and corn *ad libitum* to avoid biasing a wild pig's choice. The amounts of baits offered were based on corn consumption rates from previous wild pig trials in our facility (Snow et al. 2021). In every offering, earthworms were consumed prior to trial end thereby biasing earthworm results negatively. We placed 2 remote cameras (Reconyx PC800, Holmen, WI, USA) in each pen to record time-lapse images every 15 seconds for 12 hours from 18:00 to 06:00 in the spring and from 16:00 to 04:00 in the fall. Daytime photographs were censored to reduce stress on wild pigs by decreasing human contact during battery replacements, reduce battery costs, and reduce photo scoring effort. Bait visitation patterns of wild pigs in our facility are like those observed by Snow et al. (2016) in the Edwards Plateau. Cameras were set to start one hour before sunset each season. We mounted the cameras on T-posts approximately 1.2 m above ground in the northeast and southwest corners of each pen. Cameras were faced towards the center point of the nearest trough and located approximately 3.7 m away (Figure 1).

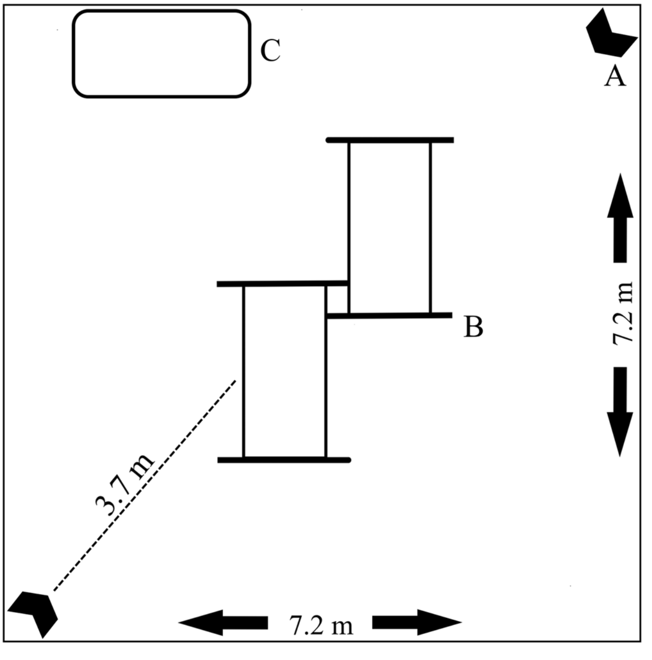


**FIGURE 1** Layout of the pens used in the 2-choice trials of wild pig baits. Pens were approximately 51.8 $m^2$. Cameras (A) were placed at the northeast and southwest corners of the pen. Cameras faced towards the midpoint of the nearest bait trough (B) approximately 3.7 m away. Water trough (C) location varied between pens and were placed to be most accessible when refilled. Spring trials took place 6 April–26 April 2021, and fall trials took place from 29 November–19 December 2021. Trials took place at the Kerr Wildlife Management Area in Hunt, Texas, USA.

**TABLE 1** Information for diet choices used in spring and fall 2-choice trials of wild pig baits. Nutrition information was obtained from the vendor. Information on live oak acorns was obtained from Short and Epps (1976). Spring trials took place 6 April–26 April 2021, and fall trials took place from 29 November–19 December 2021. Trials took place at the Kerr Wildlife Management Area in Hunt, Texas, USA.

| Diet choice | Protein (min) | Fiber (max) | Fat (min) | Cost/kg | Source |
|---|---|---|---|---|---|
| Earthworms (*Dendrobaena veneta*)[a,d] | 65% | 5% | 6% | $68.43 | Brothers Worm Farm |
| Dried mealworms (*Tenebrio molitor*)[c] | 51% | 8% | 23% | $16.83 | Happy Hen |
| Raw peanuts (*Arachis hypogaea*)[b,c,d] | 16% | 25% | 2% | $1.86 | Speer Ag, LLC |
| Live oak acorns (*Quercus fusiformis*)[d] | 6% | 15% | 6% | N/A | N/A |
| Oat groats (*Avena sativa*)[d] | 11% | 7% | 5% | $1.37 | Essential Feeds |
| Split peas (*Pisum sativum*)[c] | 25% | 15% | 2% | $0.56 | Reus Grain, LP |
| Roasted soybeans (*Glycine max*)[c] | 41% | 14% | 18% | $0.93 | Golden Oak Milling Company |
| Corn (*Zea mays*) | 10% | 11% | 4% | $0.43 | Reus Grain, LP |

[a]Earthworms were presented in a peat moss medium to preserve moisture. In the final trial, earthworms were frozen for at least 24 hours before being placed in the bait troughs.

[b]Peanuts were presented in their shells.

[c]Item was tested in spring.

[d]Item was tested in fall.

## Consumption of test baits

At the end of each 5-day trial, teams of ≥4 observers categorized, collected, and weighed remaining bait in each trough and that which had been spilled on the ground. We sorted any mixed baits from one another or from other materials with our hands, soil sifts, and plastic sorting tubs. Amount (kg) of each bait type consumed was calculated by subtracting bait remaining from the amount provided at the beginning of the trial. We compared the mass consumed of each test bait to corn to determine if any test bait was consumed more than corn during that season. Then we compared the consumption of each test bait to other test baits of the same season, considering they were all offered under the same conditions with an alternative food source. Our inferences from the second comparison are relative to when an alternate food was available to wild pigs, which is typical of free-range settings. We also calculated a percent preference value for each test bait as in Solà-Oriol et al. (2009):

$$\%\ \text{preference} = \frac{\text{test bait eaten (kg)}}{\text{total bait eaten}} \times 100.$$

We compared the preference values among baits from the same season using linear mixed-effects models with package lmerTest (Kuznetsova et al. 2017) in program R (R Core Team 2021). We logit transformed the percent preference values to stabilize variance. We included bait type as our fixed predictor and pen nested within trial as random effects to account for repeated measures and random variation among pens within trials. For each bait preference model, we calculated 95% confidence intervals surrounding regression coefficients (β) for nonoverlap of zero to indicate significant statistical differences. Prior to the final trial in the fall, preliminary review of the camera data revealed that some earthworms were escaping from the trough without being consumed by wild pigs. We excluded the first 3 trials from analysis of consumption. To prevent escape, earthworms that were used in the final trial were frozen for at least 24 hours before being placed in the troughs. Camera data confirmed that no worms escaped from the trough during the final trial, and 100% of the earthworms were consumed. Complete removal of earthworms prior to end of trial would bias earthworm preference values negatively because only corn remained.

We refrained from calculating earthworm preference given the small sample size and known source of bias. To compare earthworm consumption to that of the other fall test baits, we used an ANOVA to compare the consumption in kilograms of the 3 instances where frozen earthworms were used to the 3 instances of highest consumption of each of the other test baits used in the fall. We used Tukey's Honestly Significant Difference test to discern specific differences between groups. For all models using consumption data, we used $\alpha = 0.05$ to indicate statistical differences in preferences among baits.

## Accessing test baits

We examined trough access rates of wild pigs to determine any changes over time. We used data from the camera images to calculate an index of the number of times wild pigs accessed each trough each night. We scored each photo according to the number of wild pigs that had any part of their head inside of the trough (i.e., any part of head above the cavity, and below the topside of a trough). We summed the number of wild pigs that were recorded with their head inside the trough with corn or test bait for each pen for each night of the study. We compared the access rates to corn and test baits for each pen within each season versus total accesses for each pen within each season using mixed-effects negative binomial models using package lme4 (Bates et al. 2015) in Program R. We included bait type, day of trial, and an interaction of bait type × day of trial as fixed predictors. We included pen nested within trial as random effects to account for repeated measures and random variation among pens within trials. We also included an offset for the total number of trough accesses (corn and test bait) that occurred within a pen on any given night to make inferences to the access rate. For each bait access model, we calculated 95% confidence intervals surrounding regression coefficients ($\beta$) for nonoverlap of zero to indicate significant statistical differences. Bait access data were collected for the 2 baits with the highest preference values from each season. Data were also collected for acorns as previous studies have found that acorns are a staple of wild pig diet, and the wild pigs used in this study have likely been exposed to acorns previously.

# RESULTS

## Consumption of test baits

Overall consumption across all pens and baits averaged 19.62 kg (SD = 6.3) in the spring and 20.8 kg (SD = 10.4) in the fall. All baits offered were consumed to some degree during each season (Table 2), but no test baits had a preference value greater than 50% (Figure 2). During the spring, we detected a negative effect of bait type for split peas ($\beta = -3.33$; 95% CI = −4.86–−1.80), soybeans ($\beta = -1.66$; 95% CI = −3.19–−0.13), and peanuts ($\beta = -1.65$; 95% CI = −3.18–−0.13), but no effect for mealworms ($\beta = -1.36$; 95% CI = −2.88–0.17). Our nested random effects of pen within trial had a variance of 1.58 and standard deviation of 1.26. For the model that did not include corn as a bait, we did not detect an effect of peanuts ($\beta = -0.30$; 95% CI = −1.52–0.93) or soybeans ($\beta = -0.31$; 95% CI = −1.53–0.92) on logit-transformed bait preference values relative to that of mealworms. We did detect a negative effect from split peas ($\beta = -1.98$; 95% CI = −3.20–−0.75) using this model. Our nested random effects for this model had a variance of 1.62 and standard deviation of 1.27. During the fall, we did not detect any effect from bait type for acorns ($\beta = -1.29$; 95% CI = −3.7–1.13), oats ($\beta = -1.57$; 95% CI = −3.99–0.84), or peanuts ($\beta = -0.16$; 95% CI = −2.57–2.26) on logit-transformed bait preference values relative to that of corn. Our nested random effects of pen within trial had a variance of 3.92 and a standard deviation of 1.98. For the model that did not include corn as a bait, we did not detect an effect from oats ($\beta = -0.29$; 95% CI = −2.11–1.53) or peanuts ($\beta = 1.13$; 95% CI = −0.69–2.95) on logit-transformed bait preference values relative to that of acorns. Our nested random effects of pen within trial had a variance of 3.5 and standard deviation of 1.87. In the fall, earthworms were censored from

**TABLE 2** Consumption (kg) and access data for spring and fall 2-choice trials of wild pig baits. Consumption was averaged across the 9 instances that a particular test bait was presented. Individual preference values were calculated by dividing kilograms of test bait consumed by kilograms of total bait consumed in a pen and multiplying that value by 100. Access was averaged across the 5 nights of each trial and across the 9 instances that a particular test bait was presented. Spring trials took place 6 April–26 April 2021, and fall trials took place from 29 November–19 December 2021. Trials took place at the Kerr Wildlife Management Area in Hunt, Texas, USA.

| | $\bar{x}$ consumption (SE) | $\bar{x}$ % preference (SE) | $\bar{x}$ nightly access (SE) |
|---|---|---|---|
| Spring | | | |
| Soybeans | 2.84 (0.97) | 12.49 (4.96) | N/A |
| Split peas | 0.56 (1.05) | 3.76 (5.33) | N/A |
| Mealworms | 3.12 (1.0) | 15.47 (5.36) | 126 (30.88) |
| Raw peanuts | 3.22 (0.99) | 18.36 (5.33) | 152 (49.46) |
| Corn[a] | 16.76 (1.02) | 84.96 (2.5) | 494 (52.10) |
| Fall | | | |
| Oat groats | 2.95 (2.04) | 16.86 (8.46) | N/A |
| Acorns | 2.49 (2.11) | 17.46 (8.49) | 73 (21.18) |
| Earthworms[b] | 16.92 (2.26) | N/A | 506 (53.56) |
| Raw peanuts | 5.04 (2.11) | 35.37 (8.29) | 232 (75.47) |
| Corn[a] | 13.79 (1.17) | 68.6 (3.99) | 425 (36.57) |

[a]Corn values are pooled from all 2-choice tests in a season.

[b]Earthworms were presented in a peat moss medium to preserve moisture. In the final trial, earthworms were frozen for at least 24 hours before being placed in the bait troughs.

preference analysis because some escaped (Trials 1–3) or were completely consumed before the end of trial 4. However, we did find that consumption of frozen earthworms was greater than the 3 highest consumption values of each fall test bait ($F_{3,8} = 11$ $P = 0.003$; Figure 3).

## Accessing test baits

During the spring, we did not detect any effect from the interaction of bait type × day of trial for mealworms ($\beta = 0.09$; 95% CI = −0.18–0.36) or peanuts ($\beta = 0.14$; 95% CI = −0.13–0.41) on the rate of bait access. Similarly, the day of trial did not affect the rate of access ($\beta = -0.02$; 95% CI = −0.18–0.13), indicating no change in access over time for any of the diet choices. However, we found that access rates were lower for mealworms ($\beta = -1.80$; 95% CI = −2.71–−0.89) and peanuts ($\beta = -1.64$; 95% CI = −2.53–−0.76), respectively, relative to corn. Variance and standard deviation of nested random effects for pen within trial were both ≤0.001 for the spring access model. We also found no differences from the model comparing rates of access between mealworms and peanuts. For this model, our nested random effects had a variance of 3.88 and a standard deviation of 1.97.

During the fall, we did not detect any effect from the interaction of bait type × day of trial for acorns ($\beta = -0.05$; 95% CI = −0.24–0.14), earthworms ($\beta = -0.13$ 95%; CI = −0.32–0.06), or peanuts ($\beta = -0.04$ 95%; CI = −0.23–0.14) on the rate of bait access. We also did not find any effects of day ($\beta = 0.04$; 95% CI = −0.05–0.14) on rate of bait access. No effect of day indicates that rate of bait access did not vary over time for any of the baits. We found that bait access rate was lower for acorns ($\beta = -1.79$; 95% CI = −2.45–− 1.12) relative to corn. We also found no differences in access rate between corn and earthworms ($\beta = 0.17$; 95% CI = −0.48–0.82) or between corn and

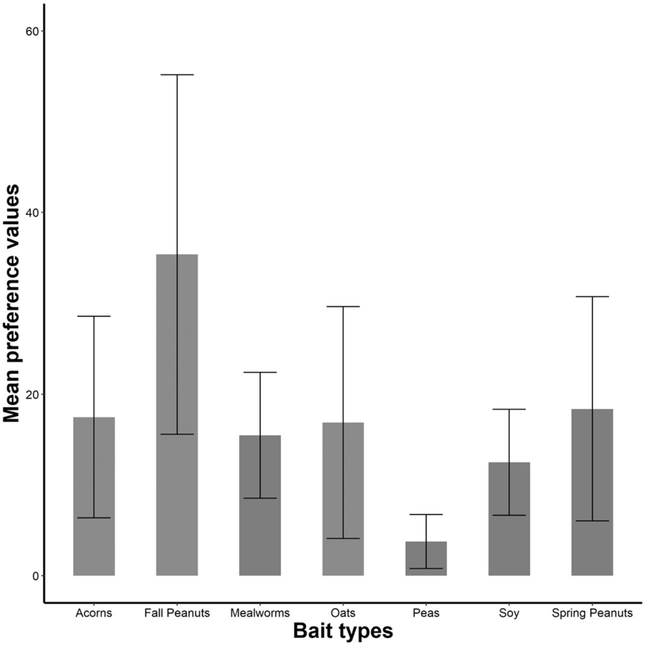


**FIGURE 2** Mean preference values for all test baits from the 2-choice trials of wild pig baits. Earthworms were not included as there were never earthworms left at the end of any of the 5-day trials. Spring trials took place 6 April–26 April 2021, and fall trials took place from 29 November–19 December 2021. Trials took place at the Kerr Wildlife Management Area in Hunt, Texas, USA.

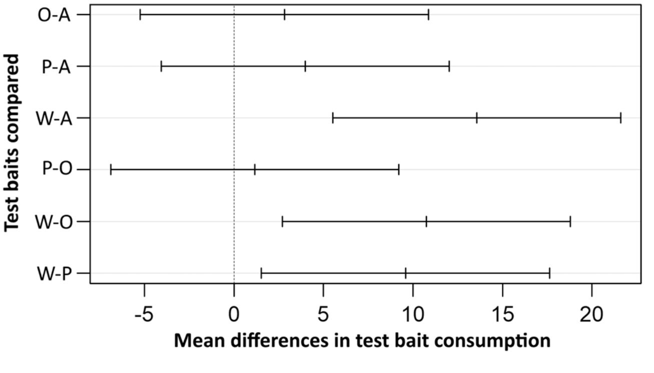


**FIGURE 3** Mean differences for total consumption of fall test baits from 2-choice trials of wild pig baits. Letter (A) represents the 3 instances where acorn consumption was highest, (O) represents the 3 instances where oat consumption was highest, (P) represents the 3 instances where peanut consumption was highest, and (W) represents the 3 instances where no earthworms escaped the trough at any point during the trial. Spring trials took place 6 April–26 April 2021, and fall trials took place from 29 November–19 December 2021. Trials took place at the Kerr Wildlife Management Area in Hunt, Texas, USA.

peanuts ($\beta = -0.51$; 95% CI = −1.16–0.12). For this model, our nested random effects had a variance of 0.004 and a standard deviation of 0.06. We did not find any effects for interactions between bait type × day ($\beta = -0.17$; 95% CI = −0.4–0.07) for earthworms or peanuts ($\beta = -0.06$; 95% CI = −0.32–0.19) on rate of bait access when comparing fall test baits to each other. We also found no effect for day ($\beta = 0.06$; 95% CI = −0.13–0.24) on rate of test bait access, indicating that access to the test baits did not change over time during the fall trials. When comparing fall test baits to each other, we did find that earthworms ($\beta = 2.4$; 95% CI = 1.27–3.53) and peanuts ($\beta = 1.18$; 95% CI = 0.038–2.32) were accessed more than acorns. Our nested random effects for this model had a variance of 0.69 and a standard deviation of 0.83.

# DISCUSSION

Overall, none of the test baits seemed to be preferred more than corn during either season. Corn preference is not surprising as the captive wild pigs used in our study consumed corn regularly, and corn has been established as a highly preferred bait for wild pigs in numerous studies (West et al. 2009, Massei et al. 2011). When comparing the test baits relative to each other, however, we identified that wild pigs showed preference for earthworms in the fall. Earthworms were consumed more than other alternative baits in the fall and were accessed at rates comparable to those of corn. In the *ad hoc* comparison of frozen earthworm consumption to corn, an additional bias toward corn occurred, due to complete consumption of earthworms before the trial ended. Nonetheless, earthworm consumption exceeded that of corn in all 3 samples. Protein is critical to maintenance and growth of pigs and the high level in earthworms (i.e., 65%) may have biased our results. However, the lack of significant family-wise differences between acorns, oat groats, and peanuts consumption suggest that our observations were not driven solely by protein content. For example, acorns (6% protein) were consumed similarly to oats (11% protein). Considering an expected value of 50% for either bait in a 2-choice trial, our consumption data suggest that earthworms were equally attractive to wild pigs as corn. Given that previous work has found that domestic pigs exhibit neophobia towards new food sources (Figueroa et al. 2013) and take weeks to develop a dietary preference based on nutrition content (Black et al. 1986, Kyriazakis et al. 1991), our results provide some evidence that the wild pigs used in our study have been exposed to earthworms before and identified them as a desirable food source. Wild pigs consume earthworms in other parts of the U.S. (Giffin 1978, Anderson et al. 2018) and Europe (Hafez et al. 1962, Baubet et al. 2003), and our results provide some evidence that wild pigs in Central Texas consider earthworms to be a desirable food source as well. It is also possible that the wild pigs used in this study have never been exposed to earthworms before but developed a taste for earthworms based on their palatability. Other research examining diet preference in domestic pigs has found that diet preferences based on palatability can emerge in under 24 hours (Solà-Oriol et al. 2009). Determining what aspects of earthworms make them more desirable to wild pigs relative to the other alternative baits could lead to the development of more effective wild pig attractants in the U.S. and in Europe.

The standard deviations and variances of random effects of pen nested within trial for models examining differences in percent preference values were often greater than fixed effect estimates for all our models. Furthermore, the preference values for individual pens ranged from 1.2% to 83.4% for peanuts in the fall, 0.5% to 54.5% for peanuts in the spring, and 0.4% to 60.2% for oats. Large standard deviations and variances of random effects and wide ranges in our calculated preference values indicate that responses among different groups of pigs to our test baits varied considerably, making it difficult to discern clear differences between most of our test baits. Indistinction of wild pig preference to our test baits provides evidence that attraction to any bait may vary between groups of pigs. This variance in preference for most of our baits makes the fact that all earthworms were consumed at every instance more noteworthy. Variability between groups, however, was not as apparent for wild pigs that were provided earthworms as a bait option. Each group of pigs that were provided earthworms consumed virtually all that they were offered. In general, these results indicate that a bait that is very attractive to one group of wild pigs may not be attractive to another. Variable attraction of different wild pigs to identical baits fully justifies further research into blending different baits together to increase attractiveness to wild pigs.

Surprisingly, we found that acorns were accessed significantly less than all other baits in the fall. Acorns are a staple of wild pig diet when present both in the U.S. and Europe (Barrett and Birmingham 1994, Massei et al. 1996, Calenge et al. 2004), and it has been thought that the yearly acorn mast may influence variation in success in attracting wild pigs with corn (Barret and Birmingham 1994, West et al. 2009). If this is true, our results indicated that this is not a product of diet preference, and there are likely other factors influencing this phenomenon. Wild pigs also accessed acorns at a significantly lower rate than they did peanuts which suggests that dietary preferences can quickly emerge in wild pigs, even when presented with diet choices they are unfamiliar with. Onset of dietary preferences within 1 day has been demonstrated by previous work that claimed differences in diet palatability were the cause of similar results (Solà-Oriol et al. 2009). The fact that a novel bait was accessed more frequently than acorns, a food resource that was likely familiar to these wild pigs, indicates that neophobia to novel food sources may not be as prominent a factor in bait selection as is bait palatability.

Our study may have benefitted from using wild pigs that were naïve to corn. Given that these wild pigs were all fed a diet that included corn prior to the beginning of the study, it is likely that they were biased toward consuming corn. Corn bias may have been compounded by any neophobia the wild pigs may have experienced towards baits they had never been exposed to before (Figueroa et al. 2013). Thus, our study design could have created a bias towards corn consumption over unfamiliar bait types. Finding a population of wild pigs that have not been exposed to corn was not feasible in our captive situation, but this might be a next step for future studies. Our study was also limited in that most of these wild pigs were separated from their conspecifics when they were sorted into the pens. Separation has been shown to lead to atypical behavior in pigs (Gieling et al. 2011). Furthermore, while the access data did provide some evidence that pigs are more likely to access some baits over others, they did so in a setting where the pigs had very limited space to move around. Future studies evaluating bait attractiveness in wild pigs may benefit from utilizing a free-range setting where wild pigs are able to travel with conspecifics. Such a study would more closely resemble the scenario wildlife managers encounter when managing wild pigs and provide the opportunity to examine how movement of a wild pig sounder throughout a large area varies when different baits are present.

## MANAGEMENT IMPLICATIONS

Wild pig population abundance and associated economic consequences are increasing every year. Wildlife managers should make efforts to trap wild pigs when corn on the landscape, such as from deer feeders or agricultural fields, is less abundant. Furthermore, we found that a potential alternative to corn may exist. High consumption and access rates to earthworms justifies further investigation into attributes of earthworms that are attractive to wild pigs. Earthworms or baits enhanced with natural extracts or synthetic additives thereof, may help increase attractiveness for wild pigs, especially in situations where corn is insufficient. Given the cost and perishable nature of earthworms, it seems likely that feasible advancements would be limited to natural extracts or synthetics used as bait additives to enhance flavor or smell. Surprisingly, we also found that acorns were not competitive with corn in terms of consumption or bait access which necessitates further research into dietary choices of wild pigs in the fall to discern what food sources may be reducing effectiveness of corn-baited traps. We recommend further evaluating the attractiveness of alternative baits, seasonality, and length of time to acclimation with free-ranging wild pigs to provide guidance on which baits to use to during different times of year, which could lead to higher success in the removal of wild pigs.

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## CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

## ETHICS STATEMENT

All study procedures were approved by the United States Department of Agriculture, National Wildlife Research Center, Institutional Animal Care Committee (QA-3406).

## DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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## REFERENCES

Ahmed, S. M., A. Pervez, M. F. Khan, H. Zafar, N. Sahar, and J. Khan. 2017. Enhancement of poison bait acceptance through taste additives in short-tailed mole rat (*Nesokia indica*) infesting datepalm orchards in Nok-kundi and Mashkale in province Balochistan, Pakistan. Journal of Phytopathology and Pest Management 4:13–21.

Anderson, W. M., R. K. Boughton, S. W. Wisely, M. M. Merrill, E. H. Boughton, M. S. Robeson, and A. J. Piaggio. 2018. Using DNA metabarcoding to examine wild pig (*Sus scrofa*) diets in a subtropical agro-ecosystem. Proceedings of the 28th Vertebrate Pest Conference. University of California, Davis, U.S.A.

Anderson, V., R. Harrold, D. Landblom, G. Lardy, B. Schatz, and J. W. Schroeder. 2002. A guide to feeding field peas to livestock. North Dakota State University. <https://library.ndsu.edu/ir/bitstream/handle/10365/5375/as1224.pdf?sequence=1>. Accessed 27 Sep 2022.

Anderson, A., C. Slootmaker, E. Harper, J. Holderieath, and S. Shwiff. 2016. Economic estimates of feral swine damage and control in 11 US states. Crop Protection 89:89–94.

Ballari, S. A., and M. N. Barrios-García. 2014. A review of wild boar Sus scrofa diet and factors affecting food selection in native and introduced ranges. Mammal Review 44:124–134.

Barrett, R., and G. Birmingham. 1994. Wild Pigs. Pages 65–70 *in* S. E. Hygnstrom, R. M. Timm, and G. E. Larson, editors. The Handbook: Prevention and Control of Wildlife Damage. Cooperative Extension Service, University of Nebraska, Lincoln, USA.

Barrios-Garcia, M. N., and S. A. Ballari. 2012. Impact of wild boar (*Sus scrofa*) in its introduced and native range: a review. Biological Invasions 14:2283–2300.

Bates, D., M. Machler, B. Bolker, and S. Walker. 2015. Fitting linear mixed-effects models using lme4. Journal of Statistical Software 67:1.

Baubet, E., Y. Ropert-Coudert, and S. Brandt. 2003. Seasonal and annual variations in earthworm consumption by wild boar (*Sus scrofa scrofa* L.). Wildlife Research 30:179–186.

Black, J., R. Campbell, H. Williams, K. James, and G. Davies. 1986. Simulation of energy and amino acid utilization in the pig. Research and Development in Agriculture 3:121–145.

Bomar, G. W. 1983. Texas Weather. Volume 1. University of Texas Press. Austin, U.S.A.

Calenge, C., D. Maillard, P. Fournier, and C. Fouque. 2004. Efficiency of spreading maize in the garrigues to reduce wild boar (*Sus scrofa*) damage to Mediterranean vineyards. European Journal of Wildlife Research 50:112–120.

Campbell, T. A., and D. B. Long. 2007. Mammalian visitation to candidate feral swine attractants. The Journal of Wildlife Management 72:305–309.

Carlisle, K. M., N. Didero, S. McKee, J. Elser, and S. A. Shwiff. 2021. Towards a more comprehensive understanding of wild pig (*Sus scrofa*) impacts on agricultural producers: insights from a Texas case study. Crop Protection 150:1–10.

Choquenot, D., R. J. Kilgour, and B. S. Lukins. 1993. An evaluation of feral pig trapping. Wildlife Research 20:1–13.

Choquenot, D., J. McIlroy, and T. Korn. 1996. Managing vertebrate pests: feral pigs. M. Bomford, editor. Australian Government Publishing Service, Canberra.

Corn, J., and T. Jordan. 2017. Development of the national feral swine map, 1982–2016. Wildlife Society Bulletin 41:758–763.

Figueroa, J., D. Solà-Oriol, X. Manteca, and J. F. Pérez. 2013. Social learning of feeding behaviour in pigs: effects of neophobia and familiarity with the demonstrator conspecific. Applied Animal Behaviour Science 148:120–127.

Garcelon, D. K., K. P. Ryan, and P. T. Schuyler. 2005. Application of techniques for feral pig eradication on Santa Catalina Island, California. Pages 331–340 *in* Proceedings of the sixth California Islands Symposium. National Park Service Publication CHIS-05-01, Arcata, California, USA.

Gieling, E. T., R. E. Nordquist, and F. J. van der Staay. 2011. Assessing learning and memory in pigs. Animal Cognition 14: 151–173.

Giffin, J. 1978. Ecology of the feral pig on the island of Hawai'i: final report. State of Hawaii, Dept. of Land and Natural Resources, Division of Fish and Game, Honolulu, Hawaii, USA.

Gould, F. 1975. Texas Plants: A Checklist and Ecological Summary. Texas Agricultural Experiment Station, College Station, USA.

Hafez, E., L. Suption, and J. Jakway. 1962. The Behavior of Swine. Behavior of Domestic Animals. William and Wilkins, Baltimore, Maryland, USA.

Hone, J. 1983. A short-term evaluation of feral pig eradication at Willandra in Western New South Wales. Wildlife Research 10:269–275.

Kinsey, J. C. 2020. Ecology and management of wild pigs. Texas Parks and Wildlife Department, Austin, USA.

Kinsey, J. C., R. L. Reitz, and J. A. Foster. 2016. Development of a self-contained carbon dioxide euthanasia trailer for large-scale euthanasia of feral swine. Wildlife Society Bulletin 40:316–320.

Kuznetova, A., P. B. Brockhoff, and R. H. B. Christensen. 2017. lmerTest package: tests in linear mixed effects models. Journal of Statistical Software 82:13.

Kyriazakis, I., G. C. Emmans, and C. T. Whitfemoret. 1991. The ability of pigs to control their protein intake when fed in 3 different ways. Physiology & Behavior 50:1197–1203.

Lavelle, M. J., N. P. Snow, J. W. Fischer, J. M. Halseth, and E. H. VanNatta. 2017. Attractants for wild pigs: current use, availability, needs, and future potential. European Journal of Wildlife Research 63:86.

Leary, S., W. Underwood, R. Anthony, S. Cartner, T. Grandin, C. Greenacre, S. Gwaltney-Brant, M. McCrackin, R. Meyer, D. Miller, et al. 2020. AVMA guidelines for the euthanasia of animals: 2020 edition. American Veterinary Medical Association, Schaumber, Illinois, USA.

Lewis, J. S., J. L. Corn, J. J. Mayer, T. R. Jordan, M. L. Farnsworth, C. L. Burdett, K. C. VerCauteren, S. J. Sweeney, and R. S. Miller. 2019. Historical, current, and potential population size estimates of invasive wild pigs (Sus scrofa) in the United States. Biological Invasions 21:2373–2384.

Massei, G., P. V. Genov, and B. W. Staines. 1996. Diet, food availability and reproduction of wild boar in a Mediterranean coastal area. Acta Theriologica 41:307–320.

Massei, G., S. Roy, and R. Bunting. 2011. Too many hogs? A review of methods to mitigate impact by wild boar and feral hogs. Human-Wildlife Interactions 5:79–99.

McCann, B. E., and D. K. Garcelon. 2008. Eradication of feral pigs from Pinnacles National Monument. The Journal of Wildlife Management 72:1287–1295.

McKee, S., A. Anderson, K. Carlisle, and S. Shwiff. 2020. Economic estimates of invasive wild pig damage to crops in 12 US states. Crop Protection 132:105105.

Pimentel, D. 2007. Environmental and economic costs of vertebrate environmental and economic costs of vertebrate species invasions into the United States. Managing Vertebrate Invasive Species. USDA National Wildlife Research Center Symposia. Fort Collins, Colorado, USA.

R Core Team. 2021. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Seward, N., K. C. Vercauteren, G. W. Witmer, and R. M. Engeman. 2004. Feral swine impacts on agriculture and the environment. Sheep & Goat Research Journal 19:34–40.

Short, H. L., and E. A. Epps. 1976. Nutrient quality and digestibility of seeds and fruits from southern forests. The Journal of Wildlife Management 40:283–289.

Snow, N. P., J. M. Halseth, J. A. Foster, M. J. Lavelle, J. W. Fischer, M. P. Glow, I. A. Messer, S. M. Cook, and K. C. VerCauteren. 2021. Deterring non-target birds from toxic bait sites for wild pigs. Scientific Reports 11:19967.

Snow, N. P., J. M. Halseth, M. J. Lavelle, T. E. Hanson, C. R. Blass, J. A. Foster, S. T. Humphrys, L. D. Staples, D. G. Hewitt, and K. C. VerCauteren. 2016. Bait preference of free-ranging feral swine for delivery of a novel toxicant. PLoS ONE 11:e0146712.

Solà-Oriol, D., E. Roura, and D. Torrallardona. 2009. Feed preference in pigs: effect of cereal sources at different inclusion rates. Journal of Animal Science 87:562–570.

State of Hawaii. 2007. Review of Methods and approach for control of non-native ungulates in Hawaii. State of Hawaii Department of Land and Natural Resources Division of Forestry and Wildlife, Honolulu, USA.

West, B., C. Benjamin, A. L. Cooper, J. B. Armstrong, and H Jack. 2009. Managing wild pigs: a technical guide. Berryman Institute. Logan, Utah, USA.

Williams, B. L., R. W. Holtfreter, S. S. Ditchkoff, and J. B. Grand. 2011. Trap style influences wild pig behavior and trapping success. Journal of Wildlife Management 75:432–436.

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