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ABSTRACT

Food animal welfare is an issue of great concern, as society has a responsibility for animals under human care. Pork is the most consumed meat worldwide, with more than a billion pigs being slaughtered globally every year. Still, in most countries, sows are restrained in farrowing crates throughout lactation. In these crates, sows are confined with bars to an area that is just slightly larger than their body. Thus, moving and turning around, grooming, or expressing other natural behaviors are typically impossible. In this study, we utilized a simple and practical modification of conventional farrowing crates to designed farrowing pens, by removable confinement bars, which provide the flexibility to change the housing system from one to another. Our objective was to examine the parameters of production and hair cortisol concentrations after different restraint periods during lactation. Analyses included data from 77 sows and their 997 piglets. Sows were housed in farrowing crates, but the confinement bars were removed after different periods, from 3 days post-farrowing to full restraint. For certain analyses, sows were grouped into Short or Long Restraint groups (3–10 days vs 13–24 days, respectively). Multiple linear regression revealed that for any additional day in restraint of the sows, piglets' weaning rate decreases by 0.4% ($P < 0.05$). Moreover, the total number of weaned piglets per litter was higher in the Short Restraint group as compared to the Long Restraint group (10.4 ± 0.3 vs 9.7 ± 0.3, respectively; $P < 0.05$). Accordingly, total litter weight on the weaning day tended to be higher in the Short Restraint group (68.8 ± 2.2 vs 64.9 ± 1.8 kg; $P = 0.1210$). The requirement for medical treatments during lactation (e.g., antibiotics, NSAID) tended to be less frequent in the Short Restraint group (Sows: 21.9% vs 40%; $P = 0.1219$. Piglets: 2.4% vs 17.1%; $P = 0.0609$). Hair cortisol as a marker for chronic stress during lactation decreased when the restraint period was shortened in both sows and piglets. Our analysis revealed that sows' hair cortisol is a significant mediator between the restraint of the sow and its piglets' hair cortisol (Sobel test; $P < 0.05$). For every day of sows' restraint, sows' hair cortisol increased by 0.5 pg/mg, and for any additional unit of sows' hair cortisol, piglets' hair cortisol increased by 0.36 pg/mg. In conclusion, sustainable swine farming management can be beneficial for both animals and farmers; limiting sow restraint during lactation is expected to reduce stress, enhance welfare and production, and potentially improve the economics of swine operations.

Implications

The restraint of sows during farrowing and lactation is a top welfare concern. In the current study, welfare and production parameters were measured under different restraint periods during lactation. Overall, shortening the restraint period of sows, decreased piglets' mortality; decreased hair cortisol, as a marker for chronic stress, in both the sows and their piglets; as well as improved their health. Implementation of the suggested management may enhance production and welfare in the swine industry, which would benefit the animals, the farmers as well as the public.

Introduction

The welfare of food animals is a major increasing concern to the public, as well as to stakeholders in the global agro-food system. Livestock farming is no longer challenging just due to the pressure to meet the demands of feeding billions of people around the world, but also due to the resulting ethical disputes (Ellison et al., 2017). However, due to concerns that management changes would increase production cost and reduce production efficiency, farmers are often reluctant to accept policies toward better animal welfare. Over recent years, there is a tremendous

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criticism toward some standard practices in the swine industry. The swine industry produces the most consumed meat worldwide, with a global industry of over a billion pigs reared and slaughtered annually (McGlone, 2013). In most countries, one of the most common practices that are being criticized for impairing animal welfare is the full restraint of sows in farrowing crates throughout the lactation period (Baxter et al., 2012; Johnston and Li, 2013; Nicolaisen et al., 2019). In these farrowing crates, sows are confined with bars to an area which is just larger than their body, so they can hardly stand or lie down, while moving and turning around, grooming or expressing other natural behaviors, are typically impossible (Peltoniemi and Oliviero, 2015). This restraint during lactation is a top welfare concern, as it can impair both the health and well-being of sows and their piglets (Baxter et al., 2012; Johnston and Li, 2013; Nicolaisen et al., 2019).

Common alternative housing systems to farrowing crates during lactation include farrowing pens, indoor group housing, and outdoor housings (Peltoniemi and Oliviero, 2015). In these alternatives, more space is available for the sows and their piglets, and interactions between them are possible. In contrary to the alternatives, in the farrowing crates, the ability to express natural behaviors is very limited (Peltoniemi and Oliviero, 2015). Initially, the reason for using these crates, besides management convenience, is to prevent the piglets from being crushed by the sow during the lactation period (Gu et al., 2011; Peltoniemi and Oliviero, 2015), as piglets crushing is a major economic loss in the swine production (Kilbride et al., 2012). However, it has been shown that the confinement of sows in farrowing crates during the lactation period is not only a risk for the sow but also for the piglets. Several studies have shown that the farrowing duration of crated sows tends to be longer, which is a risk for the vitality of the newborn piglets (Gu et al., 2011); furthermore, the lack of movement under restraint may increase the risk for skin lesions and lameness (Heinonen et al., 2013). These in turn, may potentially increase the risk for crushing piglets and may lead to lower production performances (Fitzgerald et al., 2012). In addition, prolonged restraint may lead to unwanted behavior such as an increase of stereotype behaviors (Arellano et al., 1992), impaired maternal behavior, as well as to impaired cognitive abilities of the piglets. Under restraint, the piglets fail to earn essential skills from the sow, such as eating solid food from an early stage, which is important for feed intake and growth performance (Oostindjer et al., 2011a and 2011b). These risks to the sows and their piglets in farrowing crates, may be even more remarkable when nesting material is not provided (Peltoniemi and Oliviero, 2015). Yet, although nesting material is important, larger space allowance, even without any material, has been shown to encourage maternal behavior (Jarvis et al., 2004).

To prevent the negative implications of sow restraint as elaborated above, farrowing pens may be used as an alternative. Farrowing pens, depending on their design, can be considered a welfare-friendly alternative, as the sow can move more freely and interact with its piglets (Oostindjer et al., 2011a and 2011b; Baxter et al., 2012).

According to the European Union legislation (Council Directive 2008/120/EC), although full restraint in stalls has been forbidden during most of the pregnancy period, farrowing crates are still permitted and commonly used. To win farmers' support and compliance to abandon the use of these farrowing crates and replace it with more animal-friendly management, the alternative must be practical, easily implemented on most farms, and should be proven not to harm or preferably improve production parameters.

Cortisol, a glucocorticoid produced by the adrenal cortex in response to ACTH secretion, is considered as an indicator of the body's hormonal responses to stress (Baxter et al., 2012). It is regulated by the hypothalamic–pituitary–adrenal (**HPA**) axis and may stimulate numerous stress responses, such as changes in the metabolism of sugar and carbohydrate, fat, and protein. Furthermore, prolonged high cortisol secretion may induce suppression of the immune system (Trevisan et al., 2017). As a biomarker, cortisol can be measured in blood, urine, and saliva. In addition, as cortisol accumulates in the hair over time, its analysis has increasingly been used, in humans and some animal species, as a non-invasive method to obtain information on long-term HPA-axis activity for weeks prior to the sampling day, for the evaluation of chronic stress (Meyer and Novak, 2012). Interestingly, several authors have reported on the association between altered physiologic status and high cortisol concentrations in blood and hair (Greff et al., 2019; Heimburge et al., 2019), including in pigs (Morgan et al., 2019). However, there is a lack of information regarding hair cortisol concentrations in sows and their piglets, and the possible interrelationships between them, when housed in farrowing crates as compared to designed farrowing pens during lactation.

In this study, we utilized a simple and practical modification of conventional farrowing crates to designed farrowing pens, with the flexibility to change the housing system from one to another. Our objective was to examine the parameters of production and hair cortisol concentrations after different restraint periods during lactation.

Material and methods

The study was performed at Lahav Animal Research Institute (LAHAV C.R.O; Kibbutz Lahav, Israel) and the Hebrew University, and was ethically approved by the Hebrew University's Institutional Animal Care and Use Committee (MD-16-14754-2).

Modifications of the lactation crates; from farrowing crates to deigned farrowing pens

Modifications of the farrowing crates were made to alter the confinement of sows during lactation into free pens with easily removable confinement bars (Fig. 1). Changes included partial bar removal and changing of others, so it could be removed or added easily when required. After this modification (Fig. 1; moving from position A to position B), the sows had shared space for lying down and interactions with the piglets, while the piglets still had free access to secure space, with a slatted floor covered by a rubber mattress, accessible only to them. In addition, the sow could be restrained effortlessly when required (Fig. 1; position A). The slatted floor pen included an automatic electronic feeder and a water source for the sow, and a separate creep feeder for the piglets. Solid commercial food (Ambar Feed Institute, Israel) was provided twice a day by automatic electronic feeders to

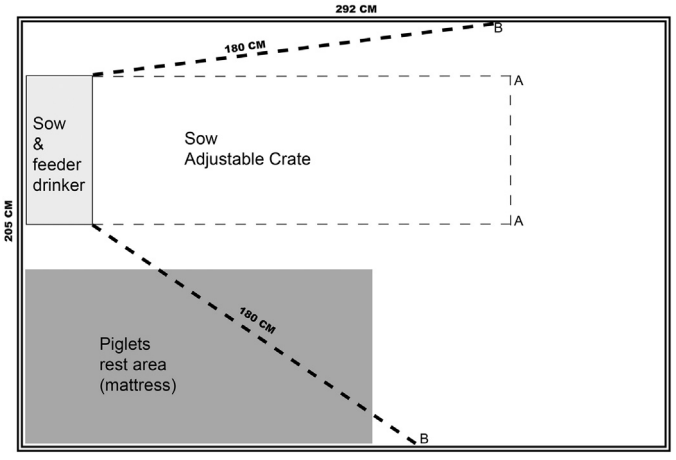

Fig. 1. Modifications of the existing farrowing crates to designed farrowing pens. The pen size was 292 cm length and 205 cm width with removable confinement bars (180 cm length). The confinement bars could easily be arranged (a) in close position to restrain the sow, or (b) in an open position, in which the sow could move more freely and interact with its piglets. In both positions, piglets still had free access to a secure space allocated to them only.

each sow, and *ad libitum* for the piglets, according to the recommendations of the Nutrient Requirements of swine.

Animals and study design

The study included 77 sows from parities 2–8 (parity 2, $n = 15$; parities 3–8, $n = 62$), a mixed breed of Landrace, Large-White, Pietrain, and Duroc, identified by ear tags, and their 997 piglets. Prior to this study, sows were restrained for 14–24 days during the lactation period; thereafter, they were inseminated and were kept in a group housing system for most of the gestation, as we previously reported (Morgan et al., 2018). For the current study, 2–4 days before the anticipated farrowing date, sows were transferred into farrowing crates, and a new approach was tested. Accordingly, sows were divided randomly to a different restraint period, continuously from 3 days post farrowing up to full restraint (Supplementary Table S1). At the end of the restraint period for each sow, confinement bars were opened. For certain analyses, sows were grouped into either a Short or a Long Restraint group. In the Short Restraint group ($n = 42$ sows, and their 552 piglets), confinement bars were opened at 3–10 days after farrowing (mean ± SEM: 5.5 ± 0.4d; median and quartiles: 4d, 3–8.25d); while in the Long Restraint group ($n = 35$ sows, and their 444 piglets), confinement bars were opened at least 13 days after farrowing, up to the end of lactation (mean ± SEM: 17.9 ± 0.8d; median and quartiles: 16d, 13-23d). Piglets were weaned at the age of 23 ± 1 days.

Hair cortisol analyses

For analyses of hair cortisol during lactation, hair was clipped from each sow and its piglets just before weaning (from the same area and amount of hair). The hair was collected from the rump area, just above the tail, and each sample was individually stored in aluminum foil at −20 °C until cortisol extraction. Cortisol extraction and analysis were according to a validated protocol for pigs, as previously described (Morgan et al., 2019). Briefly, each hair sample (250 mg) was washed twice in isopropanol, dried, and grounded to powder, and cortisol was extracted using methanol. The extracted cortisol, along with standards and quality controls, were analyzed by commercial ELISA (Salimetrics ELISA kit, catalog no. 1-3002, Carlsbad, CA, USA). Intra- and inter-assay coefficients of variation were both <5.0%.

Collection of production, survival, and physical condition data

Production parameters were recorded by Farm® software (AgroVision. Deventer, The Netherlands). Data recorded included: parity, farrowing date, weaning date, litter size, total litter weight at birth, and individual weaning weight. Weaning rate was calculated as the number of weaned piglets out of the number of live piglets at the age of 3 days (when the confinement bars were first removed for some of the sows). The farm veterinary team was blinded to the different study groups, and treated the animals according to their routine protocols; data regarding the administration of the medical treatments (e.g., antibiotics, NSAIDs) for sows and piglets was recorded. Piglets date of death, when relevant, was also recorded by farm's employees.

Statistical analyses

Statistical analyses were performed using commercial statistical software (IBM SPSS Statistics, version 22.0). Normal distribution of each variable was examined by testing the skewness and kurtosis, the shape of the normal Q–Q plot, and by Shapiro–Wilk's test. Accordingly, Mann–Whitney test was used to compare the distribution of production and welfare measures between the Short and Long Restraint groups (separately for sows from the second parity, and those from 3 to 8 parities). Proportion data were analyzed using the Chi-square test. Kaplan–Meier curves and Log-rank test were used to analyze the survival of piglets from birth to weaning. Multiple linear regressions were utilized to identify which characteristics of the sows best predict the weaning rate, as well as piglets' hair cortisol concentrations. For the prediction of hair cortisol concentrations, the characteristics of the sows were entered into the model in steps, and the Sobel test (Preacher and Hayes, 2008) was used to test if maternal cortisol was a mediator between the restraint period of the sow and her piglets' hair cortisol. Unless noted otherwise, descriptive statistics are given as mean ± SEM or as frequency (n) with percentages (%). A *P*-value 0.05 was considered statistically significant. All reported *P*-values are two-tailed.

Results

Hair cortisol concentrations in the Short versus Long Restraint groups

Among sows from parities 3–8, hair cortisol before weaning was significantly lower in the Short Restraint group (36.3 ± 4.1 pg/mg) as compared to the Long Restraint group (42.4 ± 2.4 pg/mg; $P < 0.05$). However, there was no such difference among sows from second parity (Short Restraint group: 38.1 ± 9.4 pg/mg. Long Restraint group: 42.7 ± 9.5 pg/mg; $P = 0.905$). Furthermore, linear regression was utilized in steps and revealed: (1) for every additional day in restraint of the sow, sows' hair cortisol increased significantly by 0.5 ± 0.11 pg/mg (Fig. 2a; $P < 0.05$); (2) for any additional unit of sows' hair cortisol, piglets' hair cortisol significantly increased by 0.36 ± 0.13 pg/mg (Fig. 2b; $P < 0.05$); (3) the total effect of sows restraint on its piglets hair cortisol was also significant (for every additional day in restraint of the sows, its piglets' hair cortisol significantly increased by 0.43 ± 0.202 pg/mg; Fig. 2c; $P < 0.05$); and (4) in multivariate linear regression, in which both sows' restraint period and sows' hair cortisol concentrations were included, the direct effect of sows' restraint on its piglets' hair cortisol (0.28 ± 0.21 pg/mg) was not significant (Fig. 2C'; $P = 0.196$). Therefore, the Sobel test was utilized and revealed that sows' hair cortisol was a significant mediator between the restraint of the sow and its piglets' hair cortisol concentration ($Z = 2.3299$, SE = 0.0786; $P < 0.05$). The indirect effect (the effect of the mediator) was 0.152 (95%CI: 0.034–0.363; calculated by 5000 Bootstrap samples). Thus, sows' hair cortisol decreased when the restraint period of sows was shortened, and their piglets' hair cortisol decreased accordingly (Fig. 2; $P < 0.05$).

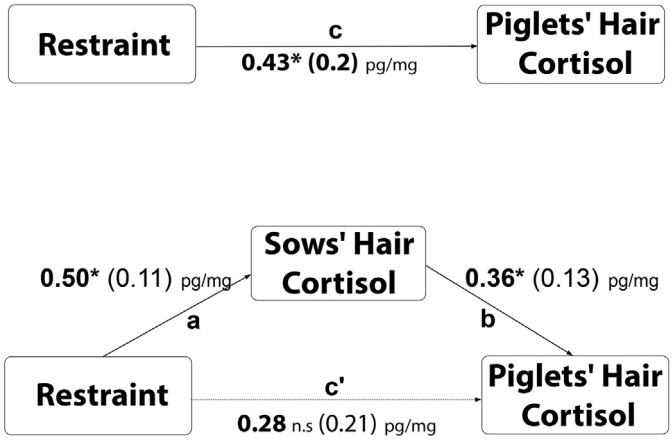

Fig. 2. Association between restraint and hair cortisol concentrations in sows and their piglets. Hair cortisol concentration in sows was found as a significant mediator between the restraint of the sow and the piglets' hair cortisol concentrations. (a) For every additional day in restraint, sow's hair cortisol increased and (b) for any increase of one unit in sows' hair cortisol its piglets' hair cortisol increased accordingly. (c) The total effect of sows' restraint on piglets' hair cortisol was also significant. The direct effect of sows restraint on their piglets' hair cortisol, when sow hair cortisol, the mediator, was included in the model, is presented in C'. The presented numbers are coefficient, the SEM in parentheses, and significant effects ($P < 0.05$) are marked with asterisks.

Requirements for medical treatments in the Short versus Long Restraint groups

Overall, the requirement for medical treatments (e.g., antibiotics, NSAIDs for diarrhea, lameness, or wounds) for both the sows and piglets was lower in the Short Restraint group as compared to the Long Restraint group. In second parity sows, there were no differences in requirement for medical treatments during lactation (20%), but among their piglets, medical treatments were significantly less common in the Short Restraint group as compared to the Long Restraint group (0% vs 15%, respectively; $P < 0.05$). Sows from parities 3–8 tended to require fewer medical treatments in the Short Restraint group as compared to the Long Restraint group (21.9% vs 40%, respectively; $P = 0.1219$). Among their piglets, there was also a tendency toward a lower requirement for medical treatments in the Short Restraint group as compared to the Long Restraint group (12.4% vs 17.1%; $P = 0.0609$).

Production parameters in the Short versus Long Restraint groups

Linear regression revealed that the significant risk factors for decreased weaning rate (the number of weaned piglets out of the number of live piglets at the age of 3 days, since until then the treatment groups were in the same conditions) were litter size and restraint period. For every additional day in restraint of the sow, the weaning rate decreased significantly by 0.4% (Fig. 3; $P < 0.05$). For every additional piglet, above eight piglets in the litter, weaning rate significantly decreased by 3.4% (Fig. 3; $P < 0.05$).

When sows were divided into a Short Restraint group and a Long Restraint group, the analyses indicated that among sows from parities 3–8, the average number of weaned piglets per litter was significantly higher in the Short Restraint group (10.4 ± 0.3 vs 9.7 ± 0.3 piglets; Fig. 4B; $P < 0.05$), although there were no significant differences in the number of born alive piglets between the groups. The total litter weight on weaning day tended to be higher in the Short Restraint group by 3.9 kg per litter on average (Fig. 4B; $P = 0.1210$), while the average weight per piglet did not differ. Kaplan–Meier curve for piglet mortality over time indicated that the majority of the dead piglets died on the first 3–4 days in lactation when all sows were still restrained (Fig. 5). It is important to point out that these piglets were not taken into account in the analyses of the weaning rate, and were included in the Kaplan–Meier curve, to provide further information.

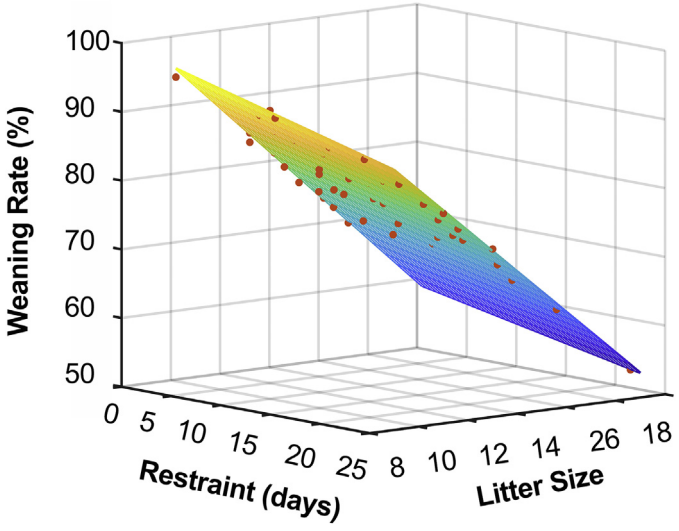

Fig. 3. Significant predictors for weaning rate of piglets during lactation. Linear regression revealed two significant predictors for survival rate (the number of weaned pigs out of the number of live piglets at the age of 3 days); for every day of restraint, weaning rate significantly decreased by 0.4% ($P < 0.05$); and for every additional piglet in the litter (above 8 piglets) weaning rate decreased by 3.4% ($P < 0.05$).

Discussion

The awareness for animal welfare and well-being has increased dramatically in recent years, and there is a growing criticism among the general public, which can no longer be overlooked by the swine industry. Therefore, in the current study, we dealt with one of the top concerns—sows restraint during lactation (Baxter et al., 2012; Johnston and Li, 2013). Our approach was to achieve farmers' compliance and be implemented successfully, welfare-friendly alternatives should be beneficial for both the animals and the farmers. Therefore, the rationale of this study was to improve the existing system, by performing minimal and practical changes to the existent facility (e.g., farrowing crates) to increase animal welfare and to reduce the stress of sows and their piglets during the lactation period, without harming or even improving production performance. This stems from the understanding that stress may negatively affect performance, and therefore, better animal welfare has the potential to enhance production (Turner et al., 2005). This hypothesis is supported by the results of the current study, since overall, shortening the restraint period of sows during lactation improved the welfare and the production parameters of the sows and their piglets. Accordingly, shorter restraint was associated with decreased hair cortisol as a marker for chronic stress, lower requirement for medical treatments, increased weaning rate, lower mortality, and overall higher litter weight at weaning. These findings are consistent with previous studies which reported that in designed farrowing pens, when the sow is not restrained, the sow can interact with its piglets, and that the piglets learn essential skills at an early age from their dam (Oostindjer et al., 2011a and 2011b); on the contrary, restraining the sows in conventional farrowing crates, can potentially increase stress and impair piglets cognitive abilities and performances (Arellano et al., 1992; Oliviero et al., 2008; Baxter et al., 2012). Future studies should investigate cortisol metabolism in sow and how it influences its piglets, during and after the lactation period. Furthermore, there is a requirement for novel and reliable biomarkers for stress and welfare besides cortisol. Furthermore, future research can benefit from additional behavioral measures, as previously suggested (Sondergaard et al., 2011; Matthews et al., 2017).

In the current study, the requirement for medical treatments (e.g., antibiotics and NSAIDs) was lower in the Short Restraint group among sows from parity 3–8 and their piglets. Interestingly, among sows from the second parity, the requirement for medical treatment did not differ between the Short Restraint group and the Long Restraint group. This may be explained by the fact that those young and relatively inexperienced dams are under high pressure of farrowing, restraint, lactation, and so on, which can potentially lead to a high level of stress, resulting in impaired health. In support of that, hair cortisol, as a marker for chronic stress, was significantly higher when the restraint period was longer among sows from parities 3–8, but did not differ between the Short Restrain group and the Long Restraint group among sows from the second parity. To the best of our knowledge, the possible influence of the restraint period on hair cortisol of sows and their piglets, and the possible association between them have never been studied prior to the current study. Still, the present results are complementary to previous studies that found higher serum cortisol in sows kept in longer confinement period during lactation, except for sows in the first and second parity, in which such differences could not be found (Zhang et al., 2017). Interestingly, sows' hair cortisol was found in the current study as a significant mediator between the restraint of the sow and its piglets' hair cortisol concentration. In other words, sows' hair cortisol concentration increased for each additional day of restraint, and accordingly, piglet's hair cortisol increased. This relationship between mothers' and their offspring's hair cortisol was studied in other species (Dettmer et al., 2015; Grant et al., 2017; Tarullo et al., 2017), but as far as we know,

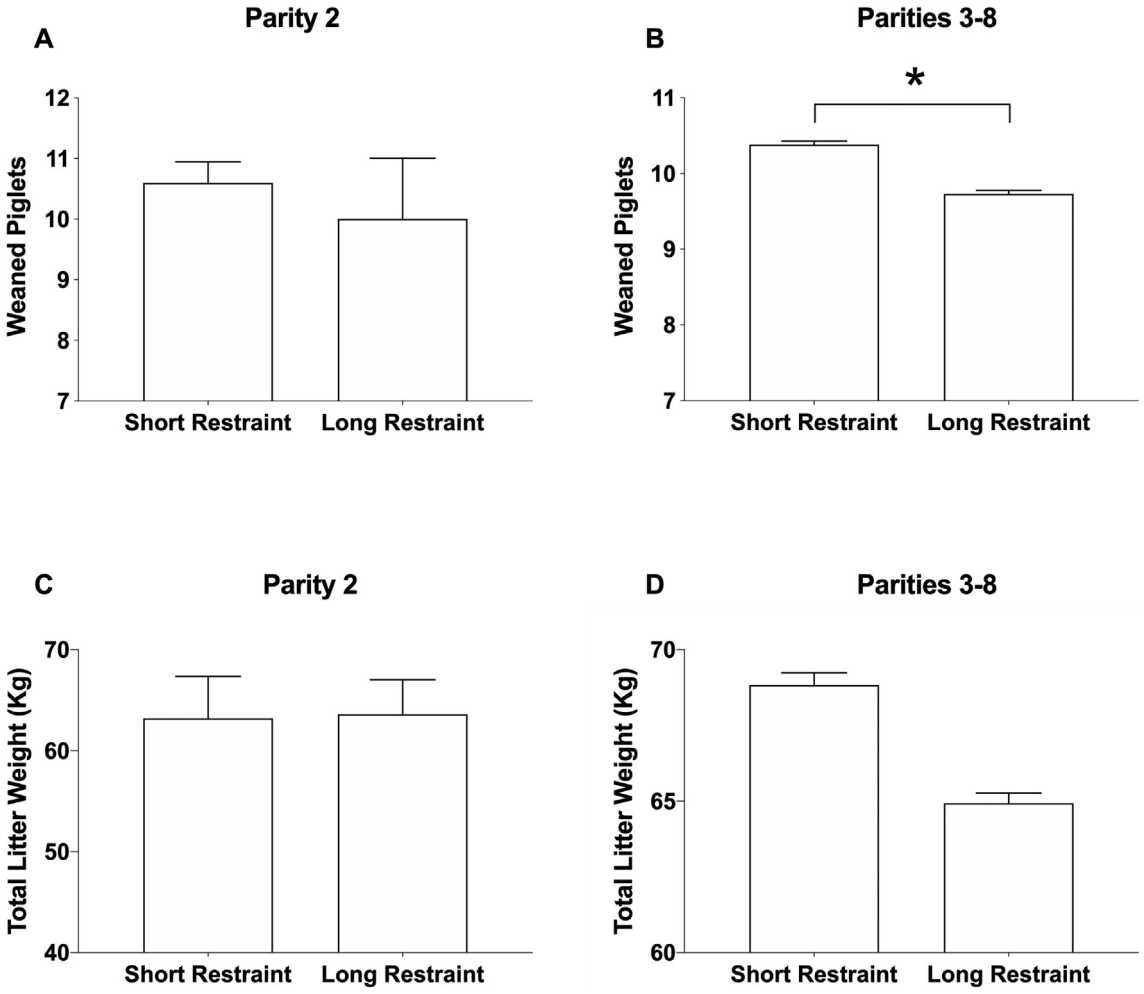

Fig. 4. Number of weaned piglets and litter weight in the Short vs Long Restraint groups. Among sows from parity 3–8, in the Short Restraint group, the number of weaned piglets was significantly higher (panel B; $P < 0.05$), and the total litter weight on the weaning day tended to be higher (panel D; $P = 0.1210$), as compared to the Long Restraint group. However, among sows from the second parity, there were no significant differences in the number of weaned piglets (panel A; $P = 0.2100$), or total litter weight (panel C; $P = 0.2700$).

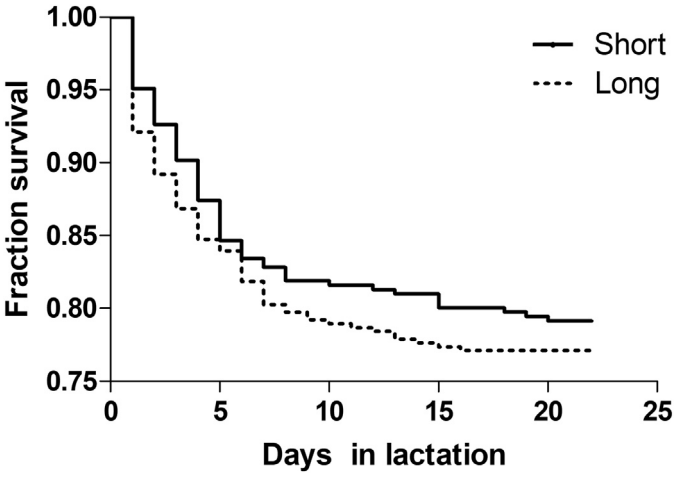

Fig. 5. Piglets mortality overtime during lactation in the Short vs Long Restraint groups. In both groups, mortality was mostly during the first 3–4 days post-farrowing, when all sows were restrained. Overall, there was no significant difference in survival rate when sows were divided into a Short Restraint group and a Long Restraint group ($P = 0.4620$), according to the Kaplan–Meier analysis that takes into account the day of death and all piglets from birth to weaning.

relevant information on pigs is very limited (Morgan et al., 2019). The current results revealed that the restraint period impairs not only the sow's well-being but also its piglets. Hair samples of the piglets were collected on weaning day, and therefore, the measurement of cortisol concentrations is assumed to represent its accumulation mainly during the lactation period (piglets are born with very short and sparse hair). Sows hair was also collected on weaning day for all sows, thus, it includes the whole lactation period in all groups. Nonetheless, it cannot be ruled out that cortisol measurements were also affected by the accumulation of cortisol in the hair prior to this study (during the end of the gestation). Since the growth rate of the hair in pigs is relatively slow, we avoided shaving before farrowing and then re-shaving again only after 3 weeks (on weaning day) to be sure that a sufficient amount of hair, from the same specific anatomical location, would be available for analyses. To minimize the influence of this potential bias, sows included in the study shared the exact management prior to this study during gestation, and therefore it is less likely to be a significant factor.

It is known that production and reproduction can be impaired by stress in many ways (Turner et al., 2005; Kongsted, 2006; Morgan et al., 2019), thus, the increasing stress during early life may also have long term effects on piglets' future performances, beyond the weaning period. The mechanisms underlying the relationship between sows' and piglets' hair cortisol are not yet known; however, it is possible that the stress imparted by living in a confined space is transferred from the sow to her piglets by a combination of maternal behavior

and cortisol present in her milk. Indeed, at least in humans and rhesus monkeys, the behavior of nursing offspring is related to their mother's milk cortisol content (Grey et al., 2013; Hinde et al., 2015).

Regarding the production performance of the pigs, overall, parameters were improved when the restraint period was shortened. Promoting the welfare of sows by shortening the restraint period during lactation was associated with lower mortality of the piglets, and accordingly, higher total litter weight. Shortening the restraint period of lactating sows without impairing the survival rate, and even improving it, is crucial in the swine industry. According to the relevant literature, the intensive management of swine farms, combined with sows' predisposition to rear fewer offspring than are born, leads to a piglet mortality rate of typically 16–20% (Edwards and Baxter, 2015). At the farm where this study was conducted, the mortality rate had been more than 22% on average, but it decreased when the restraint period was shortened during the study. Our analysis revealed that after 3 days of age, for every additional day in restraint, the weaning rate significantly decreased by 0.4% (Fig. 3); furthermore, the average number of total weaned piglets was higher in the Short Restraint group for most sows (Fig. 4B), with an increased total litter weight (Fig. 4D).

Crushing by the sow is a major reason for pre-weaning mortality among piglets. It typically happens due to a combined circumstance: a piglet that does not move away when its dam is lying down, the unsuccessful avoidance of the sow from lying down on the area, and the lack of its reaction to the trapped piglet (Andersen et al., 2011; Edwards and Baxter, 2015). Restraint of sows during gestation and lactation can harm their body condition and cause leg injuries. As a result, it may impair its ability to lie down gently and rise quickly when needed (Damm et al., 2010; Baxter et al., 2012; Bench et al., 2013). Thus, increasing the space available for the sow to move may explain the improvement in both piglet survival and lower requirement for medical treatments, as shown in this study. These results are consistent with previous reports, which showed lower mortality in designed pens as compared to conventional confinement in farrowing crates (Weber et al., 2007). Although some studies reported a higher mortality rate when sows were not restrained during lactation (Hales et al., 2014) or no significant differences (Kilbride et al., 2012), this discrepancy may be explained by the differences among the varied pen designs, as well as farm management.

Although the current study presents significant advantages to the designed farrowing pens, it has few main limitations. All sows in the study were restrained for at least 3 days post farrowing, and no environmental enrichment was provided, due to the farmers' objection at that time. According to the Kaplan–Meier Curve analysis, most of the mortality had occurred up to the first 3 days, when all sows were still restrained, as has been reviewed in the literature (Edwards and Baxter, 2015). However, it has been shown that environmental enrichment decreases piglets' mortality by improving maternal behavior (Herskin et al., 1998). Thus, the performances and welfare improvements potentially could be even greater if meaningful environmental enrichment had been supplied, and if sows were not restrained at all, but unfortunately, this was not studied directly in our study. Future studies are warranted to test these issues. In addition, preferably, the division of the sows should have been completely homogeneously for all days of restraint, from no restraint to full restraint. However, since it was a field study in a commercial farm, functioning under the Israeli changing legislation, restraint periods of 3–10, and 13–24 days in restraint were represented in the study. The time in restraint was significantly shorter in the Short Restraint group (5.5 ± 0.4d) as compared to the Long Restraint group (18 ± 0.8d). Our rationale for the group division was based on the standard management that was used in the farm and across Israel (typically 2 weeks to full restraint). However, new Israeli legislation from the Ministry of Agriculture was considered that limited the restraint period to a maximum of 14 days. Accordingly, we aspired to test the “conventional management” with the approaching “new management”. Accordingly, prior to farrowing, sows were divided randomly to continuous restraint periods from 3 days to full restraint (homogenized for opening days). However, due to technical limitations (e.g., weekends, availability of farm team, and proper adjustable creates), there were changes during the study, that were controlled in the analyses.

In summary, with relatively small modifications of the conventional farrowing crates to designed open pens, shortening the restraint period of lactating sows enhanced production performance of sows and piglets, decreased the requirement of medical treatments, and decreased chronic stress of sows and their piglets, as evaluated by hair cortisol analyses. As consumers prefer sows that are not restrained (Baxter et al., 2012), and as it improves production and welfare, limiting the restrain during lactation can potentially be beneficial to all customers, producers, and animals, and therefore should be widely implemented.

Supplementary materials

Supplementary data to this article can be found online at https://doi.org/10.1016/j.animal.2020.100082.

Ethics approval

The study was ethically approved by the Hebrew University's Institutional Animal Care and Use Committee (MD-16-14754-2).

Data and model availability statement

None of the data were deposited in an official repository; however, data generated or analyzed during this study are included in this article. For additional information please contact the corresponding author (tal.raz@mail.huji.ac.il).

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Declaration of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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