LITERATURE REVIEW:
PRACTICAL APPLICATIONS OF CREEP FEEDING OF PIGLETS

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Contents

Introduction 3

i. The role of creep feeding 3

ii. Impacts of creep provision on piglet feed intake, health and performance 3

iii. Estimating creep feed intake and proportion of creep eaters 6

Theme 1: Composition (*What* to creep feed) 9

1.1 Medicated creep feeds 9

1.2 Complexity of the creep diet 9

1.3 Specialised ingredients and dietary diversity 12

2.1 Pellet size 13

2.2 Milk replacer, gruel and soft creep pellets 17

2.3 *Creep feeder types and encouraging exploratory behaviour* 19

2.4 Frequency of creep feed replacement 20

Theme 3: Timing (*When* to creep feed) 22

3.1 Age at first offering, duration of creep feeding and timing relative to weaning 22

3.2 Prioritising litters for creep feeding 24

3.3 Influence of creep feeding on sow performance in late lactation – a trade-off between mother and piglets? 25

Conclusions 26

Appendices 28

Appendix 1: Study summary 28

References 35

Introduction

i. The role of creep feeding

Weaning is arguably the most stressful event in the life of a commercial pig, where they are separated from their mother and potentially their litter mates, mixed with unfamiliar pigs in an unfamiliar environment, and are removed from their milk source and required to adapt to solid feed, often abruptly (Campbell et al., 2013). Consequently, neophobia in the young piglet may result at this time, which can negatively impact their post-weaning feed intake, growth performance, health and survival, and welfare (Miller and Holzman, 1981; Figueroa et al., 2019). Subsequently, several gastrointestinal tract (GIT) changes take place within the pig in this time period (Pluske et al., 1997; Zabielski et al., 2008). The combination of these factors can be compounded by GIT upsets, scours and deterioration in overall health of pigs after weaning, resulting in the post-weaning "growth check" (Pluske, 2016; Jayaraman and Nyachoti, 2017).

In non-domesticated settings, weaning in pigs is a gradual process which can start from 8 weeks, extending until the offspring are 22 weeks of age (Newberry and Wood-Gush, 1985; Jensen and Stangel, 1992). Creep feeding is the practice of providing solid and/or gruel feed to piglets *before* weaning in a commercial environment, in tandem with milk intake from the sow. This practice operates on the premise that piglets will be able to adapt to solid feed more easily after their milk supply has been cut off at weaning, reducing the level of neophobia to the new feed source (Figueroa et al., 2019).

Another valuable advantage of creep feeding is to supplement feed intake in suckling pigs, as the milk output of most modern sows cannot keep up with the demands of the growing piglet. This means that sow milk production is often the limiting factor in piglet growth rates in late lactation; however, growth potential of these piglets is very high and creep feed can be used to supplement milk in these cases (Tokach et al., 2020). Indeed, creep consumption increases as piglet nutrient demands increase closer to weaning (Pajor et al., 1991). Nevertheless, and as shown by Pluske et al. (1995), creep feed intake (as an average across studies) accounts for only ~ 5% of total dry matter intake of the sucking piglet.

ii. Impacts of creep provision on piglet feed intake, health and performance

In the literature, the impact of creep feeding on performance of piglets before and after weaning has been assessed in a number of ways. These include (but are not limited to) creep feed disappearance (as a measure of feed intake), interactions with the feeder, growth rates before and after weaning, the number (or proportion) of piglets experiencing a growth check after weaning, gastrointestinal health and development before and after weaning, proportion of piglets requiring medication in the lactation and/or nursery periods, and pre- and post-weaning mortality rates. The numerous benefits of creep feeding on piglet growth performance have been extensively reviewed in the recent literature (Jayaraman and Nyachoti, 2017; Tokach et al., 2020; Blavi et al., 2021; Wensley et al., 2021b; Canibe et al., 2022; Muro et al., 2023).

Briefly, creep feeding has been shown to improve growth rates of piglets in the week prior to weaning (Tran et al., 2014; Middelkoop et al., 2020) and may even improve piglet survival before weaning (Sulabo et al., 2010a), hence impacting number of piglets weaned. However, these outcomes are largely inconsistent between studies and depend on several interfering factors, which will be discussed in the current review. The benefit of creep feeding does not lie solely in the growth performance of piglets before weaning or does not always manifest in improvements in piglet weaning weight. Most of this benefit of provision of creep feed can be seen after weaning, allowing creep-fed piglets to mitigate the post-weaning growth check, as creep feeding has prepared them for the change to a solid diet, which lessens the chances of dramatic drop in performance at this point. Furthermore, measures such as the proportion of eaters or recorded eating behaviours (time spent at feeder, number of interactions with feeder etc.) may tell us more about the welfare benefits of creep feeding before weaning, rather than growth performance improvements (or lack thereof) in this period. Piglets that had a higher creep feed intake during lactation spent less time displaying aggressive behaviour and lower number of injuries post-weaning, potentially indicating reduced stress following weaning (Middelkoop et al., 2019).

Studies seem to consistently suggest that piglets that consume solid feed before weaning consume more solid feed after weaning or show more feeding-directed behaviours than those that only consume sows' milk (Bruininx et al., 2002; Sulabo et al., 2010c; Muns and Magowan, 2018; Lee et al., 2021). The impact of this improved feed intake after weaning on piglet growth performance in this period is equivocal with some studies finding creep-fed piglets grow faster in the period immediately following weaning (Bruininx et al., 2002; Pluske et al., 2007; Lee et al., 2021) and others showing no differences (Barnett et al., 1989; Sulabo et al., 2010a; Muns and Magowan, 2018; Middelkoop et al., 2020). Differences between studies may be confounded by refeeding syndrome of weaned piglets in this period (van Kempen et al., 2023) where piglets that do not eat soon after weaning but instead retain significant amounts of water in their tissues, resulting in higher perceived 'feed efficiencies'. This phenomenon, as well as the age at weaning deserves to be further studied in relation to creep feeding as it may be that access to creep feed could help to mitigate this condition in weaned piglets.

Research indicates that creep feed intake may alter the production of digestive enzymes and hence influence the gut development of young pigs to prepare them for switching to a solid diet at weaning (de Passillé et al., 1989; Byrgesen et al., 2021; Canibe et al., 2022). This, however, varies within and between litters as a result of a variation in the actual intake, which drives enzyme induction in these animals. Some studies also suggest that creep feeding may also alter the microbiota within the gastrointestinal tract (GIT; reviewed by Canibe et al., 2022) and even increase circulating IgA concentrations which may suggest improvement of the gut barrier immune response (Tran et al., 2014). The continuity of feed intake after weaning, encouraged by creep feeding, has also been shown to prevent villous atrophy, improve net absorption in the intestine and hence reduce the risk of development of post-weaning diarrhoea (Pluske et al., 1996; Madec et al., 1998; Kuller et al., 2007a; Jayaraman and Nyachoti, 2017).

Collins et al. (2013) found that piglets that were good eaters of creep feed (based on the quantitative measurement of dye in faeces, as described by Pluske et al., 2007) gained significantly more weight in the first 5 days after weaning than those classified as moderate, small or non-eaters, and this effect carried over until 49 days of age, albeit the treatment response was not as strong (Fig. 1). A similar finding was seen in the studies by Bruininx et al. (2002) and Pluske et al. (2007).

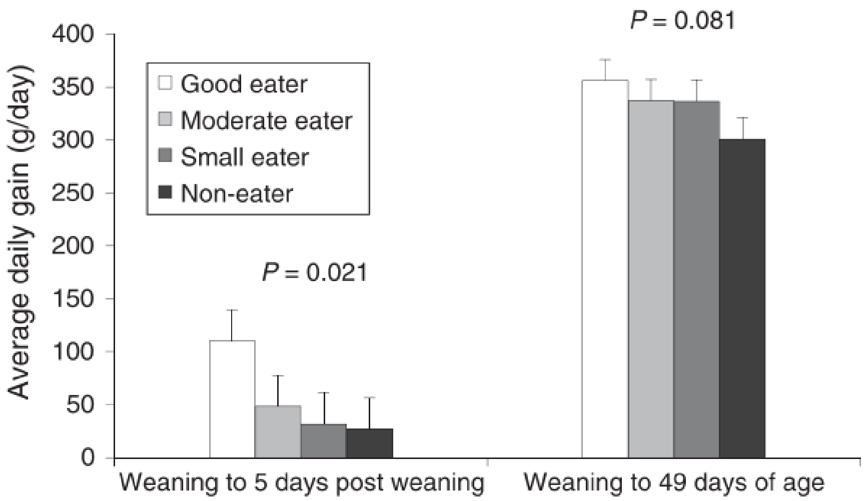

Fig. 1: Influence of individual creep feed intake during the pre-weaning period on growth performance from weaning to 49 days of age (from Collins et al., 2013).

What is not well understood is the influence of creep feeding on whole-of-life performance of pigs. Recently, Muns and Magowan (2018) found that bodyweight at sale was not influenced by creep feed intake before weaning and Martins et al. (2020) saw no difference in average daily gain (ADG) up to market weight in pigs provided creep feed vs. those that did not receive creep feed. This is in agreement with the study of Pluske et al. (2007), that found that piglets classed as good eaters of creep feed saw no long-term benefits in terms of weight in later growth stages up to 60 days of age compared to their counterparts that did not eat creep feed, or only consumed a small amount. This was despite a better growth rate in the first 3 days after weaning in those good eaters. Similarly, Kuller et al. (2007a) found no difference in body weight at slaughter or growth rates from 7 to 19 weeks of age between pigs that did and did not consume creep feed during lactation, despite greater ADG in creep feed consumers in the first 4 weeks after weaning. This may suggest that pigs that do not consume creep feed may exhibit catch up (compensatory) growth in later growing periods. Hence, creep feeding may not provide added benefits to final carcass value. However, there are potential advantages to creep feeding in terms of post-weaning survival and health (Muro et al., 2023; Dumas et al., 2025), which can result in improvement of animal welfare in this critical stage of life.

Differences between studies may be caused by a number of factors, such as piglet birth weight (e.g., Romero et al., 2025), weaning age (e.g., Collins et al., 2013), duration of creep feed provision (e.g., Yan et al., 2011b), diet composition (e.g., Sulabo et al., 2009) and other management factors (Middelkoop et al., 2020). It is important that the producer understands that the costs of creep feeding (feed and labour costs) are largely outweighed by the performance and welfare advantages to be gained. Indeed, the benefits of creep feeding can be largely impacted by the methods used to creep feed itself, and it is essential that we identify the best practice procedures for creep feeding to ensure the best on-farm performance. Methods to effectively measure individual creep intake of piglets that are cheap and practical need to be developed.

iii. Estimating creep feed intake and proportion of creep eaters

In the literature, creep feed intake can be measured or assessed in a number of ways, making clear conclusions and comparisons between studies sometimes difficult. One such method includes measuring the creep feed disappearance over a certain period of time (Pajor et al., 1991; Fraser et al., 1994; Sulabo et al., 2010b; Collins et al., 2013; Craig et al., 2021). This method assumes that all creep disappearance is attributable to intake by piglets and disregards any attributable to feed wastage. It is also measured on a litter basis and assumes all piglets in the litter consume the same amount of feed, which has been shown not to be the case (Tokach et al., 2020). Certain feeding behaviours have also been measured either by moment-in-time real-time recordings or via video footage (Appleby et al., 1991; Pajor et al., 1991; Fraser et al., 1994; Carstensen et al., 2005; Wattanakul et al., 2005; Middelkoop et al., 2019a), which can be used to estimate feed intake and/or creep feed interactions down to the individual piglet level. Such behaviours include time spent at the feeder, time spent with head in the feeder, number of approaches to the feeder, exploratory behaviours at the feeder such as nosing, rooting and chewing, etc.

Another approach is to measure the proportion of piglets that eat creep feed in a litter. This can be done by addition of a dye into the creep feed (Pluske et al., 2007; Tokach et al., 2020), where faecal samples are collected from piglets once or several times per day. The presence of the dye in the faeces can then be taken to mean, qualitatively, that the piglet has consumed creep feed. Suitable markers that have been used in previous experiments include chromic oxide (Kuller et al., 2007b) or indigo carmine (Pluske et al., 2007) generally added at 1% and 0.5% of the diet, respectively (Tokach et al., 2020). Indigo carmine may be more distinguishable in the faeces and therefore recommended for use in commercial studies (Pluske et al., 2007). While presence of these dyes measured in the faeces allows for determining whether an individual is a creep 'eater' or not, it is not currently possible to measure individual creep feed intakes using inert dye markers in the feed.

Dual marker techniques have also been used in a small number of studies to estimate individual feed intakes. This process involves the use of a "reference marker" (RM) which is supplemented to the animal orally at regular intervals, and another "in feed marker" (IFM) that is included in the (creep) feed at a known quantity. Faeces are then sampled several times throughout the day to determine the ratio of each marker. Individual feed intake can then be estimated using the following equation (Tang et al., 2022a; Tang et al., 2022b):

$$\text{Estimated creep intake (g/day)} = \frac{\frac{Conc.of\ IFM\ in\ faeces\ (mg/kg)}{Conc.of\ RM\ in\ faeces\ (mg/kg)} \times daily\ intake\ of\ RM\ (mg/day)}{Conc.of\ IFM\ in\ diet\ (mg/kg)} \times 1000$$

One study investigated the effectiveness of two trivalent metal markers (i.e. Lanthanum III oxide and Yttrium III oxide) to measure individual creep feed intakes in piglets with moderate success (Kim et al., 2010). In this methodology, Lanthanum oxide was administered to piglets as an oral drench and Yttrium oxide was supplemented in the creep diet. In a subsequent study (Tang et al., 2022b), a double-marker methodology was applied to estimate individual feed intake in 6 week old pigs. In that study, the authors assessed the efficacy of a pair of n-alkanes (dotriacontane, C32 and hexatroacontane, C36) and a pair of metal chlorides (Ytterbium III chloride and Chromium chloride). They found both methods to be reasonably accurate in estimating individual feed intakes; however, this relied on dosing of the reference marker 3 times a day for 2 days and faecal sampling once per day for 2 days thereafter. While these methods show some promise in estimating individual animal intakes, they require multiple manipulations of the animal to feed the RM and sample the faeces, which could bias the data. Furthermore, these methodologies assume that both the RM and the IFM have the same rate of passage through the GIT (Tang et al., 2022b), which may not be the case.

As advanced technologies and machine learning develop in this area, it may become quicker and easier to measure creep feed intakes without interference from humans – having positive welfare implications and also reducing the labour required to measure creep feed intake. For example, ear tagging technology has shown promise in measuring time spent at feeder for grazing cattle (Simanungkalit et al., 2021) and may be optimised and implemented for use in piglets in the future.

The current review aims to summarise the recent literature examining creep feeding in modern litters and culminates in a best practice guideline for producers to follow to ensure maximum benefits are gained from creep feeding practices on their farms. The content of this review will cover recent advances in the best composition of creep feed, ideal presentation of creep feed to encourage a higher proportion of piglets to consume creep feed, and/or to increase the total intake of consumers, and finally the best timing for creep feed provision in a commercial setting.

Recommendation: Creep feed should be supplied for all litters where labour, costs and availability allow, due to the numerous benefits seen from the practice.

Possible further research: Creep feeding and its impacts on 'refeeding syndrome' (rapid electrolyte repletion from a period of reduced caloric intake) in pigs deserves to be further studied to understand the relationship between creep feeding, piglet feed intakes after weaning and piglet growth rates (and hence efficiencies). Similarly, the impact on whole-of-life performance of pigs is not well understood.

Theme 1: Composition (*What* to creep feed)

1.1 Medicated creep feeds

Traditionally, creep feeds were medicated to reduce the pathogen load and to support piglets through the transition to weaning (Edwards et al., 2013) as mixing of piglets during this process increases their risk of exposure to a number of bacterial and viral pathogens (McOrist et al., 2009). This was previously thought to reduce the risk of piglets developing the post-weaning scour that occurs as a result of a number of changes in the small intestine of the pig around the time of weaning (Heo et al., 2013).

Fraser et al. (1994) found that the medicated creep diet improved piglet weaning weights and increased consumption after weaning than those piglets given a non-medicated diet. However, the two diets assessed in that study had several other differences in composition which were confounded with the inclusion of medication within the diet. Alternatives to medications in the creep diet, such as spray-dried plasma protein (SDPP) have also been studied and may improve piglet performance after weaning compared to those given antibiotics (Edwards et al., 2013).

There is a global push to reduce antibiotic use in pig (and other species) diets and hence their inclusion in creep diets is becoming scarce. Furthermore, in-feed medications can be quite expensive and require a veterinary script, with commercial nutritionists often avoiding their use in creep diets for these reasons. There may also be a risk of ingestion by the sow, which may extend withhold periods if cull sows are required to be sent to an abattoir during lactation or after weaning.

1.2 Complexity of the creep diet

Complexity of the creep feed diet has been evaluated in a number of ways in past studies, with complexity being defined as the use of expensive protein sources (Sulabo et al., 2009; Collins et al., 2013), milk proteins, or other milk products (Okai et al., 1976; Sulabo et al., 2009; Collins et al., 2013) or inclusion of highly digestible or other specialised ingredients (e.g., extruded cereals) targeting GIT health and development (Martins et al., 2020).

Early in life when sow milk is a piglet's sole source of nutrition, their GIT is unable to digest raw plant material and/or complex proteins effectively (Okai et al., 1976; Cabrera et al., 2013; Koo et al., 2017). Therefore, creep diets have historically been formulated with highly digestible ingredients (such as animal protein meals, fish meal, blood meal and plasma proteins, highly digestible starch sources, and processed grains, for example). Okai et al. (1976) reported that a complex diet, formulated with dextrose, sucrose, corn starch, dried skim milk and whey, increased piglet feed intake and weight gain after weaning, despite low pre-weaning feed intakes. Similarly, Sulabo et al. (2009) found that increasing the complexity of the creep feed (including plasma proteins, groats, fish meal and lactose) improved creep feed intakes before weaning, and this was largely as a result of a higher proportion of creep eaters (increasing from 28 to 68%). However, Collins et al. (2013) found better performance in piglets that were given a simple creep diet compared to those given a complex diet with more animal-based protein sources and whey powder. The influence of simple or complex diet ingredients may be dependent on the age at which creep feed is first given, and the interaction with weaning age, as the GIT of the piglet continues to develop.

These protein sources have been known to be expensive and can easily drive up the price of creep diets. The protein level (Whitelaw et al., 1966) and energy density (Yan et al., 2011a) of the creep diet may not actually influence the performance of piglets until at least the third week of lactation (Heo et al., 2018), which may be related to the piglets inability to digest the components of the creep effectively before this age. This may imply that a simple (cheaper) creep formulation may be offered earlier in lactation, followed by a complex (more expensive) formulation later when weaning age is extended beyond 21 days, for example. From a practical standpoint, farm staff will be less likely to replace creep feed as often as is required to keep it fresh, especially in large farrowing settings where feeding "little and often" can be time- and labour-consuming. Even though this could equally be seen as a cost-saving strategy on feed, an expensive creep feed may sit in creep bowls or on creep mats for long periods of time becoming stale and making piglets less likely to interact with it.

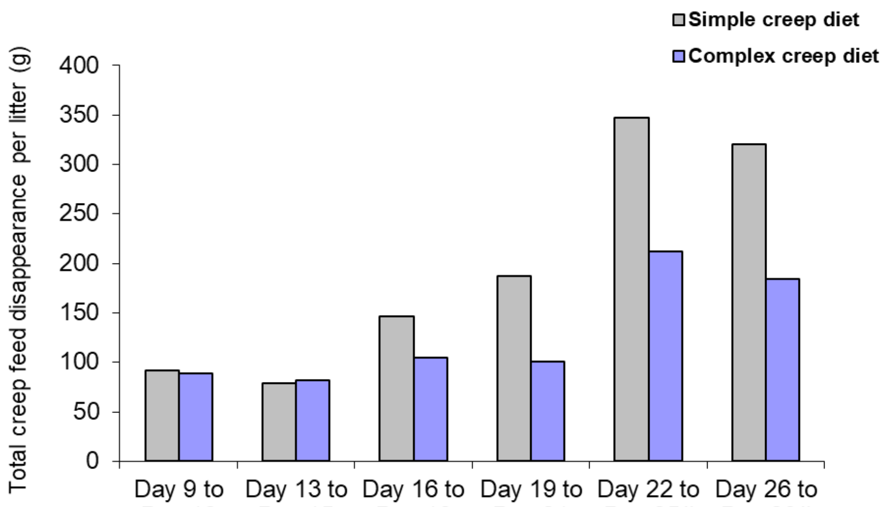

Fig. 2: Total creep feed disappearance per litter for pigs offered either a simple or complex creep diet from 9 days of age to weaning. From Collins et al. (2013).

Common thinking is that creep feeds must resemble or at least contain milk proteins and other milk components for the GIT of the piglet to be able to easily digest them. Addition of milk and/or other complex proteins to creep diets can make creep diets very expensive and may not be economical given the low pre-weaning creep feed intakes of piglets (Okai et al., 1976). In fact, a study by Collins et al. (2013) showed that inclusion of whey powder and other expensive protein sources (such as soyabean meal and fish meal) did not improve piglet lifetime growth performance of pigs, and pigs given a simple creep diet actually had higher feed intakes and growth rates immediately post-weaning (Fig. 2). This was in contrast to Okai et al. (1976), who found that pigs given a complex diet with milk protein sources (dried skim milk and whey) had higher pre-weaning feed intakes than those given a simple diet without them. Tran et al. (2014) investigated the use of yeast-dried milk (YDM) in creep diets, which was described by the authors as a 50:50 mix of near-dated milk (presumably bovine) and dried brewer's yeast. They found that inclusion of 10% YDM in creep diets improved feed intake of pigs before and 21 d after weaning when compared to piglets given a standard creep formulation. They reasoned that YDM may affect the composition of the GIT microbiota, namely of *Lactobacillus* spp. and this may have influenced lactic acid production and hence improved antimicrobial activity in the GIT. Heo et al. (2018) reported that feeding a creep diet containing ~60% milk products improved ADG of piglets in the week leading up to weaning (21 to 27 d of age) compared to feeding a weaner or a sow diet before weaning. However, these pigs had lower ADG in the first 2 weeks after weaning than the other groups and GIT development around this period was better in piglets given the weaner diet with a lower inclusion of milk products (~12.5%) both before and after weaning. They suggested that continuity of the same creep diet after weaning may be more important in terms of improving health and growth performance after weaning than the composition of the diet itself. Therefore, evidence to suggest that inclusion of expensive milk products in creep diets is equivocal in the literature, and perhaps the more important question is whether or not their inclusion is economical given the negligible improvements in piglet performance. It is worth considering that familiarity with the feed may be more important than composition when determining carryover effects of creep feed provision in the nursery.

The sow lactation diet has recently been investigated as an alternative to pelleted creep diets for piglets in lactation, which has arisen from the concept that piglets are known to access the sow feeder and consume sow feed in the weeks leading up to weaning (Heo et al., 2018; Wensley et al., 2021a). However, result from the literature do not seem to support this study. The simple creep diet used in the study by Sulabo et al. (2009) was identical in composition to the sow lactation diet and these authors found that the more complex, highly digestible creep diet resulted in better pre-weaning weight gain in piglets. More recently, Wensley et al. (2021a) found no improvements in pigs fed sow lactation feed in comparison to those feed standard or large pellet creep feeds, or compared to pigs not provided with creep feed. Piglets provided with sow lactation feed on the creep mat performed the worse of the 4 treatment groups in terms of ADG, and FCR in the 6 weeks following weaning (at 19 d of age).

This may imply that sow lactation diets are not easily digestible in suckling piglets, which may arise due to the high inclusion of ingredients of plant origin. Indeed, Heo et al. (2018) found that providing a sow diet from 14 to 21 days of age to piglets had no impact on their growth performance before or after weaning compared to provision of a highly digestible creep diet or a weaner diet in this period. However, matching the feed type that piglets are offered to the type that sows are offered (especially in terms of flavour) can facilitate social learning in lactating piglets and potentially improve their early solid feed intake (Oostindjer et al., 2010; Oostindjer et al., 2014), and this phenomenon deserves to be further explored. There has also been evidence to suggest that flavour imprinting may occur when certain essential oils are fed to the sow and then carried over into the piglet creep diet (Roura and Palou, 2019) which may influence piglet feed intakes and hence growth performance and adaptation to weaning. Feeding a similar diet to sows and piglets would reduce feed production and storage requirements (silo space, bagging and other manual handling, etc.).

1.3 Specialised ingredients and dietary diversity

More recently, "dietary diversity" has been defined as the provision of a number of diets that differ in terms of form, particle and/or pellet size, flavour, smell, colour and texture and may improve interactions between piglets and creep feed and subsequently enhance feed intake (Middelkoop et al., 2018). However, the economic viability of such diets, as well as the practicality of making, storing and feeding them, must be examined thoroughly before implementing these feeding regimes on a commercial scale. Other specialised ingredients have also been studied in creep feed composition experiments, such as dietary fibre (Clouard et al., 2018; Van Hees et al., 2019; Middelkoop et al., 2020; Choudhury et al., 2021; Van Hees et al., 2023), pre- and probiotics (Shim et al., 2005) l-glutamine, and other specialised amino acids (Cabrera et al., 2013). It is debatable as to whether inclusion of these specialised ingredients is: a) impactful, given the short feeding duration and low and highly variable intakes of individual pigs before weaning, and b) economically viable, given the considerable cost of some of these ingredients, the small volume of feed necessary and the time and labour required to feed it. Inclusion of these ingredients in young pig diets may rely on their inclusion being carried over into the nursery (and later) growth phases. Hence, further investigation of these ingredients is beyond the scope of this review.

Inclusion of flavours in sow and piglet pre- and post-weaning diets has been a topic of recent discussion. In terms of creep feed, it may be the novelty of different flavour exposure that influences piglet feed intake. Adeleye et al. (2014) found that providing five different flavoured creep feeds on different days of lactation improved piglet weight gain in the first 2 weeks after weaning, with butterscotch flavours encouraging the highest level of feed intake. These authors speculated that this was because changing the flavours encouraged exploratory behaviours towards the novel creep feeds each day. Contrary to these findings, Middelkoop et al. (2018) found that provision of 4 flavours sequentially on each lactation day, fed alongside a common creep diet with no flavours, did not improve pre-weaning feed intake compared to providing the common creep diet alongside a 'diverse' creep feed. However, these authors did not look at piglet performance after weaning. The 'diverse' creep feed used in this study differed from the common diet in terms of production methods, pellet size, flavours, ingredients and nutritional profile. Those authors concluded that this overall dietary diversity is more important for encouraging solid feed intake before weaning than flavour diversity. Nevertheless, the complexities of providing more than one type of creep feed to piglets in the short weaning transition period may not be practical, and care must be taken to ensure introduction of new, novel feed flavours (and forms) do not induce neophobia after weaning (Figueroa et al., 2013).

Addition of flavours to the sow diet to be transferred through the amniotic fluid or to milk and then continuing exposure of these flavours to piglets in their diets before and after weaning (termed "flavour imprinting") has also been explored (Campbell, 1976; King, 1979; Langendijk et al., 2007; Oostindjer et al., 2014; Roura and Palou, 2019). Early exposure to flavours in this way has been shown to increase preference for these flavours later in life in some animal species (Mennella, 2014). Indeed, continuity of flavours such as anise from the sow to the creep diet have shown promise in pigs, improving piglet feed intakes, reducing diarrhoea incidence and improving welfare of pigs after weaning in a study by Oostindjer et al. (2010). These results did not support those of Langendijk et al. (2007), who found little influence of flavour continuity on piglet performance. However, the latter study may have been impacted by the intermittent suckling regime employed in that case, and this phenomenon should be further investigated.

Recommendation: In summary, it seems that creep feed does **not** need to be medicated or include expensive milk powders or other specialised ingredients, given that pre-weaning feed intakes are low and variable and impacts on lifetime performance are not substantial. This low intake when compared to the total feed consumed by a pig gives a small proportion, which implies a relatively small cost of feed. It is important to make sure that staff, especially on owner-operated farms, are aware that creep feed is **not** expensive, as this way they will be more likely to replace it more often; however, creep feed wastage must be monitored closely. Regardless, use of flavours may be valuable in improving early feed intake of piglets.

Possible further research: There seems to be a gap in the knowledge in terms of interactions with timing of creep feeding, creep feed intake before weaning and complexity of creep feed. For example, is a less complex creep composition required when only providing creep feed for a couple of days before weaning to acclimatise piglets to solid feed (e.g. when weaning age is low and actual creep feed intake is not expected) vs. when providing creep feed for a longer period of time before weaning to improve solid feed intake before weaning (e.g. when weaning age is high)? Furthermore, the literature is lacking an economic analysis of different creep feed formulations.

Theme 2: Presentation (*How* to creep feed)

2.1 Pellet size

Traditionally, creep pellet size has been based on the size of the pig (e.g., a small pellet for a small pig) and modelled on the pellet sized used for growing pig diets. This is due to ease of production and to allow for familiarising piglets with solid feed similar in form to what they would see after weaning. However, the recent literature has had a focus on providing larger diameter creep pellets to piglets (Fig. 3). These large pellets are thought to resemble nuts and berries that piglets would interact with naturally in the wild before being weaned from their mothers (A'Ness et al., 1997). Furthermore, larger pellets may suit a growing pig's teeth and jaw structure, assisting with teething and allowing the creep feed to be more easily consumed than smaller pellets and improving appetite of piglets (Tucker et al., 2010; Van den Brand et al., 2014).

Fig. 3: Example of a small (4 mm diameter) and large (>9 mm diameter) creep pellet. From Craig et al. (2021).

Providing larger creep feed pellets (e.g. > 8 mm in diameter) to litters from an early age (3 days) has been shown to increase creep disappearance before weaning (Van den Brand et al., 2014; Craig et al., 2021). Furthermore, feeding large creep feed pellets seem to be just as advantageous to gilt and sow progeny, with both groups having similar rates of creep feed disappearance (Fig. 4; Craig et al., 2021). If anything, it may seem that gilt progeny may consume more larger pellets in early lactation (days 3 to 10) than sow progeny. Another advantage of a larger creep pellet diameter is the reduced wastage, where larger pellets are less likely than smaller pellets to get between gaps in flooring and fall into effluent pits (Van den Brand et al., 2014; Middelkoop et al., 2018; Craig et al., 2021). This may even suggest that, in studies where creep feed disappearance was measured, the proportion of disappearance attributable to feed wastage may have been higher in groups of pigs provided smaller pellets compared to larger ones.

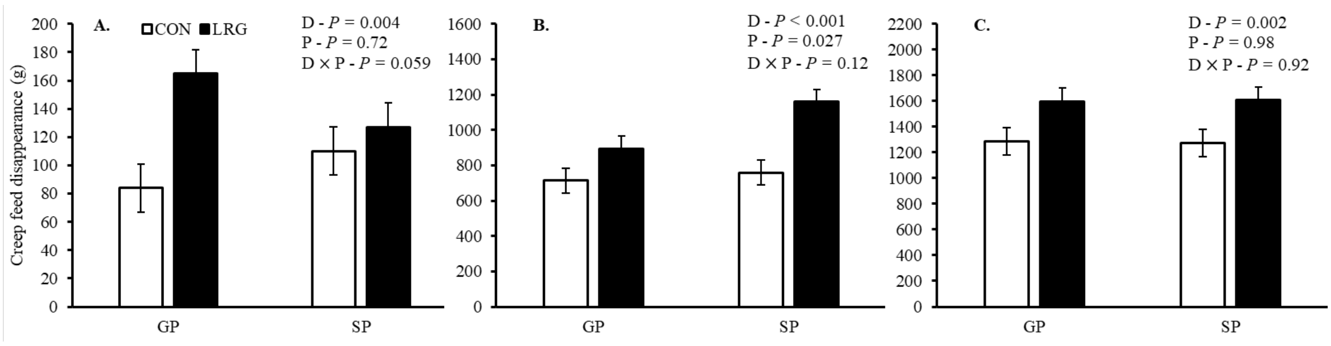

Fig. 4: Total creep feed disappearance in gilt progeny (GP) and sow progeny (SP) litters when fed either a small creep pellet or a larger creep pellet from A) days 3 to 10 of lactation, B) days 11 to 20 of lactation, and C) day 21 of lactation to weaning (26 d). From Craig et al. (2021).

The benefit of feeding large creep pellets may lie in improving the creep feed intake of piglets already likely to interact with creep feed (i.e., eaters) rather than encouraging more of those with no interest in the creep feed to eat it (i.e., non-eaters; Clark et al., 2016). Indeed, Clark et al. (2016) reported no difference in the proportion of eaters when pigs were given access to a 3.2 mm diameter pellet vs. a 12.7 mm diameter pellet. Similarly, Wensley et al. (2021a) found providing a larger creep pellet (12.7 mm) on the floor for 4 days prior to weaning (at 19 days of age) did not improve the proportion of eaters. However, large pellets may at least encourage piglets to explore and play with the solid feed or the feeder. This may encourage them to interact with solid feed after weaning as well and increase their familiarity with it. Edge et al. (2005) reported that piglets provided with a 5 mm pellet from 10 days of age explored the creep feeder more often than those provided with a 1.8 mm traditional pellet. Recently, Hewitt et al. (2023) reported a similar finding, where large 12 mm pellets encouraged feeder exploration and object play before weaning when provided to litters for 4 days before weaning.

Despite the apparent increases in creep feed consumption before weaning when offered larger pellets, it does not seem that provision of large pellets increases pre-weaning growth rates of piglets or weaning weights (Van den Brand et al., 2014; Craig et al., 2021). However, the real advantage of provision of large creep pellets is shown in the improved performance after weaning. Provision of large creep pellets has been shown to improve ADFI in the first week or so after weaning, an effect consistently seen between recent studies (Van den Brand et al., 2014; Clark et al., 2016; Craig et al., 2021). This impact on early feed intake after weaning, as expected, translated to better body weight gains in these studies, and this has recently been further verified in the study by Zemitis et al. (2023). Furthermore, in the study by Wensley et al. (2021a), piglets given large pellets had the lowest rates of mortality and removal after weaning compared to those given no creep feed, small pellets or sow lactation feed. However, the differences between the small and large creep pellet groups were not significant, and this phenomenon needs to be investigated further. Indeed, the proportion of pigs medicated after weaning in the study by Craig et al. (2021) was significantly lower in pigs given large creep pellets vs. small creep pellets before weaning. This may indicate that provision of large creep pellets, likely through improving adaptation to solid feed after weaning, may result in improved health of young pigs around this stressful time.

Large pellets used in different studies vary considerably in terms of size, particularly diameter. Edge et al. (2005) initially compared two different creep pellet sizes and found no difference in performance between pigs given large or small pellets. However, in that study, the diameter of the large pellets was 5.0 mm, and small pellets were 1.8 mm. These large pellets are similar in size to the regular creep pellets currently given in commercial production. Other studies have investigated large pellets of 9 mm (Craig et al., 2021), 10 mm (Van den Brand et al., 2014), 12 mm (Van den Brand et al., 2014; Hewitt et al., 2023; Zemitis et al., 2023), 12.7 mm (Clark et al., 2016; Wensley et al., 2021a), 14 mm (Middelkoop et al., 2018) and up to 20 mm (Wensley et al., 2023). However, the optimal pellet size for creep feeds is yet to be determined. Notably, the optimal length of the large pellet has not been studied, with some studies using a pellet 10-12 mm in length (Van den Brand et al., 2014; Craig et al., 2021), others providing large pellets of varying lengths (Wensley et al., 2023) while others have not reported pellet length. This is an important knowledge gap for further investigation.

Issues may arise with production of large pellets at the feed mill. For example, there is concern that production of large pellets may produce more fines than production of small pellets (Van den Brand et al., 2014; Mazutti et al., 2017) since large pellets are more vulnerable to damage as a result of their large surface areas. Furthermore, a separate dye is required to cut pellets to larger sizes and changing from a small to a larger dye within a commercial feed mill can increase production times significantly (C.J. Brewster, pers. comm.). Given that creep pellets are commonly made in small batches, it may not be economical to produce these pellets unless they are required in large quantities for multiple farms. Therefore, it may be of interest to produce diets for older pigs in large cubes as well, not only to ensure continuity of feed type and hence potentially avoid neophobia, but also to allow large-pelleted diets to be produced in significant quantities to warrant the loss of production time at the feed mill. However, there may be some on-farm issues with feed systems not being compatible with larger pellet size. To date, research on performance of pigs given large pellets has largely been focused on pre-weaning creep feeds. Clark et al. (2016) reported that provision of large pellets (12.7 mm diameter) before weaning improved piglet growth 7 days after weaning, regardless of whether the large pellets were continued in this period. However, more recent work by Wensley et al. (2023) has indicated that providing larger pellets ("enrichment cubes", 28-51 mm length and 20 mm diameter) post-weaning may reduce the proportion of pigs not eating in the first 3 to 7 days after weaning and therefore their body weight loss in this period, and this deserves to be further studied.

Recommendation: Where possible, provide creep feed in a large pellet to both sow and gilt progeny before weaning.

Possible further research: There is a clear knowledge gap when it comes to the best size (e.g. diameter and pellet length) and exposure period before (and/or after) weaning for creep feed pellets and a study in this area would be interesting. Furthermore, the impact of provision of large creep pellets on piglet health and GIT development around weaning is important to explore. Several questions remain to be answered in this area, such as: is there a benefit to continuing to provide large creep pellets after weaning? Does the feed formulation of the larger creep pellets need to be expensive and complex (e.g. contain highly digestible ingredients, milk powders) or cheap and simple (e.g. provide little nutritional benefit, made using simple ingredients, etc.)? Is there any benefit to providing large and small creep pellets simultaneously?

2.2 Milk replacer, gruel and soft creep pellets

Feeding milk replacer to piglets during lactation has shown promise in the literature, with liquid fed piglets being heavier at weaning than piglets not offered supplemental feed (Dunshea et al., 1998; Bruininx et al., 2002; Wolter et al., 2002; Sulabo et al., 2010a; Van Oostrum et al., 2016), or those offered pelleted creep feed (Kim et al., 2001; Christensen and Huber, 2021; Lyderik et al., 2023). This may be attributable to higher pre-weaning feed intakes in milk replacer fed piglets than in dry creep-fed piglets (Blanchard et al., 2000). Lyderik (2023) also recently found that the weight of the digestive system was heavier in liquid fed pigs compared to dry creep fed pigs at the same age, and they had higher villi in the jejunum and apparent digestibility of fat and ash. In that study, liquid fed piglets remained heavier than dry creep fed piglets at 9 weeks of age. Previous studies have found similar growth improvements in the weaner period (Kim et al., 2001; Sulabo et al., 2010a) compared to pigs not given creep or those provided with solid creep feed. Furthermore, piglets given milk replacer in lactation showed improved growth in the grower-finisher period (Wolter et al., 2002) in comparison to those not provided creep feed. However, recently Christensen and Huber (2021) found no impact on growth performance in the weaner period of liquid fed piglets, despite improvements in weaning weight compared to those given a pelleted commercial creep feed or no creep feed.

Milk replacers have been used to supplement the sow’s milk supply for piglets in Australian systems in the past; however, application of these systems is time consuming and difficult. Traditionally, milk replacer feeding systems have utilised creep feeders, with the stockperson mixing up the replacer from a powder and manually tipping it into feeders once or several times per day. This can be time consuming, physically labour intensive, and unhygienic. Artificial systems that deliver milk replacer to piglets are common in Europe where hyper-prolific sows struggle to provide milk for their larger litters (Kobek-Kjeldager et al., 2021). These systems may offer an alternative to improve delivery of milk replacers in our farrowing sheds; however, installation may be a costly exercise. Trough design may also dictate how much milk replacer piglets can consume and hence must be taken into consideration as well (Christensen and Huber, 2021; Kobek-Kjeldager et al., 2021).

Another problem with providing milk replacer in place of solid creep feed is that piglets do not get the chance to adapt to a solid diet before the abrupt change occurs at weaning. If providing milk replacer before weaning to ease the weaning transition, it is important to continue to provide a milk replacer in tandem with solid feed for a period after weaning (Dunshea et al., 1999; Kobek-Kjeldager et al., 2020; 2021).

To overcome this problem, gruel feeding before weaning may be considered, which involves mixing the solid creep diet with either water or milk replacer (Brooks and Tsourgiannis, 2003; Blavi et al., 2021). The advantage of this is that the liquid diet more closely resembles the solid diet, and pigs can be slowly introduced to solid feed over a short period (Kim et al., 2001; Brooks and Tsourgiannis, 2003; Pluske et al., 2018). Softer diets such as gruel may also help alleviate dental pain in pigs, which may cause oral discomfort in pigs around 17-21 days of age and cause them to avoid solid food during this period (Tucker et al., 2010). Findings from studies involving gruel feeding before weaning have been inconsistent. Piglets may consume more dry matter from gruel feed than they do from pelleted creep feed in the first 3 weeks of life (Byrgesen et al., 2021; Fig. 5). However, the higher dry matter disappearance in this case may have been attributable to feed wastage, with liquid feed being easier to spill out of feeders and therefore this may not accurately represent piglet intake.

Martins et al. (2020) found that gruel fed pigs had higher average daily feed intake (ADFI) between 3 and 7 days of age than those given a solid creep diet; however, ADFI was not different on any other pre-weaning days between the two groups. In this study, pigs given gruel feed before weaning had a higher variability in liveweight at 19 weeks of age which may impact saleability. Boston et al. (2022) found that piglets that were gruel-fed a diet with mostly soluble ingredients from 7 days of age until weaning had heavier weaning weights than those pigs not given any supplementary feed. However, gruel creep feeding before weaning has been linked with an increase in diarrhoea and/or a reduction in faecal consistency scores before weaning (Lee and Kim, 2018; Martins et al., 2020). Kobek-Kjeldager et al. (2021) also found no difference in eating or drinking frequencies of piglets or feed intakes in the first weeks after weaning when provided gruel for a period before and after weaning.

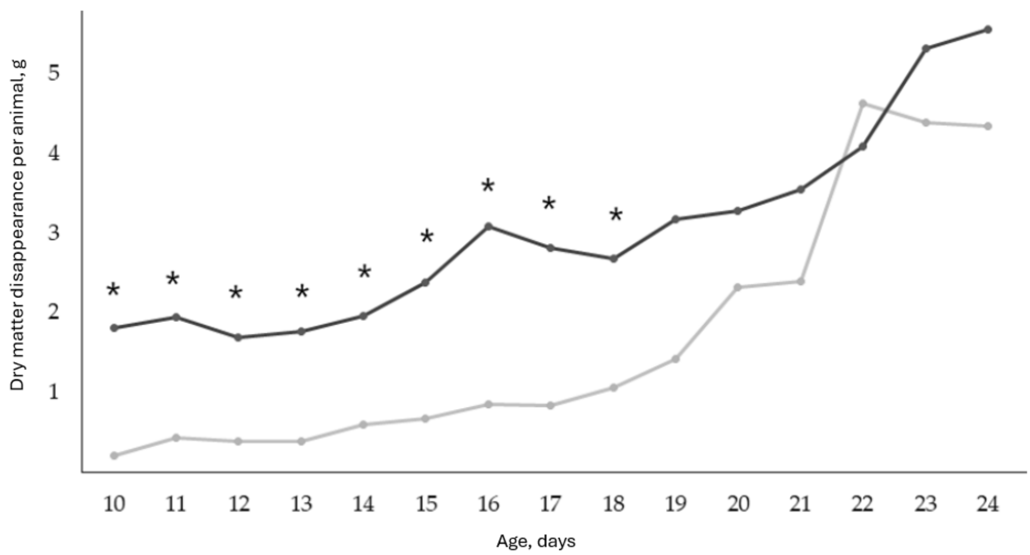

Fig. 5: The average daily dry matter (DM) disappearance per animal in litters fed dry creep feed (light grey) vs. gruel creep feed (dark grey) from 10 to 24 days of age. *Difference between dietary treatments was significantly different ($p < 0.05$). Adapted from Byrgesen et al. (2021).

Inconsistent results between studies on gruel feeding as an alternative to solid creep diets may be due to ratios of liquid to solid feed in the formulation, different presentations of gruel feed and/or the continuation of gruel feed after weaning. Again, hygiene becomes a problem when delivering gruel to piglets before weaning, which can also be a time consuming and laborious process.

Another option for creep feeding recently explored in the literature is the use of semi-moist creep pellets with >20% moisture, in comparison to a traditional creep pellet that typically contains about 10% moisture (Chen et al., 2021; Hewitt et al., 2023; Zemitis et al., 2023). In these studies, while feeding a high moisture pellet improved the development of the intestinal tract and piglets ate more in the 1-2 days before and after weaning (Chen et al., 2021), total creep-feed intake was not different compared to pigs fed a hard creep pellet and growth rates of piglets around weaning were not improved (Hewitt et al., 2023; Zemitis et al., 2023). Authors noted that the impact of reduced dietary density in these soft pellets may be why improvements in growth of piglets supplemented these diets was not seen around weaning. Storage of high moisture pellets would also present challenges, as when creep feeds are distributed in small amounts, storage time is usually quite high and soft pellets may be more susceptible to mould growth and increase the chance of mycotoxicity (Jacela et al., 2010).

Recommendation: Milk replacer provision can be a good option to supplement sow milk and increase weaning weights when labour is not limiting. It is paramount that staff are cleaning feeders thoroughly and regularly to avoid poor hygiene within the pens; however, this can be time consuming. In order to help piglets adjust to solid feed after weaning, provision of these liquid creep diets should be continued post-weaning and offered in concert with dry pellets.

Possible future research: Investigation of milk replacer delivery systems and economic analysis of their adoption in our production systems would be of interest. Also, what are the seasonal impacts of gruel feeding before weaning? Is there an optimum duration of gruel feeding before and after weaning to adapt piglets to solid feed?

2.3 *Creep feeder types and encouraging exploratory behaviour*

The way that creep feed is presented to the piglets may have a significant influence on how they interact with the feed and how much they consume. Feed can be supplied in small creep bowls, troughs, traditional feeders with hoppers, or simply spread onto the floor or on the creep mat. Recently, research has been focused on evaluating different types of feeders on encouraging piglets to interact with and/or consume creep feed.

Generally, the more feeder spaces, the greater the consumption of creep feed and the longer the pigs spend at the feeder (Appleby et al., 1991; Appleby et al., 1992). This allows piglets to learn from and imitate each other at the feeder, encouraging more piglets in the litter to feed (Appleby et al., 1991; Oostindjer et al., 2014). Wattanakul et al. (2005) found that piglets approached a trough feeder more often than piglets offered creep feed in a traditional round creep bowl fitted with a hopper and ate significantly more solid feed before weaning. Indeed, Sulabo et al. (2010b) found an open trough feeder increased creep feed disappearance; however, the number of eaters was not influenced by the feeder type in that study (compared to creep presented in a round creep bowl with or without a hopper). The authors speculated that the increased disappearance of feed was due to more wastage rather than actual feed intake. Furthermore, the authors observed that piglets were more likely to root around in and lie on top of the trough feeders, which increased wastage, and that pigs were more likely to eat while standing parallel to the feeder, reducing access for their littermates. This may have been due to the significant amount of space that the feeder occupied in the pen, leaving less room for other natural piglet behaviours. However, this was not observed in the study by Wattanakul et al. (2005). Given these results, it seems that creep feeder design needs to be carefully considered to encourage piglets to consume creep feed and reduce wastage.

Encouraging play and exploratory behaviours in piglets may be pivotal to increase interest in solid creep feed before weaning (Blackshaw et al., 1997; Wattanakul et al., 2005; Hewitt et al., 2023). Middelkoop et al. (2019b) examined presenting creep feed in a 'play feeder' to stimulate their curiosity and improve interactions with the feeder and hence feed intake. Piglets with creep feed provided in these play feeders spent significantly more time exploring the feeder and eating creep feed, and a higher proportion of the litter were shown to be exploring the creep feeders. This finding supported previous work by Kuller et al. (2010) who found that a trough-style 'play feeder' with protrusions to promote piglet curiosity encouraged piglets to bite on the protrusions or the feeder itself, to make more visits to the feeder and to eat more creep feed. This may suggest that a feeder type such as this may have an added impact on animal welfare, as it may provide a form of enrichment before weaning. Furthermore, in the study of Middelkoop et al. (2019b), piglets provided with creep in these feeders had a higher post-weaning feed intake and growth rate, and a lower incidence of scours, body lesions, and ear and tail damage after weaning, which supports this theory that play type feeders may improve piglet welfare around weaning. Feeding creep feed on the floor or on a mat in the creep area can be favoured by producers, as it requires no specialised equipment and increases the surface area for piglets to interact with the creep feed. However, comparisons between provision of creep on the floor compared to in a feeder are poorly represented in the literature, which represents an opportunity for further study.

2.4 Frequency of creep feed replacement

How often creep feed is replaced is largely determined by availability of labour. Daily creep feed replacement may encourage further pre-weaning feed intake (Appleby et al., 1991; Wattanakul et al., 2005) and may stimulate piglets to explore creep feeders as the novelty of the new offering of creep feed may attract them (Adeleye et al., 2014). Frequent replacement of creep feed in small amounts may help piglets have more dietary diversity to help keep their interest in solid feed before weaning and hence improve feed intakes after weaning. In humans this is most definitely the case, and when presented with the same food repeatedly, habituation theory has shown that humans will present less and less appetite for that same food/food type at each presentation and demonstrate a reduced liking for it each time (Myers Ernst and Epstein, 2002; Epstein et al., 2007; Epstein et al., 2009). Furthermore, dietary diversity is positively linked to many aspects of human health, such as maintaining a healthy GIT microbiota (Heiman and Greenway, 2016). While this presents logistical challenges in management of pig production on a commercial scale, creep feeding around weaning – when feed only needs to be allocated to piglets in small amounts – may be the perfect time to exploit this phenomenon in young pigs. There is scope for further work to be done in this area.

In one study by Adeleye et al. (2014), piglets were given a different flavour creep feed each day and it was found that trough exploration was enhanced by this diversity of creep flavours (vs. a standard creep feeding regime) at day 18 of lactation, particularly around the time that the new creep feed was presented in the trough. Over both treatments, visits to the creep feeder were more pronounced around the time that the creep feed was replaced (0700 h and 1400-1500 h). However, contrary to this assumption, work by Sulabo et al. (2010b) found, when compared to a pan feeder or a rotary feeder without a hopper, attaching a hopper to a rotary feeder actually resulted in the highest proportion of piglets classed as eaters. The hopper attached to the feeder allows the feed to be self-replacing, ensuring creep is continuously available to piglets, which may be why the proportion of eaters was increased in that study (Tokach et al., 2020). In this regard, it is important to ascertain the impact of regular creep replacement on piglet resilience in later life, as it has recently been shown that positive interactions with humans through routine husbandry procedures in the farrowing house can improve early life resilience in pigs and their later attitudes towards humans (Hayes et al., 2021; Lucas et al., 2024a, b, c, d).

Recommendation: Replace creep feed at least daily, in small amounts to keep fresh, if this can be done cheaply.

Possible future research: Does feed replacement need to be done by hand (labour) to encourage creep feeder exploration, or can a self-replacing feeder be used to save time? What is the relationship between this frequent feed replacement and resilience of creep-fed piglets in later life?

Theme 3: Timing (*When* to creep feed)

3.1 Age at first offering, duration of creep feeding and timing relative to weaning

Pajor et al. (1991) identified two possible hypotheses driving piglets to consume creep feed. The first is the maturation hypothesis, where creep feed intake may be driven by the increasing digestive maturity of piglets as they age and grow. The second is the compensatory feeding hypothesis (Barber et al., 1955; Middelkoop et al., 2019a), which suggests that piglets start creep feeding as their demand for milk and need for nutrients for growth starts to exceed the production of milk from their dam. Under free-ranging/wild conditions, piglets begin grazing and eating solid food from four weeks of age, although continue to suckle from their dam until 17 weeks of age (Petersen, 1994). The work of Pajor et al. (1991) suggested that both hypotheses may be true, the former driving intake at early ages (e.g. in the first 3 weeks of life) and the latter driving intake at later ages. A third potential hypothesis is that piglets are simply curious, and this curiosity drives them to interact with the creep feed because it is there.
Indeed, creep feed consumption significantly increases in the last week before weaning, which has been shown in a number of studies (e.g., Fraser et al. 1994; Bruininx et al., 2002; Pluske et al., 2007; Sulabo et al., 2010a; Collins et al., 2013; Huting et al., 2017; Muro et al., 2023). However, these conclusions are mostly based on data from litters that are provided creep from a very early age. The interaction between day of first creep feed exposure and creep feed intake at different ages is poorly presented in the literature. A recent meta-analysis by Muro et al. (2023) identified that piglets need to be supplied creep feed for a minimum of 14 days before their litter weight at weaning is influenced.

There have been a number of studies investigating different durations of creep feeding (regardless of weaning age); however, results from these studies are variable. Klindt (2003) found providing creep feed for only 2 days before weaning did not influence piglet growth before or after weaning. Similarly, Sulabo et al. (2010c) found that creep provision for only 2 or 13 days before weaning did not improve piglet growth performance. Those authors did observe that creep feed given for 13 days increased the proportion of eaters compared to starting creep provision at 2 or 6 days before weaning. However, the authors concluded that this difference would not be economical, as increasing the proportion of eaters would only marginally increase the total creep feed intake, with little impact on performance. In that study, a large proportion of eaters (>70% of the litter) were identified when piglets were only given creep feed 2 days before weaning, suggesting that pigs may not need early exposure to creep feed to encourage intake in the few days prior to weaning. On the other hand, more recently Lee and Kim (2018) found that provision of creep feed from 7 days of age until weaning (at 24 days of age) improved weaning weight and piglet pre-weaning ADG than provision of creep feed from 14 or 21 days of age. Collectively it seems that provision of creep feed from a younger age may increase familiarisation of piglets to solid feed, encouraging more piglets to eat the creep feed than would normally as they approach weaning. However, this additional creep exposure is most likely not economical, from a cost-benefit perspective, as daily creep replacement is time consuming and the improved growth performance of piglets due to the longer duration of exposure may not be significant to warrant the additional labour.

Given the two hypotheses regarding creep feed intake mentioned above, at younger weaning ages (e.g. around 3 weeks of age), it is important to assess whether creep feeding is likely to be effective in this case. Milk production of the sow is thought to peak around day 20 of lactation (Hansen et al., 2012) but this would likely vary with different genetics and across herds. Even when creep feed was provided from an early age, individual creep feed intakes were negligible by 21 days of age in the studies by Collins et al. (2013) and Huting et al. (2017). Furthermore, studies examining creep feed intakes in piglets weaned at 21 days of age seem to record a relatively low consumption of creep feed in piglets this age at weaning (Van den Brand et al., 2014; Martins et al., 2020). Pigs weaned at this age seem to suffer from neophobia and take an extended time to consume solid feed after weaning (Van den Brand et al., 2014; Figueroa et al., 2019). While little actual intake of creep feed is observed in pigs weaned at 3 weeks of age, it seems that this early exposure to dry feed may alleviate some of this neophobia after weaning. For example, in the study of Sulabo (2009), eaters of creep feed given only for the last 4 days prior to weaning at 21 days had improved growth performance after weaning compared to non-eaters.

Acceleration of creep feed intake by eaters seems to occur around the fourth week of life (reviewed by Canibe et al., 2022) and this may suggest that piglets weaned at older ages (e.g. > 28 days) will be more responsive to creep feed supplementation than those weaned younger. Indeed, creep feeding piglets has been shown to improve GIT health and growth performance in the last week before weaning in a number of studies where pigs were weaned on or after 28 days of age (Aumaitre, 1972; Middelkoop et al., 2020). Collectively, results from recent studies indicate that creep feeding becomes more important as weaning age goes up (Callesen et al., 2007a; Collins et al., 2013; Blavi et al., 2021). Older pigs more readily accept solid feed, and it is generally accepted that creep feed intake is highest in the week immediately before weaning, regardless of weaning age (Bruininx et al., 2002; Pluske et al., 2007; Sulabo et al., 2010c; Tokach et al., 2020). Therefore, it seems that the time that piglets start to consume considerable amounts of solid creep before weaning has more to do with their maturity than the length of exposure to the creep feed itself. It may therefore be reasonable to only present creep feed within the last week before weaning – regardless of weaning age – in order to minimise associated feed and labour costs. However, a recent systemic review and meta-analysis by Muro et al. (2023), found that creep feed consumption increased as number of days exposed to creep feed increased, regardless of weaning age. In that meta-analysis a total of n = 20 studies were used with weaning age ranging from 21 to 49 days of age (24 ± 3.3 d; mean ± SD). These authors found that creep feed should be given for at least 14 days before weaning weight can be influenced. The economics of this deserve to be further explored.

3.2 Prioritising litters for creep feeding

Creep feeding may be more important for certain litters than others. The higher the litter size, the more important additional feed source may be for the piglets in that litter and the more likely the milk production of the sow will be limiting the growth of her piglets. For example, if there are less teats than there are piglets in the litter, milk intake of some piglets may be limited as they are required to compete with their littermates for a teat at each suckling bout. This all relies on the compensatory feeding hypothesis mentioned above being true, and this hypothesis is generally accepted, with creep feeding recommended for large litters with extended lactation lengths (e.g. hyper-prolific sows) (Blavi et al., 2021). In the study of Kuller et al. (2004), it was evident that when milk intake of piglets was limited (in this case by an intermittent/split suckling regime) they increased their creep feed intake from day 14 of lactation until weaning (at day 25).

Milk production is lower in primiparous sows compared to multiparous sows due to differences in mammary development and partitioning of nutrients in late gestation and lactation (Pluske et al., 1998; King, 2000; Farmer et al., 2024), and hence this may influence the creep feed consumption patterns of gilt vs. sow progeny. In our previous study (Craig et al., 2021) we found gilt progeny had lower creep feed disappearance than sow progeny in mid-lactation (days 11 to 20); however, there was no difference in earlier or later lactation and we did not record the proportion of creep feed eaters in each litter. In contrast, Huting et al. (2019) showed that there was a higher proportion of creep feed eaters in gilt litters compared to sow litters, but did not report overall creep feed intake. Differences between these two studies may be explained by the fostering techniques used. Minimal fostering was undertaken in the former study (<10%), whereas the majority of piglets (74%) were fostered in the latter study. Indeed, relationships between parity of the birth dam and the rearing dam and their impacts on piglet creep feed consumption may be quite complex and deserve to be further studied.

There is conjecture in the literature as to whether birth weight of piglets influences creep feed intake. The study of Sulabo et al. (2010a) suggested that the heavier piglets are at birth, the more likely they won't consume creep feed at all during lactation. However, Pajor et al. (1991) found that these heavier piglets ate more creep feed than lighter piglets in the same litter. Huting et al. (2017) demonstrated that more lighter born piglets failed to consume creep feed during lactation than their heavier counterparts, in contrast to the findings of Sulabo et al. (2010a). However, in the former study, consumers of creep feed were generally the lightest pigs in later lactation (19 days of age), despite whether they were in a litter of piglets of a similar size (uniform) or a litter of mixed sizes and weights. This was in agreement with the findings of Sulabo (2009) where piglets classified as creep feed eaters were generally lighter on day 18 of lactation and at weaning. Pajor et al. (1991) suggested that body weight of piglets may influence their creep feed consumption as it may be an indicator of their developmental maturity and their dominance over their litter mates at the creep feeder. The impact of piglet weight on creep feed consumption may also be influenced by the uniformity of the litter. This was in fact the case in the study of Huting et al. (2017) who found that heavy weight piglets in uniform litters (mixed with other heavy weight piglets) were the biggest consumers of creep feed, compared to heavy weight piglets in mixed weight litters, or light weight piglets in uniform or mixed litters.

Other factors that may influence the creep feed consumption of piglets include lactation feed intake and restriction of the sow (Sulabo et al., 2010a; Middelkoop et al., 2019a) or heat stress of the sow in summer (Azain et al., 1996; Renaudeau and Noblet, 2001; Tokach et al., 2020). It seems from these studies creep feed intake was higher for piglets suckling sows that were restrict-fed compared to fed *ad libitum* in lactation and in hotter months compared to cooler months. Furthermore, the likelihood that a pig will consume creep may be sex-dependent (Kuller et al., 2007a). These authors found that 30% of females were designated as creep eaters in comparison to 21% of males. So, the feeding regime, health status, season and/or sex ratio of the litter may also be important in determining which litters would most benefit from creep feeding.

From the available evidence it seems that some litters may consume creep feed more than others, and one of the main contributing factors to this is the milk availability from the sow in later lactation. It is important that the producer considers creep feeding in the context of the milk production of their own gilts and sows. For example, they may want to prioritise creep feeding in gilt litters, litters where there are more piglets than teats around weaning, and litters suckling sows which may have their milk production compromised or poor teat quality due to health or management factors. This knowledge may help producers manage additional labour and costs associated with delivery of creep feed.

3.3 Influence of creep feeding on sow performance in late lactation – a trade-off between mother and piglets?

In extended lactations, with highly productive sows, where the sows nurse their piglets for prolonged periods, creep feeding may offer an additional benefit in that provision of solid feed allows piglets an alternate source of nutrients to milk. This may relieve some of the pressure from the sow when she is suckling a large litter. This is an overall understudied aspect of creep feeding that deserves further work.

Recently this impact has been explored in the literature in terms of the impact on sow body weight and backfat loss during lactation. Heo et al. (2018) found no influence on sow condition in lactation when comparing between three creep feeding regimes; however, those authors did not compare to a control group with no creep feeding. Sulabo et al. (2010a) found no impact of creep feeding on changes in sow body condition or sow feed intake in lactation; with creep feeding even increasing the wean to oestrus interval in that study. The lack of impact on sow body condition or feed intake in lactation was backed up in a later study by the same authors (Sulabo et al., 2010c). A more recent study by Christensen and Huber (2021) found a similar result where provision of creep feed from 5 days of age (either in the form of a commercial creep pellet, a pelleted milk replacer or a liquid milk replacer) did not influence sow body weight, backfat loin depth loss in lactation or lactation feed intake. However, those studies were conducted in sows weaned at 21 days of age, where creep consumption of piglets may be negligible and hence could fail to reduce the metabolic load on the sow in late lactation.

There may also be a concern that providing creep feed to litters at later ages may cause piglets to replace milk intake with solid feed intake and hence contribute to a more gradual weaning of the sow through intermittent suckling (Turpin et al., 2016). This can increase the incidence of 'silent' return to oestrus in lactation and hence reducing production efficiencies. This is another area that seems to be not very well studied, and work by Kuller et al. (2007a) has suggested that intermittent suckling of piglets does increase the proportion of sows that ovulate during lactation. The question then becomes whether creep feeding can have a similar impact if piglets are replacing milk intake with solid creep consumption. Therefore, it is evident that work into the impact on the sow of creep feed provision when litters are weaned at later ages (e.g. >28 days) is lacking. It will also be important to investigate the influence of creep feeding on reducing udder damage near weaning, which is lacking in the current literature. It may be that providing creep reduces fighting around the udder in older piglets and hence impacts on the number or severity of facial or udder injuries.

Recommendation: Supply creep feed in the last week before weaning. Actual consumption of creep feed is not as critical as exploration of creep feed before weaning. If labour is limiting, focus on creep feeding litters where the sow has lower milk production (e.g. gilt litters, sows not eating, scouring litters, when weaning age is extended).

Possible future research: How does short-term creep feeding in litters with higher weaning ages influence the sows' performance (e.g. body condition loss, lactation feed intake, udder damage, ability to return to oestrus)?

Conclusions

In conclusion, the conjecture in the literature around the effectiveness of creep feeding may impact its adoption in modern pig production. Often, farm staff may be reluctant to creep feed as they believe the feed is expensive or that piglets do not eat it before weaning and hence, they do not see the benefits that come with creep feeding after weaning and tend to prioritise other farm operations to the constant provision of creep feed, especially when time is limiting. The current review has identified a number of knowledge gaps that may be of interest in the future to further investigate the impact of creep feeding in commercial production systems.

Areas of interest identified include:

- Interactions between timing of creep feeding and diet complexity, i.e. if creep feeding for only a short period of time (3-5 days), does the diet need to be expensive and nutritious? Furthermore, an economic analysis in this area would be of interest.

- Investigation into the ideal creep pellet size, how to present it to piglets and whether to continue provision of larger pellets after weaning to make them more economical and encourage familiarity.
- Exploring automatic feeding systems for liquid or gruel feeding before weaning and an economic analysis of what is out there will be important as our litter sizes increase, sow milk production becomes more limiting, and as labour becomes more scarce.
- We don’t yet know how often creep feed should be replaced and the impact of frequent replacement on piglet and sow resilience in the farrowing house and later life, as well as the efficiency of human vs. automated feed replacement.
- Interactions between available teat number, litter size and creep feed consumption around weaning in order to prioritise litters for creep feeding.
- An economic analysis would be valuable to identify which litters we should prioritise for creep feeding. For example, if labour is limiting, can we just provide creep feed to those litters that we know really need it, and how do we identify those litters?

From the literature there seems to be a real benefit of creep feeding for transitioning pigs to weaning. However, the correct implementation of a creep feeding regime on a commercial farm can be hampered by poor execution and it is vital that we simplify creep feeding in order to increase adoption by producers. The information outlined in the current review and the suggestions made for further research will go a long way in achieving this.

Appendices

Appendix 1: Study summary

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
Advantages of creep feeding						
Barnett et al. (1989)	34	Creep vs. no creep	10 d to wean	28 d	NS	✗ Little benefit of creep feeding
Bruininx et al. (2002)	21	Creep vs. no creep Eaters vs. non-eaters	11 d to wean	28 d	NS	↑ Eating behaviours and visits to feeder post-weaning ↓ Time between weaning and first feed
Carstensen et al. (2005)	12	Creep vs. no creep	14 d to wean	28 d	NS	↑ Shedding of haemolytic *E coli* in pigs offered, but not interested in, creep feed
Edwards et al. (2011)	85	Creep vs. no creep	19 d to 27 d	28 d	Both	↑ Survival post-weaning for GP and SP
Huting et al. (2017)	37	Birth weight variation (uniform vs. mixed litters) x no creep feed vs. creep	10 d to wean (given supp milk before this)	28 d	NS	↑ % of creep feed eaters for heavy pigs in uniform litters vs. heavy pigs in mixed litters or light pigs
Kuller et al. (2004)	112	Control vs. intermittent suckling (IS) for last 11 d	7 d to wean	27 d	SP	↑ Creep FI in IS litters ↓ WWT in IS litters ↑ FI post-weaning in IS litters
Kuller et al. (2007a)	62	Control vs. IS for last 11 d	7 d to wean	28 d	Both	✗ No impact on % of eaters ✗ No impact of creep feeding on WWT but ↑ BWT 4 wk post-weaning

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
Middelkoop et al. (2020)	22	Creep vs. no creep Pre- and post-wean (2 x 2)	2 d to wean or 2 wk post- wean	30 d	SP	↑ GR last 7 d pre-weaning ↑ Visits to feeder 2 wk post-weaning
Muns and Magowan (2018)	51	Creep vs. no creep Low vs. high starter diet allowance (2 kg vs. 6 kg/pig)	18 d to wean	28 d	NS	↑ FI 1 wk post-weaning
Murphy et al. (unpublished data)	40	Creep vs. no creep	14 d to wean	28 d	Both	✗ Little benefit of creep feeding on post-weaning performance
Pajor et al. (1991)	4	None	10 d to wean	28 d	NS	↑ Pre-weaning BWT gain
Pluske et al. (2007)	6	Good vs. moderate vs. non-eaters	12 d to wean	13 d	SP	✗ No impact on pre-weaning growth ↑ GR in the first 3 d post-weaning
Sulabo et al. (2010a)	84	Lactation feed intake Creep vs. no creep	3 d to wean	21 d	Both	↓ PWM when fed creep ↑ ADG of eaters 28 d post-weaning
<u>Composition of creep feed</u>						
Collins et al. (2013)	96	Weaning age and simple (veg protein) vs. complex creep feed (animal protein, whey powder)	9 d to wean	22 or 29 d	Both	↑ Creep disappearance in pigs offered simple creep ↑ FI and GR post-weaning in pigs, especially when weaned at 29 d
Edwards et al. (2013)	154	Spray dried porcine plasma (SDPP) vs. yeast derived protein meal (NUP) vs. medicated control creep	19 d to wean	27 d	Both	↑ GR post-weaning in SDPP creep-fed pigs compared to medicated control creep
Figueroa et al. (2019)	48	Flavoured (garlic or aniseed) vs. non-flavoured Late gestation sow diets vs. creep diet (2 x 2)	10 d to 20 d	-	NS	✗ No influence on piglet performance of flavour continuity

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
Fraser et al. (1994)	24	Simple (corn, barley, soybean meal) vs. complex (medicated, no soybean meal)	14 d to wean	28 d	NS	↑ FI and growth performance 2 wk after weaning with complex diet
Heo et al. (2018)	24	Creep vs. weaner vs. sow feed provided as creep feed	14 d to wean	28 d	SP	↑ FI before weaning with creep diet ↑ FI and GR after weaning with weaner diet
Okai et al. (1976)	36 (E1) 48 (E2)	No creep feeding vs. simple, semi-complex or complex creep diets (both Exp.)	10 d to wean 14 d to wean	21 d 35 d	NS	↑ FI before and after weaning with complex creep ↑ GR after weaning with complex creep for 21 d weaning age but not with 35 d weaning age
Lee et al. (2021)	8	Creep vs. no creep Phytase vs. no phytase in post-weaning diet (2 x 2)	2 d to wean	28 d	NS	↑ GR 1 wk post-weaning ✗ No interaction between creep feeding and phytase supplementation
Sulabo et al. (2009)	96	No creep vs. simple vs. complex creep Eaters vs. non-eaters	18 d to wean	21 d	NS	↑ % of eaters with complex diets ↑ GR of eaters (3, 28 d) post-weaning
Tran et al. (2014)	24 (E1, E2) 23 (E3)	No creep vs. creep vs. creep with yeast-dried milk product (YDM)	7 d to wean	24 d	Both	↑ WWT in SP offered creep ↑ GR post-weaning (28 d) with YDM (GP and SP)
Yan et al. (2011b)	30	Unflavoured creep vs. vanilla flavour vs. cheese flavour (powder creep)	5 d to wean	28 d	Both	↑ FI pre-weaning with flavours ↑ ADG and G:F post-weaning
Creep feeder types and presentation						
Appleby et al. (1991)	8	1) Single two-space feeder unchanged	21 d to wean	28 d	Both	↑ FI pre-weaning with more feeders

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
		2) Clean feeder with fresh food supplied at 9am 3) Clean feeder with fresh food supplied 3x day 4) 3 feeders unchanged				
Kuller et al. (2010)	72	Common feeding system vs. playfeeder (PF)	7 d to wean	26 d	Both	↑ FI pre-weaning with PF ✗ No difference in % of piglets visiting feeder
Middelkoop et al. (2019a)	37	Conventional vs. PF	4 d to wean	24 d	GP	↑ Feeder exploration with PF ↑ GR post-weaning with PF
Norden et al. (unpublished data)	60	No creep feeder vs. commercial feeder vs. Pan-type feeder	14 d to wean	28 d	SP	✗ No benefit of creep feeding on post-weaning performance
Sulabo et al. (2010b)	54	Rotary feeder with or without hopper, pan feeder	18 d to wean	21 d	NS	↑ Feed disappearance and ↑ % of eaters with rotary feeders with hopper
Wattanakul et al. (2005)	24	Sow fed in feeder vs. sow also fed on floor (piglet access) Commercial hopper vs. shallow tray	14 d to wean	28 d	NS	↑ Feeder approaches and ↑ FI pre-weaning with sow fed on floor
<u>Form of creep feed</u>						
Byrgesen et al. (2021)	29	Dry vs. liquid creep feed	10 d to wean	24 d	Both	↑ GR pre-weaning ↑ Intestinal enzyme activity with dry creep feed ✗ No difference in % of eaters
Chen et al. (2021)	18	Powder vs. hard pellet vs. soft pellet creep feed	14 d to wean	21 d	SP	↑ FI pre-weaning with soft pellet

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
Christensen and Huber (2021, 2022)	56	Commercial creep feed Liquid milk replacer Pelleted milk replacer No creep feed (x simple or complex weaner feed)	5 d to wean	21 d	GP	↑ GIT enzyme activity and absorptive capacity at weaning
Clark et al. (2016)	26	3.2 mm vs. 12.7 mm pellets – swapping at weaning phase (2x2)	10 d to wean	21 d	NS	↑ Pre-weaning survival with larger pellet ↑ FI and GR post-weaning (7 d) ✗ No impact on eaters or interaction between creep or nursery pellet size
Craig et al. (2021)	240	4 mm vs. 9 mm pellets	3 d to wean	26 d	Both	↑ Creep disappearance pre-weaning with larger pellet ↑ GR and FI post-weaning ↓ Medications post-weaning
Edge et al. (2005)	24	1.8 mm vs. 5.0 mm pellets – plus different sizes post-weaning	10 d to wean	28 d	NS	↑ Feeder exploration pre-weaning with larger pellet ✗ No impact on performance
Hewitt et al. (2023)	84	Standard vs. semi-moist pellets Small (4 mm) vs. large (12 mm) pellets (2 x 2)	4 d pre- to 7 d post-weaning	20 d	Both	✗ No impact of larger pellets on piglet performance pre- or post-weaning ↑ Feeder exploration and object play
Martins et al. (2020)	16	No creep (CON) vs. dry creep feed (DCF) vs. gruel creep feed (GCF)	3 d to wean	21 d	Both	↑ F:G and FI (3-7d) in GCF vs. DCF ↑ Variation in slaughter weight in GCF vs. CON
Van den Brand et al. (2014)	19 (E1) 39 (E2) 18 (E3)	2 vs. 12 mm diameter pellets (E1) 2 vs. 10 mm diameter pellets (E2)	4 d (E1), 3 d (E2), and presumably 0 d (E3) to wean	25-28 d (E1 & 2) 25-30 d (E3)	SP (E1) Both (E2) SP (E3)	↑ Exploratory behaviour with large pellet ↑ Creep FI pre-weaning

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
Wensley et al. (2021a)	264	Control (no creep) vs. standard (1/8”) creep vs. large (1.2”) creep vs. sow lactation feed floor fed	15 d to wean	19 d	NS	↑ ADG 1 wk post-weaning ✗ No impact on pre-weaning FI
Wensley et al. (2023)	28	Light vs. heavy BWT Large 20 mm cubes provided pre- or post-weaning, or both	16 d to wean	20 d	NS	↓ BWT loss in first 7 d when offered large cubes post-weaning (regardless of offered pre-weaning)
Zemitis et al. (2023)	112	Standard vs. semi-moist pellet Small (4 mm) vs. large (12 mm) pellets (2 x 2)	3 d pre- to 8 d post-wean	26 d	SP	⇩ GR before and post-weaning with semi-moist pellets ↑ GR 9 d post-weaning with large pellets
Timing of creep feeding						
Agnol et al. (2023)	13	Creep fed from 5 or 10 d of age	5 or 10 d to wean	21 d	NS	↑ Post-weaning ADG in first 7 d post-weaning for longer creep feeding duration
Callesen et al. (2007a,b)	96	Weaning age vs. diet type	14 d to wean	27 or 33 d	NS	✗ No difference in ADG pre-weaning or incidence of post-weaning diarrhoea in eaters vs. non-eaters ✗ Interactions between weaning age, diet type and eater classification were significant but not clear
Klindt (2003)	48	Creep fed 5 or 2 d before weaning	5 d to wean or 2 d before wean	13-20 d	Both (P1,2)	↑ ADG pre-weaning and WWT in larger litters (> 8 pigs) when creep fed from 5 d of age ↑ GR post-weaning and yield of marketable pork
Sulabo et al. (2010c)	54	Creep feeding from d 7, 14 or 18 of life	7, 14 or 18 d to wean	20 d	NS	↑ % of eaters when creep feeding for longer durations

Study	N (litters)	Treatments	Age at creep feeding	Age at weaning	GP/SP	Impact of creep feeding
						↑ FI and GR post-weaning (3 d) of eaters vs. non-eaters ✗ No impact on pre-weaning performance
Yan et al. (2011b)	32	No creep feed or feeding from 5, 10 or 15 d of age	5, 10, 15 d to wean	21 d	Both	↓ Post-weaning diarrhoea score when creep feeding from 5 or 10 d ↓ Sow cortisol concentrations at weaning and ↓ WOI

ADG = average daily gain, F:G = feed to gain ratio, FI = feed intake, GR = growth rate, NS = not specified, PWM = pre-weaning mortality, WOI = wean to oestrus interval, WWT = weaning weight.

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