DEVELOPMENT OF DIGESTIVE FUNCTION AND NUTRITION/DISEASE INTERACTIONS IN THE WEANED PIG

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SUMMARY

There are many aspects to digestive development in the young pig. These include ıe structure and function of the stomach and small intestine epithelium, digestive ecretions from the stomach, pancreas, bile and small intestine and establishment of a table commensal flora in the gut. Digestive capacity increases rapidly during the first few veeks. The piglet is able to digest significant quantities of sucrose, starch and other components not found in sows' milk even during the first week and can be weaned to a liet containing raw cereal, soya bean meal etc as early at 10 d of age. There is considerable evidence that digestive enzyme secretions can be substrate-induced by feeding creep to suckled pigs. However there is no evidence that this significantly improves performance post-weaning. Pigs weaned at 2-4 weeks of age usually show depressed food intake during the first 1-2 weeks post-weaning. Intakes can be improved by feeding liquid diets, using pelleted diets containing high levels of milk products and ensuring adequate, easily accessible water supplies. There are marked reductions in various parameters of digestive development during the first few days post-weaning. These include stunting of the villous architecture of the small intestine, reductions in activity of intestinal enzymes, reduced absorption of xylose in *vivo* and of alanine *in vitro.* However, in pigs not infected with *E. coli,* digestibility of weaner diets remains high indicating that there is considerable over-capacity in the digestive tract. The immediate post-weaning period poses a high risk of enteric (mainly haemolytic *E. coli)* infection. The reasons for this have not been fully elucidated but a number of factors, probably interrelated, can be identified as being involved to a greater or lesser extent. These include (a) loss of intrinsic factors present in sows' milk (b) increased flow of nutrients to the lower gut due to lower digestibility of weaner diets (c) alterations in mucosal integrity as a result of the villous stunting observed (d) the appearance of specific oligiosaccharide receptors (e) interaction with rotavirus infection (f) immune-mediated damage from dietary antigens (g) immuno-suppressive effects of stress-related hormones eg corticosteroid (h) changes in the antimicrobial activity of the commensal flora. Oral vaccination of the dam provides some degree of protection to sucking and weaned pigs but oral vaccination of the piglets prior to weaning is of no additional benefit. Intake of a very low dose of a pathogenic organism prior to weaning can be sufficient to precipitate *E. coli* scour in the post-weaning period. Provided that severe dehydration does not occur pigs recover spontaneously within 3-7 d. High-fibre diets may be of some benefit in ameliorating the effects of E. *coli* but dietary approaches to preventing *E. coli* proliferation appear to be unviable. The role of probiotics in preventing or ameliorating post-weaning scour remains to be confirmed though some encouraging results have been reported from field studies.

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INTRODUCTION

Whether pigs are weaned at 2 or 6 weeks of age the first 2 weeks post-weaning represent a period of adaptation and potential stress and can be regarded as one of the most critical periods in the production cycle. The objectives during this period may be summarised as:

1. Minimize scour, gut oedema etc and avoid mortality
2. Minimize the severity of the inevitable growth check
3. Establish satisfactory appetite
4. Minimize weight spread within groups.

The major factors contributing to the achievement of these objectives are (1) proper hygiene/management, (2) adequate environment (temperature, ventilation), (3) diet composition, physical form and feeding regimen. The need for good hygiene is recognised by every responsible pig producer. However, enteric disease frequently occurs in the weaned pig despite what would be regarded as good management conditions. Although the importance of ambient temperature and ventilation has been recognised by research workers it is perhaps not always given sufficient attention on the farm. Over the last 30 years a large amount of research has been concentrated on the digestive development and dietary requirements of the young pig and on its susceptibility to disease. Within the last 10 years the nutrition/disease interaction has been under scrutiny in many laboratories around the world. The main aim of this paper will be to attempt to summarize our present state of knowledge on these aspects and discuss the implications for the pig producer.

DIGESTIVE DEVELOPMENT IN THE SUCKLED PIG

The main features of digestive development are (a) the anatomical and morphological changes in stomach and small intestine (SI) particularly the villous and crypt architecture of the small intestine (b) changes in rates of secretion of gastric acid, pancreatic enzymes etc and in the activity of brush-border enzymes associated with carbohydrate digestion (c) establishment of a stable intestinal flora (d) changes in the rates of fluid secretion/resorption in the small and large intestines.

Structure and function of the intestinal epithelium

The digestive tract of monogastric animals is lined almost entirely with a single layer of columnar epithelium (Eastwood 1977) forming the mucosal membrane. This membrane, which is involved in digestion and absorption and functions as a physical barrier to the penetration of potentially harmful agents, is continuously being renewed. The surface area is maximised by the presence of finger-like projections or villi along the surface. Cells are shed from the tips of the villi and renewed by cell division in the crypts of Lieberkuhn. Secretion occurs in the lower regions of the villi (less mature cells) and absorption in the more mature cells further along the villi. In the young sucking pig the villi are long and narrow. They are longer in gnotobiotic than in conventional pigs and begin to shorten by around 3 weeks of age. Crypt hyperplasia is observed at this stage indicating a change in the kinetics of enterocyte turnover. This may be partly due to the intake of contaminating material eg sows' faeces, since more rapid deterioration occurred in pigs with access to feed and faeces than in 'clean' pigs (Miller et al. 1986). The control

of cell turnover in the mucosa is very complex involving several hormones, the concentration of various luminal nutrients, the bacterial flora and the toxins which they produce, and immunological responses to food constituents, viruses and other antigens.

The gut immune system

Passive immunity The nature of the placenta in the pig prevents transfer of macromolecules eg immunoglobulins from the maternal to the foetal circulation. Hence, the newborn pig is dependent on circulating maternal antibodies and other factors from colostrum and milk for disease resistance. This so-called passive immunity protects the pig for the first 3 to 4 weeks by which stage the pig begins to develop its own 'active' immune system. The immune system can be considered as functioning at 2 levels - the systemic system and the gut which provides a barrier against orally ingested pathogens. During the first 48 h colostrum provides mainly IgG which is absorbed into the serum. Subsequently the main immunoglobulin in milk is IgA which provides protection within the SI by eliminating potential pathogens (Porter, Parry and Allen 1977). In addition to the immunoglobulins in milk there are also a number of non-specific defence factors. These include lactoferrin and lysozyme (Johansson 1960) and the lactoperoxidase system (Reiter et al. 1964).

Active immunity The mucosal surface is faced with a large number of new antigenic challenges during the first few weeks. Both immunologic and non-immunologic mechanisms are involved in protecting the mucosa. The latter include gut peristalsis, indigenous microflora, the mucin layer, hydrochloric acid production and the presence of bile salts (Byrne 1980). Once the immune system begins to develop, antibodies are secreted. Oral immunization with killed *E. coli* resulted in increased levels of IgA in intestinal secretions (Watson et al. 1979). Similarily administration of *L. casei* resulted in stimulation of humoral immunity and also induced a local antibody response to intero pathogens (Perdigon et *at*. 1988).

Digestive enzyme activity in the stomach and small intestine

Stomach The major changes in the stomach are the development of gastric acid secretion and increases in the activity of pepsin and trypsin (Lewis et al. 1957; Cranwell 1977). Gastric acid production occurs from birth but the lactic acid production which occurs with milk appears to depress the development of acid secretion which responds to creep consumption or early weaning (Cranwell et al. 1976). The ability to maintain a low stomach pH may be important in inhibiting oral infection by pathogenic bacteria (Fuller 1986). The contribution of gastric proteolysis to protein digestion in pigs younger than 28 d is minor (Braude et al. 1970). The pancreatic secretions and the brush-border enzymes in the small intestine are apparently of relatively greater importance in digestive development.

Intestinal enzymes Lactase activity is high at birth and remains high in the suckled pig up to 5 weeks of age (Walker 1959). Sucrase activity increases rapidly from negligible levels at birth (Walker 1959) and is adequate to deal with up to 35% sucrose in the diet by 2 weeks of age (Lucas and Lodge 1961). The brush-border glucoamylase activity is the combined activity of a range of a-glucosidases which Dahlqvist (1961) classified as maltases 1A, 1B, II and III on the basis of heat stability. The former two are mainly active towards isomaltose and sucrose respectively whereas maltase II and III act on the

products of starch digestion and hence assume major importance in the post-weaning stage. They respond rapidly to substrate (Kelly et al. 1990a) and it would seem logical that consumption of creep-feed prior to weaning would enhance post-weaning performance. However, this has not been proven.

Pancreatic secretions The pancreas is the main source of proteolytic enzymes (trypsin, chymotrypsin, elastase and carboxypeptidase), and also produces amylase which digests starch, and lipase which is involved in fat digestion. Trypsin, chymotrypsin, and lipase are all relatively high at birth and activity rises during the first few weeks. The level of α-amylase is low at birth. It increases fairly rapidly and the young pig can digest significant quantities of cooked starch even by 7 d of age (Cunningham 1959). It was widely believed that the pig cannot readily digest raw cereal starch prior to 3 weeks of age (Lucas and Lodge 1961). However, pigs weaned at 10 d showed normal digestive capacity with diets containing up to 17% raw wheat in addition to 25% flaked maize (McCracken and Patterson 1980) and pigs weaned at 14 d performed moderately well on a diet containing 22% raw cereal and 12% soya bean meal (McCracken and Patterson 1981). There is considerable evidence that chymotrypsin, trypsin and a-amylase all increase in response to substrate induction.

The indigenous gut flora

The alimentary tract of the healthy pig is bacteriologically sterile at birth (Kenworthy and Crabb 1963). During the first day the tract is flooded with bacteria of maternal origin and from the external environment and a wide range of bacteria, both strict and faculative anaerobes, become established. McAllister et al. (1979) reported that all groups of bacteria examined were present in the lowest numbers in the stomach and anterior small intestine and tended to increase through to the colon. Numbers of the order 109 to 1011 per gram digesta are found in the lower small intestine. Comparisons of germ-free and conventional animals showed that bacterial colonization results in decreased mucosal surface area and increased crypt depth (Abrams et al. 1963) and cell turnover of the mucosa occurs at a faster rate (Rolls et al. 1978). A wide range of environmental factors contribute to the maintenance of a stable indigenous flora. These include the host immune status, presence of specific receptor sites, availability of nutrients such as bile,, mucin and digesta, digesta flow and the oxygen reduction potential (Stewart et al. 1993). The indigenous flora functions as a protective barrier and is considered to play a major role in the suppression of pathogens. This has led to the development of probiotic strategies involving the application of beneficial organisms such as lactic acid producing bacteria normally found in the indigenous flora (Fuller 1992). This will be further discussed at a later stage.

Fluid secretion/resorption in the gut

The fluid balance in the gut is in a dynamic state. Low et al. (1978) observed that the amount of liquid leaving the duodenum was up to 4 times the daily water intake, as a result of the various secretions of the stomach, pancreas, bile etc. Most of this is resorbed in the ileum in the healthy pig with further resorption occurring in the large intestine. If the delicate balance of absorption/secretion is upset by increased secretion or reduced absorption dehydration and death can occur very quickly.

CONSEQUENCES OF WEANING

It is probable that pigs weaned at 6 weeks of age or later will already be consuming large quantities of cereal-based feed, have a reasonably developed active immune system and suffer a relatively small set-back at weaning. However, many pigs are now weaned at between 2-4 weeks of age. At this stage they are still relatively immature and the normally abrupt removal from the dam to a new environment, social group and diet can be regarded as fairly stressful challenge. Frequently food (and water) intake is low for at least the first 24 hours. Food intake may remain low for several days, not necessarily due to any inability to utilize the diet (Kelly et al. 1991a) but probably more related to the behavioural adjustment required. This low food intake has important implications for the thermal comfort of the pig, for maintenance of its body reserves of fat and for the course of digestive development.

Air temperature

One effect of reduced feed intake is a rapid fall in heat production which means that the lower critical temperature (the temperature above which the pig is comfortable and does not have to waste energy by shivering) is increased. Low temperatures will accentuate weight loss in the immediate post-weaning period and may reduce feed intake thus compounding the problem. Furthermore low temperature, fluctuating temperatures and draughts have all been implicated as factors reducing disease resistance and increasing the risks of scour and mortality (Feenstra 1985).

Studies in Belfast on pigs weaned at 14 or 28 d onto perforated floors suggest that, in still-air conditions, an air temperature of around 26°C is desirable during the first week post-weaning (McCracken and Caldwell 1980; McCracken and Gray 1984). If appetite is satisfactory the temperature may then be decreased approximately 1°C per day to 20°C. This recommendation is about 4°C lower than calculated from the Bruce and Clark (1979) model but is still regarded as a 'safe' recommendation in view of results obtained in a growth trial with 10 d weaned pigs where temperature was reduced more quickly than in the above scheme (McCracken, Caldwell and Walker 1979) and in the study of Feenstra (1985) where a temperature of 18 °C from weaning proved satisfactory. However these recommendations only apply in draught-free conditions and in the absence of acute disease problems.

High temperatures are undesirable in that; (a) feed intake may be inhibited, (b) they reduce humidity especially if outside temperatures are low and can lead to respiratory problems, (c) they are costly to provide if external temperatures are low.

Dietary factors affecting post-weaning food intake

There are a number of interrelated factors which influence post-weaning intake, including diet composition (palatability), physical form, free access to water and stimulation by frequent presentation of feed. Diets containing milk products are more readily consumed than cereal-based diets (McCracken and Patterson 1981) and the inclusion of sucrose or flavours is considered to stimulate intake. Liquid diets are more readily accepted druing the first few days but unless it is intended to continue with liquid feeding the early benefit tends to be lost when the liquid feed is discontinued (Patterson, personal communication). Offering liquid skim in limited quantities was found to provide a cheap and effective means of stimulating food intake (McCracken unpublished) but free access to skim milk can inhibit consumption of dry feed. Dry meal as opposed to

pellets appears to increase intake but this is due to increased spillage (McCracken and Patterson 1981) and actual intakes are usually higher with pelleted feed. Recently the need for water flows in excess of 400 ml/min at nipple drinkers has been identified as a source of poor feed intake post-weaning (Barber et al. 1988).

Changes in structure and function of small intestine mucosa

Immediately following weaning the villi become shortened and stunted. This can occur as a result of a 24 h fast (Hampson 1983) but shortening still occurs even if food intake is maintained at a reasonable level by tube-feeding (Kelly et al. 1991b). As discussed later it seems that the diet-induced hypersensitivity theory of Miller et al. (1982) does not explain the effects observed and it seems probable that the removal of sows' milk is involved. This could be partly the protective effects of IgA, the continuous flow of substrate maintaining a lactic fermentation and a high lactobacilli population, or the loss of an intrinsic constituent such as epidermal growth factor (O'Loughlin et al. 1985).

The effects are frequently at their worst by around day 5 post-weaning. Mean villus length was reduced by 50% in pigs tube-fed a milk/cereal based diet for 3, 5 or 7 d post-weaning (Kelly 1985). Crypt depth increased by approximately 23% in the lower ileum by 3 d post-weaning and by a similar amount in the upper jejunum by 7 d post-weaning (Kelly 1985) in pigs which remained healthy and gained 130 g/d. Such changes would be expected to increase the proportion of secretory cells and reduce the absorptive capacity of the mucosa. For example, Smith (1984) demonstrated that alanine absorption *in vitro* was decreased to less than 50% in pigs at 5 d post-weaning compared with unweaned controls and xylose absorption has frequently been found to decrease *in vivo* during the post-weaning period (eg Miller et al. 1984).

Changes in mucosal enzyme activities

There is general agreement that lactase activity falls rapidly following weaning and does not recover (Miller et al. 1986; Hampson and Kidder 1986; Kelly et al. 1991b). The evidence for sucrase and the maltases is confounded by the type of diet used, the level of intake, disease incidence and basis of measurement eg specific activity, total activity. In the study of Kelly et al. (1991b) sucrase activity increased during the 7 d post-weaning but less than that observed in suckled pigs. Total glucoamylase increased rapidly to levels approximately 10 times those observed at weaning and to at least twice the levels observed in suckled pigs of the same age. In the studies of Hampson and Kidder (1986) sucrase activity fell from pre-weaning values during the first week. Subsequently the activities of all the enzymes except lactase increase rapidly (McCracken 1981; Shields et al. 1980; Efird et al, 1982).

Changes in pancreatic secretions

Following weaning the weight of the pancreas increases rapidly (McCracken 1981; Efird et al. 1982; Lindemann et al. 1986). This has sometimes been attributed to the presence of trypsin inhibitors in soya based diets. However, the effect occurred with a milk-based diet-(Efird et al. 1982) and it appears that it is more probably an adaptive physiological response. The levels of the enzymes in the pancreas are frequently found to be reduced after weaning. However, levels of tryspin and chymotrypsin were higher in intestinal contents of weaned pigs (Efird et al. 1982) and adaptive responses in α-amylase secretion were observed in our laboratory (McCracken unpublished). It seems therefore

at incrased secretion from the pancreas probably results in increased rates of production trypsin, chymotrypsin and a-amylase which initially fail to keep pace with the outflow, ading to lowered contents in the pancreas. Rapid increases occur in pancreatic content ıring the second and third week post-weaning (McCracken unpublished; Efird et al.)82; Lindemann 1986). However pancreatic lipase activity falls dramatically following 'eaning and does not appear to recover (Efird et al. 1982), presumably reflecting the large ecrease in fat ingestion on weaner diets and decreased outflow from the pancreas.

Consequences of changes for nutrient digestibility

In view of the evidence that protease and especially carbohydrase activity is limited n the young pig and that weaning causes a temporary reduction *in vitro* and *in vivo* in ıbsorption of amino-acids and the free sugar xylose it has frequently been assumed that digestibility is poor during the post-weaning period (eg Hampson 1983). However, McCracken et al. (1980) examined the digestibility of flaked maize, included at up to 60% of the diet for pigs 11-16 d of age, and concluded that the digestibility coefficients (0.87) for dry matter and energy were almost as high as the values found in pigs weighing 50 kg. Subsequently, McCracken and Patterson (1980) measured the apparent digestibility of energy and protein in diets containing up to 17% ground wheat, 5-10 d and 20-25 d after weaning at 10 d of age. The digestibility coefficients were similar during both periods and in line with the calculated values for the diets using figures obtained in older pigs. It is difficult to obtain accurate measurements during the immediate post-weaning period but Kelly et al. (1991a) tube-fed pigs for 5 d from weaning at 14 d on a low (250 g) or high (950 g) intake of a cereal-based diet. Since the pigs were slaughtered it was possible to correct for stomach and large intestine contents. The energy digestibility coefficients (0.904 and 0.898 respectively) were not significantly different and the values were close to those expected from the ingredient composition. Protein digestibility was slightly reduced ($P<0.05$) with the high intake (0.871 and 0.848 respectively). The amount fed was almost twice that normally consumed by pigs offered pellets to appetite. It would therefore appear that there is considerable excess digestive capacity even in pigs at 2 weeks of age and that the low food intakes observed are not directly related to digestive capacity.

Changes in gut flora and effects of *e. coli* infection

There are several reports which suggest that the intestinal flora in healthy pigs is little affected by weaning (Kenworthy and Crabb 1963; Kovacs et al. 1972; Barrow et al. 1977). However McAllister et al. (1979) observed a decline in the numbers of aerobes, lactobacilli, bacteroides and clostridia in pigs weaned at 5 weeks compared to unweaned controls and we observed a shift in the Lactobacillus/*E. coli* ratio in the anterior region of the SI 3 days post-weaning (Kelly et al. 1984).

The **E.** *coli* population frequently shifts from non-haemolytic to predominantly haemolytic organisms (Kenworthy and Crabb 1963; Smith and Jones 1963; Kovacs et al. 1972; McAllister et al. 1979). These strains are frequently enterotoxigenic and hence produce toxins which interfere with the normal steady state of absorption of salt and water resulting in uncompensated net secretion of water, sodium and bicarbonate (Smith and Halls 1967; Sharp 1973), the results of which are scour, dehydration and, in severe cases, mortality.

In young pigs K88 positive **E.** *coli* are the predominant cause of diarrhoea. The K88 fimbrial adhesin mediates specific attachment to the mucosal surface and accumulating

evidence suggests that carbohydrate recognition is the principal mechanism of fimbrial intestinal interactions (Erickson et al. 1992). Predisposition to infection by adhesive enterotoxigenic organisms is thought to involve several factors. These include (a) the loss of protective factors present in sows' milk, particularly the IgA fraction, (b) an increase in nutrients eg protein and iron reaching the lower intestine and improving the competitive status of the pathogenic strains, (c) the altered mucosal integrity associated with villous stunting, (d) the appearance of specific oligosaccharide receptors (e) interaction with rotavirus infection (Lecce et al. 1983), (f) immunosuppressive effects of elevated levels of corticosteroids (Worsaae and Schmidt 1980) which may reduce the efficiency of the weaned animal to inactivate and eliminate diarrhoeal-inducing agents, (g) immune-mediated damage from dietary antigens (Miller et al. 1982) tending to increase secretion and reduce absorption, (h) changes in the composition activity of the commensal flora.

The extent to which these various factors interact is difficult to define and their relative importance remains a matter for speculation and controversy. It now seems unlikely that the hypersensitivity theory proposed by Miller et al. (1982, 1983, 1984) is of major importance. Firstly, we (Kelly et al. 1990b) and Fowler (personal communication) have failed to demonstrate any significant difference in disease susceptibility between supposedly 'sensitised' pigs and controls and have failed to 'tolerise' pigs by ensuring large intakes of creep feed prior to weaning. Furthermore, Wilson et al. (1986) have demonstrated that intra-epithelial lymphocytes (IEL), which had been implicated by Miller et al. (1985) in the hypersensitivity theory, are unresponsive *in vitro* (do not proliferate in the presence of nonspecific mitogen) in pigs under 7 weeks of age. Kelly et al. (1990a) observed similar numbers of IEL in pigs which had been abruptly weaned, 'primed' or 'tolerised' and Stokes et al. (1987) have reported that they were unable to repeat the early studies showing immune responses to dietary antigen.

A futher aspect of the **E.** *coli* story is of particular practical interest and relevance. Miller et al. (1984) and Kelly et al. (1986) have demonstrated that a very low dose (103 organisms) of a K88 positive **E.** *coli* given at around 1 week of age remains viable within the gut without proliferation until around 5 d post-weaning and then results in a high incidence of scour. In most cases the haemolytic K88 positive strain is excreted is almost pure form in the faeces for several (3-6) days and then the infection spontaneously disappears and the *E. coli* population reverts to being mainly non-haemolytic. This means that a very low infection in the farrowing accommodation could be a trigger for a much worse infection post-weaning.

Oral doses of the order 105 to 107 organisms are sufficient to trigger proliferation in weaned pigs usually within 12 to 36 h of dosing. Thus the risk of cross-contamination in a group of pigs in solid-floored accommodation is very high and even on wire or slats there is a strong probability of faecal-oral contamination. Furthermore, since the stomach pH remains above 5 for at least 1 or 2 hours after a feed (especially with heavily buffered milk replacers) the stomach provides a suitable environment for multiplication of *E. coli.* This explains how a scour problem can extend over a period of 1 to 2 weeks in a group of pigs as opposed to the relatively short period observed with individually-caged animals.

POTENTIAL FOR DIETARY INTERVENTION TO MINIMIZE *E.* **COLI SCOUR**

Oral vaccination of sows (Nagy et al. 1978) has proved to be an effective means of protecting suckling piglets against **E.** *coli* infection. Varley et al. (1986) extended this concept to the weaned pig (weaned at 24 h after consumption of colostrum). In one study there appeared to be some benefit but this was not confirmed in a follow-up study. Oral

vaccination of the weaned piglets did not improve survival rate at any stage through to 90 kg compared with untreated littermates.

Feed restriction is often advocated in cases where scour is a problem. This may be partially effective with meal diets by minimising the risk of increasing stomach pH or overloading the digestive tract. With pelleted diets feed restriction is likely to be self-defeating since hungry pigs are more likely to 'gorge' themselves and pigs which are slow to accept solid food are penalised thus increasing weight disparities in the group.

The use of diets of high fibre or low-protein content has been advocated (Bertschinger et al. 1978/79). However, the diets which appeared to be effective in preventing scour were of little nutritional value and problems occurred on transfer to normal diets. We have examined the effects of 2 sources of dietary fibre (wheat middlings and carob fibre) in association with *E. coli* challenge. In both cases there was no reduction in the incidence of *E. coli* proliferation or scour but there was a small reduction in the severity and duration of scour. The results with wheat middlings (Kelly 1985) were encouraging but the numbers of pigs used was too small to draw any firm conclusion.

The results of Miller et al. (1984) and Hampson (1986) suggest that hydrolysed protein may be beneficial. This could be due to an enhancement of absorption in the anterior part of the intestine or to a reduction in antigenicity. However, hydrolysed protein is too expensive to be considered commercially even if benefit was proven.

There has been increasing interest in the use of probiotics. These are microbial preparations (predominantly lactic acid bacteria) which are regarded as having antimicrobial activity against *E. coli.* At present, most of the published work is based on field studies performed by manufacturers and very few trials have been reported in scientific journals. Fuller (1986) has summarised the available information and has stressed the lack of scientific proof. However, results in field studies do appear promising and it is likely that they can be further exploited. The use of natural dietary constituents such as lectins and oligosaccharides to interfere with pathogen attachment to surface oligosaccharide receptors forms the basis of a new concept referred to as chemical probiosis (Pusztai et al. 1990). The success of this approach requires that feed additives either have a specificity mimicking that of pathogen fimbrial adhesins or that they are analogous to the mucosal receptor site. The prospects for the use of chemical probiotics are considerable but knowledge of the molecular mechanisms of bacterial adhesion is an important prerequisite.

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