and may explain the relative importance of *Clostridium*. In the last part of the digestive tract, the caeca, main components may be composed of dietary molecules not hydrolysable by enzymes of the host, as well as endogenous components difficult to hydrolyze. These substrates may be responsible for the development of caecal bacteria, rich in *Clostridium* that may product SCFA that may increase energy extracted from the diet for the host. In summary, in D+ birds, the digestion and maintenance metabolic cost of the digestive tract may be optimized along the different parts of the digestive tract, with action of the host physiology and enzymes in the upper and middle part, and digestive microbiota in the lower part, leading to minimal wastes.

On the contrary in the D- birds, the under-development of their gizzard, due to failure in the gizzard relaxation process, leads to a lower retention time and a higher pH in the proventriculus-gizzard complex, and seems to be responsible for a part of their lower digestive functionality. It may also be responsible for a different selection of digestive microbiota. Indeed, this smaller proventriculus-gizzard complex development may lead to lower efficiency of gizzard bacterial filter, and thus a greater bacterial load passing in the small intestine. Moreover a higher amount of undigested compounds, probably rich in starch gives a high amount of substrate for bacterial growth, and favor *Lactobacillus* development. The low digestibility in the upper part of the digestive tract may be responsible for the more developed intestine, passing through an increase of epithelium area to try to cope with high undigested compounds, and increase muscle layer to move the higher amount of digestive content. The high bacterial load may be responsible for the higher stimulation of innate digestive immune system by increasing the number of goblet cells, suggesting increased mucus production. These changes in microbiota may be responsible for the lower lipid digestibility, and thus AMEn, due in part to bile acid deconjugation. These modifications in the upper and middle part of the digestive tract may lead to modification also in the lower part, with lower fermentative activity in the caeca with different bacterial composition probably due to a change in available substrates, and this may have an effect on energy recovery in this organ. To cope with this low digestive efficiency, D- birds increase their feed intake, contributing to increased amount of digestive content and with consequences for bacterial growth.

Moreover, contrary to D- birds, D+ birds appeared to be more able to adapt to a diet of low quality such as a diet rich on non-starch polysaccharides of wheat as shown by their lower decrease in AMEn than D- birds fed with wheat of high viscosity. They may have developed a mechanism to be less sensitive to deleterious effects of these hydrosoluble polysaccharides on intestinal viscosity.

However further knowledge in physiology of D+ and D- lines is needed to test these mechanistic biological hypotheses. For example, more information is needed on the motricity and regulation of the gastric emptying as this organ seems to explain an important part of the difference between lines. Moreover, more knowledge is required at the intestinal level. Differences in anatomy of the small intestine have been described, but its digestive functionality is not known, as well as its consequences on digestive efficiency at the end of the small intestine. This knowledge would allow to determine the physiological limiting factors of digestion in order to suggest means to alleviate them. For genetic selection, it may allow to determine how this selection impacts on the phenotype and anticipate any undesirable effects before its introduction in selection schemes. Moreover, it may help to propose a list of candidate genes.

It is also important to know if D+ birds that have been selected by feeding wheat of high viscosity value, are able to adapt to other feedstuffs with other limiting factors in their digestibility. It will also be important to describe these birds in an environment closer to the production environment (on litter with animal groups, not in individual cage), as it would probably affect performances but also microbiota development, among others due to possibility of coprophagy, and then relationships between host, microbiota and digestive performances.

Regarding microbiota, it is important to know when the differences in microbiota composition between D+ and D- lines appear during the development of the birds. Moreover, a more extensive characterization is needed, as minor groups may also largely affect physiology of the host. This characterization may concern as well as the small intestine and the caeca, but also the crop. In addition, the functionality of the microbiota has to be studied, especially regarding to its consequences on the host digestive tract functionality, but also development of digestive immune function that is implied in digestive disease resistance, and consequently on global immune system.

Although relationships have been observed between bacterial groups and AMEn, the results were obtained in specific conditions (wheat diet, cage rearing). Moreover these links do not implied a causality link between these bacterial groups and phenotype such as AMEn, the phenotype being a balance between genotype, environment as diet and rearing conditions, and functionality of the digestive microbiota. Further works are thus needed to determine the involvement of digestive microbiota in digestive efficiency, measured by AMEn.

References

Amerah, A. M., Ravindran, V., and Lentle, R. G. (2009). Influence of insoluble fibre and whole wheat inclusion on the performance, digestive tract development and ileal microbiota profile of broiler chickens. *British Poultry Science*, **50**, 366-375.

Apajalahti, J., Kettunen, A., and Graham, H. (2004). Characteristics of the gastrointestinal microbial communities, with special reference to the chicken. *World's Poultry Science Journal*, **60**, 223-232.

Bäckhed, F., Ding, H., Wang, T., Hooper, L. V., Koh, G. Y., Nagy, A., Semenkovich, C. F., and Gordon, J. I. (2004). The gut microbiota as an environmental factor that regulates fat storage. *Proceedings of the National Academy of Sciences of the United States of America*, **101**, 15718-15723.

Bäckhed, F., Ley, R. E., Sonnenburg, J. L., Peterson, D. A., and Gordon, J. I. (2005). Host-bacterial mutualism in the human intestine. *Science*, **307**, 1915-1920.

Beckmann, L., Simon, O., and Vahjen, W. (2006). Isolation and identification of mixed linked beta -glucan degrading bacteria in the intestine of broiler chickens and partial characterization of respective 1,3-1,4- beta -glucanase activities. *Journal of Basic Microbiology*, **46**, 175-185.

Bedford, M. R., and Cowieson, A. J. (2012). Exogenous enzymes and their effects on intestinal microbiology. *Animal Feed Science and Technology*, **173**, 76-85.

Beno, D. W., Uhing, M. R., Jiyamapa-Serna, V. A., Goto, M., Chen, Y., Vasan, A., Deriy, L. V., and Kimura, R. E. (2003). Differential induction of hepatic dysfunction after intraportal and intravenous challenge with endotoxin and Staphylococcal enterotoxin B. *Shock*, **19**, 352-357.

Binek, M., Borzemska, W., Pisarski, R., Blaszczak, B., Kosowska, G., Malec, H., and Karpinska, E. (2000). Evaluation of the efficacy of feed providing on development of gastrointestinal microflora of newly hatched broiler chickens. *Archiv für Geflügelkunde*, **64**, 147-151.

Bjerrum, L., Engberg, R. M., Leser, T. D., Jensen, B. B., Finster, K., and Pedersen, K. (2006). Microbial community composition of the ileum and cecum of broiler chickens as revealed by molecular and culture-based techniques. *Poultry Science*, **85**, 1151-1164.

Boyd, F. M., and Edwards, H. M. (1967). Fat absorption by germ-free chicks. *Poultry Science*, **46**, 1481-1483.

Cani, P. D., Amar, J., Iglesias, M. A., Poggi, M., Knauf, C., Bastelica, D., Neyrinck, A. M., Fava, F., Tuohy, K. M., Chabo, C., Waget, A., Delmee, E., Cousin, B., Sulpice, T., Chamontin, B., Ferrieres, J., Tanti, J.-F., Gibson, G. R., Casteilla, L., Delzenne, N. M., Alessi, M. C., and Burcelin, R. (2007). Metabolic endotoxemia initiates obesity and insulin resistance. *Diabetes*, **56**, 1761-1772.

Carlstedt, I., Herrman, A., Karlsson, H., Sheehan, J., Fransson, L. A., and Hansson, G. C. (1993). Characterization of two different glycosylated domains from the insoluble mucin complex of rat small intestine. *Journal of Biological Chemistry*, **268**, 18771-18781.

Carré, B. (2002). Carbohydrate chemistry of the feedstuffs used for poultry. In

Poultry feedstuffs : supply, composition and nutritive value - 2002, pp 39-56. Edited by J. M. McNab and K. N. Boorman.CABI Publishing, Wallingford (UK).

Carré, B., Mignon-Grasteau, S., Svihus, B., Péron, A., Bastianelli, D., Gomez, J., Besnard, J., and Sellier, N. (2005). Nutritional effects of feed form, and wheat compared to maize, in the D+ and D- chicken lines selected for divergent digestion capacity. In *15th European Symposium on Poultry Nutrition – 2005*, pp 42-44. Edited by World Poultry Science Association, Budapest (Hungary).

Carré, B., Mignon-Grasteau, S., Péron, A., Juin, H., and Bastianelli, D. (2007). Wheat value: improvements by feed technology, plant breeding and animal genetics. *World's Poultry Science Journal*, **63**, 585-596.

Carré, B., Mignon-Grasteau, S., and Juin, H. (2008). Breeding for feed efficiency and adaptation to feed in poultry. *World's Poultry Science Journal*, **64**, 377-390.

Caviedes-Vidal, E., McWhorter, T. J., Lavin, S. R., Chediack, J. G., Tracy, C. R., and Karasov, W. H. (2007). The digestive adaptation of flying vertebrates: High intestinal paracellular absorption compensates for smaller guts. *Proceedings of the National Academy of Sciences of the United States of America*, **104**, 19132-19137.

Champ, M., Szylit, O., and Gallant, D. J. (1981). The influence of microflora on the breakdown of maize starch granules in the digestive tract of chicken. *Poultry Science*, **60**, 179-187.

Choct, M., Hughes, R. J., and Bedford, M. R. (1999). Effects of a xylanase on individual bird variation, starch digestion throughout the intestine, and ileal and caecal volatile fatty acid production in chickens fed wheat. *British Poultry Science*, **40**, 419-422.

Clench, M. H. (1999). The avian cecum: update and motility review. *Journal of Experimental Zoology*, **283**, 441-447.

Coates, M. E. (1980). The gut microflora and growth. In *Growth in animals – 1980*, pp 175-188. Edited by T. L. J. Lawrence. Butterworths, London (UK).

Collado, M. C., and Sanz, Y. (2007). Characterization of the gastrointestinal mucosa-associated microbiota of pigs and chickens using culture-based and molecular methodologies. *Journal of Food Protection*, **70**, 2799-2804.

Crévieu-Gabriel, I., Gomez, J., Caffin, J. P., and Carré, B. (1999). Comparison of pig and chicken pepsins for protein hydrolysis. *Reproduction Nutrition Development*, **39**, 443-454.

Crévieu-Gabriel, I., and Naciri, M. (2001). Dietary effect on chicken coccidiosis. *INRA Productions Animales*, **14**, 231-246.

Crhanova, M., Hradecka, H., Faldynova, M., Matulova, M., Havlickova, H., Sisak, F., and Rychlik, I. (2011). Immune response of chicken gut to natural colonization by gut microflora and to Salmonella enterica serovar enteritidis infection. *Infection and Immunity*, **79**, 2755-2763.

Danzeisen, J. L., Kim, H. B., Isaacson, R. E., Tu, Z. J., and Johnson, T. J. (2011). Modulations of the chicken cecal microbiome and metagenome in response to anticoccidial and growth promoter treatment. *PLoS One*, **6**, e27949.

Denbow, D. M. (1999). Gastrointestinal anatomy and physiology. In *Sturkie's Avian Physiology -1999*, pp 299-325. Edited by P. D. Sturkie. Academic Press, San Diego (USA).

De Oliveira, J. E., Scott, T. A., van der Vossen, J. M. B. M., Ouwens, A. M. T., Hangoor, E., and Montijn, R. C. (2010). Establishing beneficial bacteria in the gut of chickens prior to hatching. In *2nd TNO Beneficial Microbes Conference - 2010*, pp 44. Noordwijkerhout (the Netherland).

de Verdal, H., Mignon-Grasteau, S., Jeulin, C., Le Bihan-Duval, E., Leconte, M., Mallet, S., Martin, C., and Narcy, A. (2010a). Digestive tract measurements and histological adaptation in broiler lines divergently selected for digestive efficiency. *Poultry Science*, **89**, 1955-1961.

de Verdal, H., Narcy, A., Le Bihan-Duval, E., and Mignon-Grasteau, S. (2010b). Excretion and gastro-intestinal tract development in chickens divergently selected on their capacity of digestion. In *XIIIth European Poultry Conference – 2010*, 6 pages, Tours (France).

de Verdal, H. (2011a). Genetic selection in view of limiting excretion in chickens. Thesis, 327 pages. Univ. Tours, François Rabelais (France).

de Verdal, H., Narcy, A., Bastianelli, D., Chapuis, H., Même, N., Urvoix, S., Le Bihan-Duval, E., and Mignon-Grasteau, S. (2011b). Improving the efficiency of feed utilization in poultry by selection. 1. Genetic parameters of anatomy of the gastro-intestinal tract and digestive efficiency. *BMC Genetics*, **12**, DOI: 10.1186/1471-2156-12-59.

de Verdal, H., Narcy, A., Bastianelli, D., Chapuis, H., Même, N., Urvoix, S., Le Bihan-Duval, E., and Mignon-Grasteau, S. (2011c). Improving the efficiency of feed utilization in poultry by selection. 2. Genetic parameters of excretion traits and correlations with anatomy of the gastro-intestinal tract and digestive efficiency. *BMC Genetics*, **12**, DOI: 10.1186/1471-2156-12-71.

de Verdal, H., Narcy, A., Chapuis, H., Bastianelli, D., Même, N., Le Bihan-Duval, E., and Mignon-Grasteau, S. (2011d). Genetic selection in view of limiting excretion in chickens. In *Journées de la Recherches Avicoles* - 2011, pp 212-216. Tours (France).

Diamond, B., Huerta, P. T., Tracey, K., and Volpe, B. T. (2011). It takes guts to grow a brain : Increasing evidence of the important role of the intestinal microflora in neuro- and immune-modulatory functions during development and adulthood. *Bioessays*, **33**, 588-591.

Dibner, J. J., Richards, J. D., and Knight, C. D. (2008). Microbial imprinting in gut development and health. *Journal of Applied Poultry Research*, **17**, 174-188..

Dicksved, J., Halfvarson, J., Rosenquist, M., Jarnerot, G., Tysk, C., Apajalahti, J., Engstrand, L., and Jansson, J. K. (2008). Molecular analysis of the gut microbiota of identical twins with Crohn's disease. *ISME Journal*, **2**, 716-727.

Dijk, A. v (2008). Avian defensins. *Veterinary Immunology and Immunopathology*, **124**, 1-18.

Dockès, A. C., Magdelaine, P., Daridan, D., Guillaumin, A., Remondet, M., Selmi, A., Gilbert, H., Mignon-Grasteau, S., and Phocas, F. (2011). Farming and breeding goals for sustainable animal breeding - views and expectations of stakeholders from the production chains and the general public. *INRA Productions Animales*, **24**, 285-296.

Duke, G. E. (1986). Alimentary canal : secretion and digestion, special digestive functions, and absorption. In *Avian Physiology – 1986*, pp 289-302. Edited by P. D. Sturkie. Springer Verlag, New york (USA).

Eeckhaut, V., Van Immerseel, F., Croubels, S., De Baere, S., Haesebrouck, F., Ducatelle, R., Louis, P., and Vandamme, P. (2011). Butyrate production in phylogenetically diverse Firmicutes isolated from the chicken caecum. *Microbial Biotechnology*, **4**, 503-512.

Engberg, R. M., Hedemann, M. S., Leser, T. D., and Jensen, B. B. (2000). Effect of zinc bactracin and salinomycin on intestinal microflora and performance of broilers. *Poultry Science*, **79**, 1311-1319.

Ferrando, C., Vergara, P., Jimenez, M., and Gonalons, E. (1987). Study of the rate of passage of food with chromium-mordanted plant-cells in chickens (*Gallus-Gallus*). *Quarterly Journal of Experimental Physiology and Cognate Medical Sciences*, **72**, 251-259.

Fonty, G., and Chaucheyras-Durand, F. (2008). *Digestive ecosystems*, 311 pages. Edited by J.P. Larpent. Lavoisier, Paris (France).

Forstner, J. F., and Forstner, G. G. (1994). Gastrointestinal mucus. In *Physiology of the gastrointestinal tract – 1994*, pp 1255-1283. Edited by L.R. Johnson. Raven Press, New York (USA).

Freestone, P. P., Sandrini, S. M., Haigh, R. D., and Lyte, M. (2008). Microbial endocrinology: how stress influences susceptibility to infection. *Trends in Microbiology*, **16**, 55-64.

Fritz, J. C., Burrowsandh, W. H., and Titus, H. W. (1936). Comparison of digestibility in gizzardectomized and normal fowls. *Poultry Science*, **15**, 239-243.

Fuller, R. (1984). Microbial activity in the alimentary tract of birds. *Proceedings of the Nutrition Society*, **43**, 55-61.

Furuse, M., and Okumura, J. (1994). Nutritional and physiological characteristics in germ-free chickens. *Comparative Biochemistry and Physiology*, **109A**, 547-556.

Gabriel, I., Mallet, S., and Leconte, M. (2003). Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or whole wheat added to pelleted protein concentrate. *British Poultry Science*, **44**, 283-290.

Gabriel, I., Lessire, M., Mallet, S., and Guillot, J. F. (2006). Microflora of the digestive tract: critical factors and consequences for poultry. *World's Poultry Science Journal*, **62**, 499-511.

Gabriel, I., Leconte, M., Guillon, J., Rideaud, P., Moreau-Vauzelle, C., and Dupont, C. (2007). Individual variability in the digestive flora of the broiler chicken analysed by molecular fingerprint. In *16th European Symposium on Poultry Nutrition – 2007*, pp 305-308 Strasbourg (France).

Gabriel, I., Guardia, S., Konsak, B., Leconte, M., Rideaud, P., Moreau-Vauzelle, C., Dupont, C., and Mignon-Grasteau, S. (2011). Comparison of chicken digestive microbiota selected on their metabolizable energy. In *9emes Journees de la Recherche Avicole - 2011*, pp 760-764, Tours (France).

Garcia, V., Gomez, J., Mignon-Grasteau, S., Sellier, N., and Carré, B. (2007). Effect of xylanase and antibiotic supplementations on the nutritional utilisation of a wheat diet in growing chicks from genetic D+ and D- lines selected for divergent digestion efficiency. *Animal*, **1**, 1435-1442.

Gong, J., Si, W., Forster, R. J., Huang, R., Yu, H., Yin, Y., Yang, C., and Han, Y. (2007). 16S rRNA gene-based analysis of mucosa-associated bacterial community and phylogeny in the chicken gastrointestinal tracts: from crops to ceca. *FEMS Microbiology Ecology*, **59**, 147-157.

Gong, J., Yu, H., Liu, T., Gill, J. J., Chambers, J. R., Wheatcroft, R., and Sabour, P. M. (2008). Effects of zinc bacitracin, bird age and access to range on bacterial microbiota in the ileum and caeca of broiler chickens. *Journal of Applied Microbiology*, **104**, 1372-1382.

Guban, J., Korver, D. R., Allison, G. E., and Tannock, G. W. (2006). Relationship of dietary antimicrobial drug administration with broiler performance, decreased population levels of *Lactobacillus salivarius*, and reduced bile salt deconjugation in the ileum of broiler chickens. *Poultry Science*, **85**, 2186-2194.

Guardia, S., Furet, J. P., Recoquillay, F., Juin, H., Lessire, M., Leconte, M., Rideaud, P., Moreau-Vauzelle, C., Dupont, C., Guillot, J.F., and Gabriel, I. (2009). A comparison of two methods to extract bacterial DNA of the digestive tract. In *6th International Symposium of Anaerobic Microbiology - 2009*, pp 39-40. Liblice (Czech republic).

Guardia, S., Konsak, B., Juin, H., Lessire, M., Rideaud, P., Moreau-Vauzelle, C.,

Dupont, C., Guillot, J. F., and Gabriel, I. (2011). Effects of stocking density on growth performance and digestive microbiota of broiler chickens. *Poultry Science*, **90**, 1878-1889.

Gulati, A. S., Shanahan, M. T., Arthur, J. C., Grossniklaus, E., von Furstenberg, R. J., Kreuk, L., Henning, S. J., Jobin, C., and Sartor, R. B. (2012). Mouse background strain profoundly influences Paneth cell function and intestinal microbial composition. *PLoS One*, **7**, e32403.

Hetland, H., and Svihus, B. (2001). Effect of oat hulls on performance, gut capacity and feed passage time in broiler chickens. *British Poultry Science*, **42**, 354-361.

Hong, W., Wu, Y. E., Fu, X., and Chang, Z. (2012a). Chaperone-dependent mechanisms for acid resistance in enteric bacteria. *Trends in Microbiology*, **20**, 30-39.

Hong, Y. H., Song, W., Lee, S. H., and Lillehoj, H. S. (2012b). Differential gene expression profiles of -defensins in the crop, intestine, and spleen using a necrotic enteritis model in 2 commercial broiler chicken lines. *Poultry Science*, **91**, 1081-1088.

Hooper, L. V., Wong, M. H., Thelin, A., Hansson, L., Falk, P. G., and Gordon, J. I. (2001). Molecular analysis of commensal host-microbial relationships in the intestine. *Science*, **291**, 881-884.

Hooper, L. V., Midtvedt, T., and Gordon, J. I. (2002). How host-microbial interactions shape the nutrient environment of the mammalian intestine. *Annual Review of Nutrition*, **22**, 283-307.

Hooper, L. V., and Macpherson, A. J. (2010). Immune adaptations that maintain homeostasis with the intestinal microbiota. *Nature Reviews Immunology*, **10**, 159-169.

Huyghebaert, G., Ducatelle, R., and Van Immerseel, F. (2011). An update on alternatives to antimicrobial growth promoters for broilers. *Veterinary Journal*, **187**, 182-188.

Iiboshi, Y., Nezu, R., Cui, L., Chen, K., Khan, J., Yoshida, H., Sando, K., Kamata, S., Takagi, Y., and Okada, A. (1996). Adhesive mucous gel layer and mucus release as intestinal barrier in rats. *Journal of Parenteral and Enteral Nutrition*, **20**, 98-104.

Inglis, G. D., Thomas, M. C., Thomas, D. K., Kalmokoff, M. L., Brooks, S. P., and Selinger, L. B. (2012). Molecular methods to measure intestinal bacteria: a review. *Journal of AOAC International*, **95**, 5-23.

Ismail, A. S., and Hooper, L. V. (2005). Epithelial cells and their neighbors. IV. Bacterial contributions to intestinal epithelial barrier integrity. *American Journal of Physiology - Gastrointestinal and Liver Physiology*, **289**, G779-784.

Jensen, H., Grimmer, S., Naterstad, K., and Axelsson, L. (2012). In vitro testing of commercial and potential probiotic lactic acid bacteria. *International Journal of Food Microbiology*, **153**, 216-222.

Johansson, M. E., Ambort, D., Pelaseyed, T., Schütte, A., Gustafsson, J. K., Ermund, A., Subramani, D. B., Holmén-Larsson, J. M., Thomsson, K. A., Bergström, J. H., van der Post, S., Rodriguez-Piñeiro, A. M., Sjövall, H., Bäckström, M., and Hansson, G. C. (2011). Composition and functional role of the mucus layers in the intestine. *Cellular and Molecular Life Sciences*, **68**, 3635-3641.

Juge, N. (2012). Microbial adhesins to gastrointestinal mucus. *Trends in Microbiology*, **20**, 30-39.

Jozefiak, D., Rutkowski, A., and Martin, S. A. (2004). Carbohydrate fermentation in the avian ceca: a review. *Animal Feed Science and Technology*, **113**, 1-15.

Kim, G. B., and Lee, B. H. (2005). Biochemical and molecular insights into bile salt hydrolase in the gastrointestinal microflora - A review. *Asian-Australasian Journal of Animal Sciences*, **18**, 1505-1512.

Kizerwetter-Swida, M., and Binek, M. (2008). Bacterial microflora of the chicken embryos and newly hatched chicken. *Journal of Animal and Feed Sciences*, **17**, 224-232.

Klasing, K. C., Johnstone, B. J., and Benson, B. N. (1991). Implications of an immune response on growth and nutrient requirements of chicks. In *Recent Advances in Animal Nutrition – 1991*, pp 135-146. Edited by W. Haresign and D. J. A. Cole. Butterworth-Heinemann Ltd, Oxford (UK).

Klis, J. D. v. d., and Lensing, M. (2007). Wet litter problems relate to host-microbiota interactions. *World Poultry*, **23**, 20-22.

Konsak, B., Guardia, S., Leconte, M., Moreau-Vauzelle, C., Dupont, C., Mignon-Grasteau, S., and Gabriel, I. (2011). Comparison of the digestive microbiota between two divergent lines of chickens selected based on digestive capacity. In *7th International Symposium of Anaerobic Microbiology - 2011*, pp 17. Smolenice (Slovakia).

Konsak, B., Guardia, S., Leconte, M., Moreau-Vauzelle, C., Dupont, C., Doré, J., Levenez, F., Mignon-Grasteau, S., and Gabriel, I. (2012). Comparison of the digestive microbiota between two divergent lines of chickens selected based on apparent metabolisable energy. In *8th INRA-Rowett Symposium on Gut Microbiology - 2012*, Clermont-Ferrand (France).

Kussaibati, R., Guillaume, J., and Leclercq, B. (1982a). The effect of gut microflora on the digestibility of starch and proteins in young chicks. *Annales de Zootechnie*, **31**, 483-488.

Kussaibati, R., Guillaume, J., Leclercq, B., and Lafont, J. P. (1982b). Effect of the intestinal microflora and added bile salts on the metabolisable energy and digestibility of saturated fats in the chicken. *Archiv für Geflügelkunde*,

46, 42-46.

Laboisse, C., Jarry, A., Branka, J. E., Merlin, D., Bou-Hanna, C., and Vallette, G. (1996). Recent aspects of the regulation of intestinal mucus secretion. *Proceedings of the Nutrition Society*, **55**, 259-264.

Lartigue, G. d., Barbier de la Serre, C., Espero, E., Lee, J., and Raybould, H. E. (2011). Diet-induced obesity leads to the development of leptin resistance in vagal afferent neurons. *American Journal of Physiology. Endocrinology and Metabolism*, **301**, E187-195.

Lederberg, J. (2000). Infectious history. *Science*, **288**, 287–293.

Lee, Z. M. P., Bussema III, C., and Schmidt, T. M. (2009). rrnDB: documenting the number of rRNA and tRNA genes in bacteria and archaea. *Nucleic Acids Research*, **37**, D489-D493.

Lu, J., Idris, U., Harmon, B., Hofacre, C., Maurer, J., and Lee, M. D. (2003). Diversity and succession of the intestinal bacterial community of the maturing broiler chicken. *Applied Environmental Microbiology*, **69**, 6816-6824.

Lumpkins, B. S., Batal, A. B., and Lee, M. D. (2010). Evaluation of the bacterial community and intestinal development of different genetic lines of chickens. *Poultry Science*, **89**, 1614-1621.

Lund, M., Bjerrum, L., and Pedersen, K. (2010). Quantification of *Faecalibacterium prausnitzii*- and *Subdoligranulum variabile*-like bacteria in the cecum of chickens by real-time PCR. *Poultry Science*, **89**, 1217-1224.

Lyte, M. (2010). The microbial organ in the gut as a driver of homeostasis and disease. *Medical Hypotheses*, **74**, 634-638.

Maisonnier, S., Gomez, J., Bree, A., Berri, C., Baeza, E., and Carré, B. (2003). Effects of microflora status, dietary bile salts and guar gum on lipid digestibility, intestinal bile salts and histo-morphology, in broiler chickens. *Poultry Science*, **82**, 805-814.

Malmuthuge, N., Li, M., Chen, Y., Fries, P., Griebel, P. J., Baurhoo, B., Zhao, X., and Guan, L. L. (2012). Distinct commensal bacteria associated with ingesta and mucosal epithelium in the gastrointestinal tracts of calves and chickens. *FEMS Microbiology Ecology*, **79**, 337-347.

Mathlouthi, N., Mallet, S., Saulnier, L., Quemener, B., and Larbier, M. (2002). Effects of xylanase and b-glucanase addition on performance, nutrient digestibility, and physico-chemical conditions in the small intestine contents and caecal microflora of broiler chickens fed a wheat and barley-based diet. *Animal Research*, **51**, 395-406.

Mead, G. C. (1997). Bacteria in the intestinal tract of birds. In *Gastrointestinal Microbiology: Gastrointestinal Microbes and Host Interactions – 1997*, pp 216-240. Edited by R. I. Mackie, B. A. White and R. E. Isaacson. Vol. 2,

Chapman Hall, Microbiology Series, NewYork (USA).
Menendez, A., and Brett Finlay, B. (2007). Defensins in the immunology of bacterial infections. *Current Opinion in Immunology*, **19**, 385-391.
Merwe, J. P. v d, Stegeman, J. H., and Hazenberg, M. P. (1983). The resident faecal flora is determined by genetic characteristics of the host. Implications for Crohn's disease? *Antonie Van Leeuwenhoek*, **49**, 119-124.
Mignon-Grasteau, S., Muley, N., Bastianelli, D., Gomez, J., Péron, A., Sellier, N., Millet, N., Besnard, J., Hallouis, J. M., and Carré, B. (2004). Heritability of digestibilities and divergent selection for digestion ability in growing chicks fed a wheat diet. *Poultry Science*, **83**, 860-867.
Mignon-Grasteau, S., Juin, H., Sellier, N., Bastianelli, D., Gomez, J., and Carré, B. (2010a). Genetic Parameters of Wheat- or Corn-based Diets in Chickens. In *9th World Congres of Applied Livestock Production – 2010*, 4 pages . Leipzig (Germany).
Mignon-Grasteau, S., Bourblanc, M., Carré, B., Dourmad, J. Y., Gilbert, H., Juin, H., Noblet, J., and Phocas, F. (2010b). Reducing manure in poultry and pig productions by selection. *INRA Productions Animales*, 23, 415-426.
Moore, R. J., Stanley, D., Konsak, B. M., Haring, V. R., Hughes, R. J., Geier, M. S., and Crowley, T. M. (2011). Correlations between variable broiler performance and gene expression and microflora in the gut. In *Proceedings of the 22nd Annual Australian Poultry Science Symposium – 2011*, pp 9-16. Sydney, New South Wales (Australia).
Moreto, M., and Planas, J. M. (1989). Sugar and amino acid transport properties of the chicken caeca. *Journal of Experimental Zoology*, **sup 3**, 111-116.
Muramatsu, T., Nakajima, S., and Okumura, J. (1994). Modification of energy metabolism by the presence of the gut microflora in the chicken. *British Journal of Nutrition*, **71**, 709-717.
Nir, I., Hillel, R., Shefet, G., and Nitsan, Z. (1994). Effect of grain particle size on performance. 2. Grain texture interactions. *Poultry Science*, **73**, 781-791.
Nordentoft, S., Molbak, L., Bjerrum, L., De Vylder, J., Van Immerseel, F., and Pedersen, K. (2011). The influence of the cage system and colonisation of *Salmonella Enteritidis* on the microbial gut flora of laying hens studied by T-RFLP and 454 pyrosequencing. *BMC Microbiology*, **11**, DOI 10.1186/1471-2180-11-187.
Noy, Y., and Uni, Z. (2010). Early nutritional strategies. *World's Poultry Science Journal*, **66**, 639-646.
O'Dell, B. L., Newberne, P. M., and Savage, J. E. (1959). An abnormality of the proventriculus caused by feed texture. *Poultry Science*, **38**, 296-301.
Parsons, C. M., Potter, L. M., Brown, R. D. J., Wilkins, T. D., and Bliss, B. A. (1982). Microbial contribution to dry matter and amino acid content of

poultry excreta. *Poultry Science*, **61**, 925-932..
Pearson, G. R., McNulty, M. S., McCracken, R. M., and Curran, W. (1992). Scanning electron microscopic observations of segmented filamentous bacteria in the small intestine of domestic fowl. *Veterinary Record*, **111**, 365-366.
Pedroso, A. A. (2009). Which came first: the egg or its microbia ? *The Poultry Informed Professional, University of Georgia*, **Issue 107**, July/August 2009, 1-5.
Pelhaitre, A., Mignon-Grasteau, S., and Bertin, A. (2012). Selection for wheat digestibility affects emotionality and feeding behaviours in broiler chicks. *Applied Animal Behaviour Science*, **139**, 114-122.
Péron, A., Gomez, J., Mignon-Grasteau, S., Sellier, N., Besnard, J., Derouet, M., Juin, H., and Carré, B. (2006). Effects of wheat quality on digestion differ between the D+ and D- chicken lines selected for divergent digestion capacity. *Poultry Science*, **85**, 462-469.
Putskam, M., Vizzier-Thaxton, Y., Dozier, W. A., Thaxton, J. P., Roush, W. B., Branton, S. L., Morgan, G. W., Miles, D. M., and Lott, B. D. (2005). Evaluation of stocking density on intestinal microflora of broilers. *Poultry Science*, **84**, 108.
Pym, R. A. E., Nicholls, P. J., Thomson, E., Choice, A., and Farrell, D. J. (1984). Energy and nitrogen-metabolism of broilers selected over 10 generations for increased growth-rate, food-consumption and conversion of food to gain. *British Poultry Science*, **25**, 529-539.
Pym, R. A. E. (1990). Nutritional genetics. In *Poultry Breeding and Genetics - 1990*, pp 847-876. Edited by R. D. Crawford. Elsevier edition, Amsterdam (The Netherlands).
Qu, A., Brulc, J. M., Wilson, M. K., Law, B. F., Theoret, J. R., Joens, L. A., Konkel, M. E., Angly, F., Dinsdale, E. A., Edwards, R. A., Nelson, K. E., and White, B. A. (2008). Comparative metagenomics reveals host specific metavirulomes and horizontal gene transfer elements in the chicken cecum microbiome. *PLoS One*, **3**, e2945.
Ramos-Morales, F. (2012). Acidic pH: Enemy or ally for enteric bacteria? *Virulence*, **3**, 103-106.
Rance, K. A., McEntee, G. M., and McDevitt, R. M. (2002). Genetic and phenotypic relationships between and within support and demand tissues in a single line of broiler chicken. *British Poultry Science*, **43**, 518-527.
Rastogi, R., Wu, M., DasGupta, I., and Fox, G. E. (2009). Visualization of ribosomal RNA operon copy number distribution. *BMC Microbiology*, **9**, doi: 10.1186/1471-2180-9-208.
Ravindran, V., Wu, Y. B., Thomas, D. G., and Morel, P. C. H. (2006). Influence

of whole wheat feeding on the development of gastrointestinal tract and performance of broiler chickens. *Australian Journal of Agricultural Research*, **57**, 21-26.

Rehman, H. U., Vahjen, W., Awad, W. A., and Zentek, J. (2007). Indigenous bacteria and bacterial metabolic products in the gastrointestinal tract of broiler chickens. *Archives of Animal Nutrition*, **5**, 319-335.

Reynhout, J. K., and Duke, G. E. (1999). Identification of interstitial cells of Cajal in the digestive tract of turkeys (Meleagris gallopavo). *Journal of Experimental Zoology*, **283**, 426-440.

Rougière, N., Gomez, J., Mignon-Grasteau, S., and Carré, B. (2009). Effects of diet particle size on digestive parameters in D(+) and D(-) genetic chicken lines selected for divergent digestion efficiency. *Poultry Science*, **88**, 1206-1215.

Rougière, N., and Carré, B. (2010). Comparison of gastrointestinal transit times between chickens from D+ and D- genetic lines selected for divergent digestion efficiency. *Animal*, **4**, 1861-1872.

Rougière, N., Malbert, C. H., Rideau, N., Cognie, J., and Carré, B. (2012). Comparison of gizzard activity between chickens from genetic D(+) and D(-) lines selected for divergent digestion efficiency. *Poultry Science*, **91**, 460-467.

Sakata, T., and Setoyam, H. (1995). Local stimulatory effect of short chain fatty acids on the mucus release from the hindgut mucosa of rats (Rattus norvegicus). *Comparative Biochemistry and Physiology. A. Physiology*, **111**, 429-432.

Saldeña, T. A., Saraví, F. D., Hwang, H. J., Cincunegui, L. M., and Carra, G. E. (2000). Oxygen diffusive barriers of rat distal colon: role of subepithelial tissue, mucosa, and mucus gel layer. *Digestive Diseases and Sciences*, **45**, 2108-2114.

Salter, D. N. (1973). The influence of gut micro-organisms on utilization of dietary ptotein. *Proceedings of the Nutrition Society*, **32**, 65-71.

Salter, D. N., and Fulford, R. J. (1974). The influence of the gut microflora on the digestion of dietary and endogenous proteins: studies of the amino acid composition of the excreta of germ-free and conventional chicks. *British Journal of Nutrition*, **32**, 625-637.

Salzman, N. H., Hung, K., Haribhai, D., Chu, H., Karlsson-Sjöberg, J., Amir, E., Teggatz, P., Barman, M., Hayward, M., Eastwood, D., Stoel, M., Zhou, Y., Sodergren, E., Weinstock, G. M., Bevins, C. L., Williams, C. B., and Bos, N. A. (2010). Enteric defensins are essential regulators of intestinal microbial ecology. *Nature Immunology*, **11**, 76-82.

Scheppach, W. (1994). Effects of short chain fatty acids on gut morphology and function. *Gut*, **35**, S35-S38.

Sharma, R., Young, C., and Neu, J. (2010). Molecular modulation of intestinal

epithelial barrier: contribution of microbiota. *Journal of Biomedicine and Biotechnology*, doi:10.1155/2010/305879.

Shepherd, E. M., and Fairchild, B. D. (2010). Footpad dermatitis in poultry. *Poultry Science*, **89**, 2043-2051.

Shires, A., Thompson, J. R., Turner, B. V., Kennedy, P. M., and Goh, Y. K. (1987). Rate of passage of corn-canola meal and corn-soybean meal diets through the gastrointestinal tract of broiler and white leghorn chickens. *Poultry Science*, **66**, 289-298.

Snel, J., Heinen, P. P., Blok, H. J., Carman, R. J., Duncan, A. J., Allen, P. C., and Collins, M. D. (1995). Comparison of 16S rRNA sequences of segmented filamentous bacteria isolated from mice, rats, and chickens and proposal of "*Candidatus Arthromitus*". *International Journal of Systematic Bacteriology*, **45**, 780-782.

Souza, M. R., Moreira, J. L., Barbosa, F. H. F., Cerqueira, M., Nunes, A. C., and Nicoli, J. R. (2007). Influence of intensive and extensive breeding on lactic acid bacteria isolated from *Gallus gallus domesticus* ceca. *Veterinary Microbiology*, **120**, 142-150.

Stewart, J. A., Chadwick, V. S., and Murray, A. (2005). Investigations into the influence of host genetics on the predominant eubacteria in the faecal microflora of children. *Journal of Medical Microbiology*, **54**, 1239-1242.

Suzuki, K., Kodam, Y., and Mitsuoka, T. (1989). Stress and intestinal flora. *Bifidobacteria and microflora*, **8**, 23-38.

Svihus, B. (2011). The gizzard : function, influence of diet structure and effects on nutrient availability. *World's Poultry Science Journal*, **67**, 207-224.

Szylit, O., Champ, M., Aitabdelkader, N., and Raibaud, P. (1980). Role of 5 *Lactobacillus* strains on carbohydrate degradation in monoxenic chickens. *Reproduction Nutrition Development*, **20**, 1701-1706.

Taylor, R. D., and Jones, G. P. D. (2004). The influence of whole grain inclusion in pelleted broiler diets on proventricular dilatation and ascites mortality. *British Poultry Science*, **45**, 247-254.

Thomke, S., and Elwinger, K. (1998). Growth promotants in feeding pigs and poultry. I. Growth and feed efficiency responses to antibiotic growth promotants. *Annales de Zootechnie*, **47**, 85-91.

Timbermont, L., Haesebrouck, F., Ducatelle, R., and Van Immerseel, F. (2011). Necrotic enteritis in broilers: an updated review on the pathogenesis. *Avian Pathology*, **40**, 341-347.

Toivanen, P., Vaahtovuo, J., and Eerola, E. (2001). Influence of major histocompatibility complex on bacterial composition of fecal flora. *Infection and Immunity*, **69**, 2372-2377.

Torok, V. A., Hughes, R. J., Mikkelsen, L. L., Perez-Maldonado, R., Balding, K., MacAlpine, R., Percy, N. J., and Ophel-Keller, K. (2011). Identification and Characterization of Potential Performance-Related Gut Microbiotas in Broiler Chickens across Various Feeding Trials. *Applied and Environmental Microbiology*, **77**, 5868-5878.

Vispo, C., and Karasov, W. H. (1997). The interaction of avian gut microbes and their host : an elusive symbiosis. In *Gastrointestinal microbiology – 1997*, pp 116-155. Edited by R. I. Mackie and B. A. White. Vol. 1. Chapman Hall, Microbiology Series, NewYork (USA).

Williams, J., Mallet, S., Leconte, M., Lessire, M., and Gabriel, I. (2008). The effects of fructo-oligosaccharides or whole wheat on the performance and the digestive tract of broiler chickens. *British Poultry Science*, **49**, 329-339.

Yamauchi, K., Isshiki, Y., Zhou, Z. X., and Nakahiro, Y. (1990). Scanning and transmission electron microscopic observations of bacteria adhering to ileal epithelial cells in growing broilers and White Leghorn chickens. *British Poultry Science*, **31**, 129-137.

Yang, Y., Iji, P. A., and Choct, M. (2009). Dietary modulation of gut microflora in broiler chickens : a review of the role of six kinds of alternatives to in-feed antibiotics. *World's Poutry Science Journal*, **65**, 97-114.

Zhu, X. Y., Zhong, T., Pandya, Y., and Joerger, R. D. (2002). 16S rRNA-based analysis of microbiota from the caecum of broiler chickens. *Applied Environmental Microbiology*, **68**, 124-137.

Zoetendal, E. G., Collier, C. T., Koike, S., Mackie, R. I., and Gaskins, H. R. (2004). Molecular ecological analysis of the gastrointestinal microbiota: A review. *Journal of Nutrition*, **134**, 465-472.

Zschüttig, A., Zimmermann, K., Blom, J., Goesmann, A., Pöhlmann, C., and Gunzer, F. (2012). Identification and Characterization of Microcin S, a New Antibacterial Peptide Produced by Probiotic *Escherichia coli* G3/10. *PLoS One*, **7**, e33351.